# Reducing Particulate Matter Emissions for Jet Engines by Improving Combustion Efficiency

A White Paper

HNO Green Fuels, Inc.

June 10, 2013

## Background

Jet engines are a source of gaseous and particulate emissions being released into the atmosphere. The number of species emitted by jet engines depends on the kind of fuel and the design of the jet engine. However, because the emissions of aircraft engines occur in the atmospheric regions (high troposphere and low stratosphere), which are very sensible to various perturbations, the problem of aviation effect on atmospheric processes and climate change has become very important.

Particulates when released into the environment are harmful. Particulates in engine exhaust form because of incomplete combustion of the fuel within the combustion chamber of the jet engine. Thus, particulate emissions are higher at low engine powers because combustion efficiency is lower. Particulate emissions from jet engines are highest at take-off and climb-out operations that require very high fuel flow rates. Therefore, data would be expected to show high particulate emissions around airports. Aerial depositions of exhaust particles from air traffic may have detrimental impacts on human health and the environment. High levels of ambient particulate matter have been found to adversely affect human respiratory systems, causing the development of asthma, lung cancer, and chronic bronchitis, among other problems.

Unlike internal combustion engines, particularly diesel engines where particulate filters are often employed to attempt to abate these particulate matter emissions, there is no known technology for reducing particulate matter emissions for jet engines. One of the best ways to reduce particulate matter emissions is to improve the combustion efficiency of the jet fuel.

## 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 jet 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.

Using the symmetrical, adiabatic, counterflow arrangement, the laminar flame speeds of methane + air and propane + air mixtures, with and without the addition of stoichiometrically small amounts of hydrogen, have been determined by first measuring the flame speeds with stretch and then linearly extrapolating these values to zero stretch. The results show that the flame speed is substantially increased with hydrogen addition, and that it can be linearly correlated with the flame speed without hydrogen addition and a single parameter indicating the extent of hydrogen addition. [1] (This research was supported by the Department of Energy under Contract No. DEFG03-84ER13274 and the technical monitoring of Dr. Oscar Manley)

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. In some cases the results were nearly linear. 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.

## Problem Statement

The adverse health effects of particulate matter emissions are well known throughout the world. There are no known effective strategies for particulate matter removal from jet engine exhaust. However, the best way to reduce particulate matter emissions in Jet engines is to improve the combustion efficiency of the jet fuel. There has been movement in the development of new jet engine designs that promise to bring about greater efficiency, but some of these new designs are a somewhat radical departure from current jet engine designs, which inherently brings about some resistance in the industry. It can also mean actual development and testing can be years down the road. Particulate matter issues are in need of solutions today, not years down the road.

## 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 jet 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, there is no need to modify the jet engine design to make the engine more efficient. LeefH2 produces hydrogen gas on demand, which is injected into the air used for combustion to enhance the combustion efficiency of the jet fuel. In addition to producing hydrogen, LeefH2 also produces breathable oxygen, which is released to the atmosphere for further 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 (Diesel Engines)*

LeefH2 has not yet been tested on jet engines. However, the LeefH2 technology was designed to improve the combustion efficiency of all hydrocarbon based fuels. LeefH2 has been tested extensively on gasoline and diesel internal combustion engines. HNO has plans to develop a LeefH2 prototype for jet engines. In the meantime, our current test results on diesel engines offer a glimpse into the potential impact our technology may have on particulate matter emissions reduction in jet engines.

The following tables show the test results achieved when certain amounts of hydrogen are added to the air used for combustion of diesel fuel. In each case, the particulate matter emissions were reduced by over 43%. The reduction occurred in the combustion chamber. Our diesel engine testing has been conducted at an independent EPA approved Engine Testing lab in Fullerton California. The test results shown here are 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 a heavy-duty diesel engines in the USA. The actual reports can be seen in the appendix.

**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 for reducing particulate matter emissions in the combustion process. Test results and scientific research have proven it. The only remaining question would be what is the quantity of hydrogen required to see an improvement of combustion efficiency in jet engines?

## Conclusion

It is evident that hydrogen has the effect of increasing the combustion efficiency of many fuels, including Jet fuels. Up to now, there was not an effective way to deliver hydrogen to a jet engine without storing the hydrogen on board, which is not an appealing option, for many reasons. With the LeefH2 technology, hydrogen can be safely delivered to the jet engine to improve the combustion efficiency of the jet fuel, while at the same time, tons of breathable oxygen can be released to the atmosphere to provide a positive environmental benefit to the planet.

# References

1. G.YU, C.K. LAW and C.K. WU, Laminar Flame Speeds of Hydrocarbon + Air Mixtures with Hydrogen Addition. COMBUSTION AND FLAME 63: 339-347 (1986)

# Appendices

1. Baseline-1998 Ford Diesel 350
2. LEEFH2-1998 Ford Diesel 350
3. Baseline_Cummins ISM-400
4. LEEFH2_Cummins ISM-400

## 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 |

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| 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 |

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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) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.15 | 1 | 16.48 | 42.02 | 99.80 | 99.69 | 1215 | 279450 | 5593 | 16.48 | 3.87 | 300321 |
| 0.08 | 2 | 22.55 | 80.15 | 1168.02 | 1159.89 | 43530 | 1417437 | 133600 | 22.56 | 19.60 | 1523303 |
| 0.10 | 3 | 18.55 | 61.27 | 797.21 | 783.70 | 27285 | 1122078 | 95114 | 18.56 | 15.52 | 1205885 |
| 0.10 | 4 | 22.15 | 48.98 | 1732.88 | 1705.99 | 38310 | 1390004 | 123634 | 22.16 | 19.23 | 1493821 |
| 0.05 | 5 | 19.69 | 42.37 | 1022.26 | 1002.93 | 22920 | 794076 | 77576 | 19.70 | 10.98 | 853384 |
| 0.05 | 6 | 21.44 | 50.42 | 1398.52 | 1379.15 | 33375 | 1078194 | 105433 | 21.44 | 14.91 | 1158723 |
| 0.05 | 7 | 17.88 | 40.70 | 571.36 | 554.89 | 12240 | 540835 | 44646 | 17.89 | 7.48 | 581230 |
| 0.09 | 8 | 27.04 | 57.45 | 1780.52 | 1744.18 | 46770 | 1609382 | 146584 | 27.05 | 22.26 | 1729585 |
| 0.10 | 9 | 22.23 | 49.64 | 659.22 | 633.24 | 14865 | 648310 | 55775 | 22.23 | 8.97 | 696732 |
| 0.08 | 10 | 31.85 | 64.74 | 1920.68 | 1872.89 | 52185 | 1897416 | 162771 | 31.86 | 26.24 | 2039132 |
| 0.05 | 11 | 27.07 | 59.51 | 647.42 | 614.85 | 15330 | 750735 | 58417 | 27.08 | 10.38 | 806807 |
| 0.05 | 12 | 28.53 | 53.65 | 1537.87 | 1497.56 | 38955 | 1469344 | 117201 | 28.54 | 20.32 | 1579088 |
| 0.05 | 13 | 27.26 | 49.49 | 1098.22 | 1062.17 | 27135 | 1096555 | 87432 | 27.27 | 15.17 | 1178455 |

PARTIC. WT, MG = 0.41 0.00041

| Mode | Sample Time (Sec.) | GP (g/s) | (slpm) | (sl) | $V_{sf}$ $Ft.^3$ | VMIX $Ft.^3$ |
|---|---|---|---|---|---|---|
| 1 | 90 | 0.088 | 4.3780 | 6.5670 | 0.2319114 | 3712.8 |
| 2 | 48 | 0.454 | 22.5865 | 18.0692 | 0.6381078 | 1974.8 |
| 3 | 60 | 0.361 | 17.9598 | 17.9598 | 0.6342426 | 2469.6 |
| 4 | 60 | 0.453 | 22.5368 | 22.5368 | 0.7958776 | 2467.9 |
| 5 | 30 | 0.278 | 13.8305 | 6.9153 | 0.2442097 | 1235.6 |
| 6 | 30 | 0.359 | 17.8603 | 8.9301 | 0.3153644 | 1234.9 |
| 7 | 30 | 0.211 | 10.4973 | 5.2486 | 0.1853534 | 1236.5 |
| 8 | 54 | 0.536 | 26.6660 | 23.9994 | 0.8475308 | 2220.2 |
| 9 | 60 | 0.256 | 12.7360 | 12.7360 | 0.4497676 | 2476.1 |
| 10 | 48 | 0.619 | 30.7953 | 24.6362 | 0.8700192 | 1974.0 |
| 11 | 30 | 0.296 | 14.7260 | 7.3630 | 0.2600219 | 1239.1 |
| 12 | 30 | 0.506 | 25.1735 | 12.5868 | 0.4444969 | 1235.7 |
| 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 | CO | KNOX | KNO | FUEL | EXHAUST | CO2 | NMHC | Raw Exhaust Flow (scmm) | Raw Exhaust Flow (g/h) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | GRAMS/HOUR | | | | | | | | | |
| 0.15 | 1 | 18.16 | 31.93 | 92.02 | 80.17 | 1065 | 275450 | 7466 | 17.87 | 3.81 | 296023 |
| 0.08 | 2 | 23.64 | 81.67 | 1188.37 | 1164.82 | 43485 | 1429622 | 135570 | 23.64 | 19.77 | 1536399 |
| 0.10 | 3 | 18.78 | 62.10 | 807.30 | 777.93 | 27240 | 1120635 | 95924 | 18.78 | 15.50 | 1204334 |
| 0.10 | 4 | 22.39 | 50.19 | 1736.67 | 1691.70 | 38580 | 1390697 | 124860 | 22.40 | 19.24 | 1494567 |
| 0.05 | 5 | 19.19 | 42.95 | 1025.27 | 994.36 | 22980 | 800774 | 79091 | 19.20 | 11.08 | 860583 |
| 0.05 | 6 | 20.87 | 51.64 | 1394.20 | 1365.45 | 33435 | 1082898 | 107841 | 20.88 | 14.98 | 1163778 |
| 0.05 | 7 | 17.13 | 39.57 | 573.66 | 546.65 | 12240 | 550712 | 46802 | 16.86 | 7.62 | 591843 |
| 0.09 | 8 | 26.40 | 58.75 | 1754.56 | 1704.79 | 46890 | 1633057 | 150720 | 26.40 | 22.59 | 1755028 |
| 0.10 | 9 | 21.35 | 48.34 | 658.60 | 620.50 | 14730 | 659440 | 58033 | 21.06 | 9.12 | 708693 |
| 0.08 | 10 | 30.98 | 64.84 | 1896.13 | 1833.76 | 51870 | 1903047 | 165005 | 30.99 | 26.32 | 2045183 |
| 0.05 | 11 | 26.11 | 56.48 | 639.47 | 595.38 | 15300 | 761041 | 60151 | 25.79 | 10.53 | 817882 |
| 0.05 | 12 | 27.74 | 53.51 | 1541.92 | 1488.63 | 38985 | 1484791 | 119698 | 27.74 | 20.54 | 1595689 |
| 0.05 | 13 | 26.27 | 49.45 | 1080.87 | 1031.81 | 27210 | 1115344 | 89073 | 26.15 | 15.43 | 1198648 |

PARTIC. WT, MG = 0.23 0.00023

| Mode | Sample Time (Sec.) | GP (g/s) | (slpm) | (sl) | $V_{sf}$ Ft.$^3$ | VMIX Ft.$^3$ |
|---|---|---|---|---|---|---|
| 1 | 90 | 0.088 | 4.3780 | 6.5670 | 0.23191 | 3707.1 |
| 2 | 48 | 0.453 | 22.5368 | 18.0294 | 0.6367 | 1977.0 |
| 3 | 60 | 0.361 | 17.9598 | 17.9598 | 0.63424 | 2469.9 |
| 4 | 60 | 0.453 | 22.5368 | 22.5368 | 0.79588 | 2468.0 |
| 5 | 30 | 0.278 | 13.8305 | 6.9153 | 0.24421 | 1235.3 |
| 6 | 30 | 0.359 | 17.8603 | 8.9301 | 0.31536 | 1234.9 |
| 7 | 30 | 0.211 | 10.4973 | 5.2486 | 0.18535 | 1236.3 |
| 8 | 54 | 0.536 | 26.6660 | 23.9994 | 0.84753 | 2220.9 |
| 9 | 60 | 0.256 | 12.7360 | 12.7360 | 0.44977 | 2476.3 |
| 10 | 48 | 0.619 | 30.7953 | 24.6362 | 0.87002 | 1974.7 |
| 11 | 30 | 0.296 | 14.7260 | 7.3630 | 0.26002 | 1239.0 |
| 12 | 30 | 0.506 | 25.1735 | 12.5868 | 0.4445 | 1235.0 |
| 13 | 30 | 0.389 | 19.3528 | 9.6764 | 0.34172 | 1237.7 |
| | 600 Sec. 0.17 Hr. | | | | | |

$P_{mass}$ g

6.257216 24712.22 0.90859

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

| | 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**