Diesel Engine Research and Development
At Northern Illinois University

Diesel Engine Testing To Investigate Exhaust Emission Reduction and Engine Efficiency

Abstract

There is a growing environmental crisis regarding toxic emissions from on and off road vehicles, and in conjunction with the government's push for alternative fuels, a diesel engine test stand was fabricated to test engine performance and other variables while monitoring diesel emission content and efficiency under various load conditions. The goal of the project was to gain an overall comparison of the engine's baseline diagnostics to a hydrogen assisted operation.

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Summary

The world today is faced with many environmental concerns due largely to the increase of on and off-road vehicle emissions and poor fuel consumption rates. This environmental crisis, along with the government's push of new emission reducing and fuel consumption techniques, has resulted in new research areas to be explored. This area of study has become a primary focus for The Department of Energy, Norfolk Southern Railroad, and Northern Illinois University.

The College of Engineering and Engineering Technology at Northern Illinois University have recently established a small diesel engine testing lab. The lab enables experimental testing that can monitor engine performance and exhaust emissions composition under various situations. During each test phase, every variable will be analyzed from a range of operating conditions. The pressure ratio, stoichiometric air flow rates, variable temperatures, cooling media, fuel consumption, overall efficiency and more will be evaluated. The small scale test lab was fabricated to evaluate the diesel engine thermal load, emissions, and performance of the engine. The test lab has been equipped with temperature, pressure, gas and air flow meters, a gas flow analyzer, an emission analyzer, and a computer data acquisition system.

The U.S. Department of Energy and Norfolk Southern are concerned primarily with the reduction of diesel exhaust emissions and new technologies that can raise the fuel efficiency of diesel locomotives. A hydrogen assist generator, or electrolyzer, which is currently manufactured by National Vapor Industries, Inc, was recently acquired for testing. NVI claims that their product can improve engine efficiency, decrease harmful exhaust emissions, and increase engine life. The new technology was tested at NIU's diesel engine lab, and compared against the engine's stock baseline readings. The complete diagnostics of the engine were recorded while consuming petrol diesel with and without the hydrogen assist generator.

Diesel Engine Test Lab

Briggs and Stratton Engine

To begin to understand the performance characteristics of a large scale diesel engine, a smaller scale diesel engine was acquired, tested, and understood. The engine choice was aimed to be similar to the engines used in locomotives. Currently, Norfolk Southern has a fleet of 12 and 16 cylinder diesel locomotives (nscorp.com). It would be nearly impossible to assemble a test lab, with all the needed equipment, at NIU due to funding and facility constraints. Also, the research methodology should be proven at the small scale level before attempting on a large diesel locomotive.

For these reasons, the test engine chosen is a donated Briggs and Stratton 4-cycle diesel engine. It is a 18 horsepower, inline 3-cylinder engine that will be tested and monitored thoroughly for all possible variables. The engine needed to operate similarly to the conditions of a locomotive in order to collect valuable data for comparison. The engine along with all other components was mounted on a steel test frame that allows complete mobility of the testing apparatus. Below is a table containing the general information about the engine.

Briggs and Stratton 4-Stroke Diesel Engine	
Engine	In-Line 3 Cylinder
Valve Mechanism	Gear-Driven Overhead Valve
Displacement (cc)	700
Bore x Stroke (mm)	68 x 64
Timing	1-2-3 (Front, Center, Back)
Compression Ratio	24.0 : 1
Gross HP @ 3600 RPM	18
Gross Torque @ 2400 RPM (ft. lbs.)	32.5

Table 1: Diesel Engine General Information

Land & Sea Dynamometer

To conduct engine experiments with accurate results, a load must be placed on the engine. Creating a load will simulate the actual working conditions of the engine. If the engine is tested without a load, the data collected will show results similar to accelerating the engine of a car while it is neutral. The rotational speed of the engine increases, but the car is not moving; therefore no external load is placed on the engine. A dynamometer will be used to create the load on the engine. The dynamometer is a water-brake style loading mechanism that reacts against the rotation of the input shaft (Land and Sea). An impeller is rotated by water flowing against the natural rotation of the flywheel, thus creating the load on the engine. Furthermore, it also monitors the torque and horsepower, and allows the load to vary as needed. The load can fluctuate for different engine speeds, because the engine will need to be tested for all similar situations to the diesel locomotive. The specifications for the dynamometer are shown in figure 4. The graph illustrates the maximum torque and horsepower allowed for the dynamometer. The Briggs and Stratton engine falls under both curves, making the dynamometer appropriate for experiment's application.

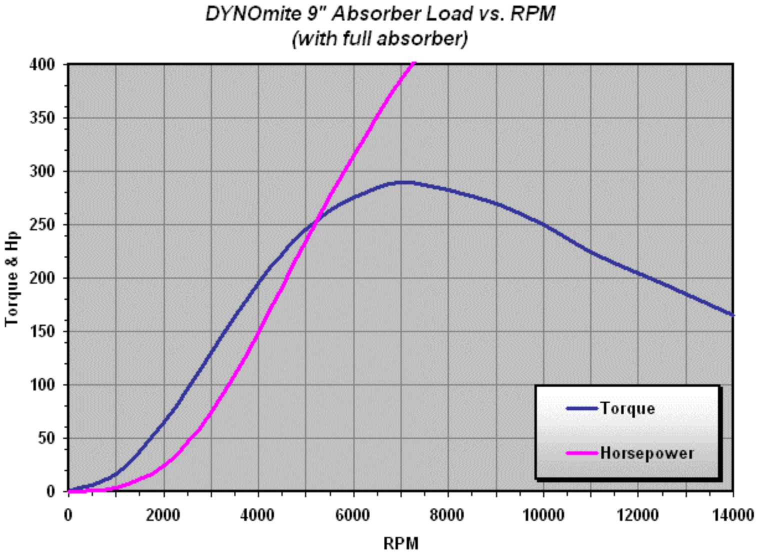

Figure 1: Torque and HP vs. RPM

To adapt the dynamometer to the engine, an input shaft will be machined to a 3 and 4 degree taper. The taper is needed so the dynamometer can be securely attached to the shaft. The shaft will then be pressed into a circular flange with the correct hole locations, and then be attached to the engine, as seen below.

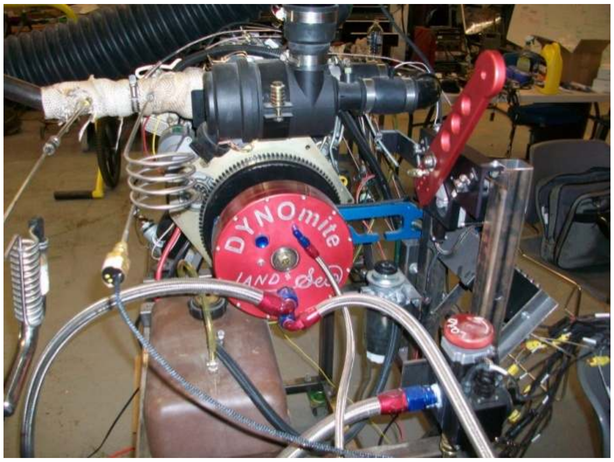

Figure 2: Adaptation of the dynamometer

Exhaust Emission Analysis

During engine testing, the emission content will need to be monitored. The individual gases most important to the research are CO, CO_2, HC's, O_2, NO_x (NO+ NO_2). A Nova five gas diesel emission analyzer will be able to provide real time monitoring of each gas, and enable data collection on a PC. The information can be related to the engine speed and load placed on the engine by the dynamometer.

Additional Equipment & Data Acquisition

To correctly identify any reasoning behind results, the engine operation must be monitored. There will be sensors to monitor all temperature issues of the engine. This includes the temperatures of intake air, exhaust air, individual cylinder head, and coolant. Also, the intake air flow and exhaust air flow will have sensors to help determine the total volumetric and mass air flow. The test stand has been equipped with a scale to measure the mass loss of the fuel tank over time. This will allow for calculations of fuel consumption rates during each engine RPM and load. To correctly understand the overall efficiency of the engine, the fuel consumption and power output of the engine will be compared.

All of the above will be correlated to the engine rotational speed, horsepower, and torque of the engine. A data acquisition module will collect real time data of the engine, and sort the information in a type of spreadsheet. The software enables the data collection, allows multiple environment simulations, graph overlaying, data averaging, histograms from previous tests, and an oscilloscope type screen that can be monitored during testing, as seen in Figure 6 (Land and Sea).

Figure 3: Screen shot of Data Recording

All information can then be documented, organized, and used for comparison to find any differences. After the complete series of tests, each test run will have distinguished characteristics that clearly show the differences against the baseline of the engine. Before any conclusions can be drawn, the complete understanding of the engine's baseline must be documented and understood.

Baseline Testing

Before an accurate comparison could be made regarding the hydrogen assist, an engine baseline was needed for petrol diesel. The testing procedure consists of multiple 20 minute runs that exert a 100% load at different RPM ranges, as seen in Table 2. Each test was designed to maintain the engine speed and load to reach a constant torque and horsepower. Since the test was conducted under steady state conditions, an accurate conclusion could be made about the fuel consumption. These conditions were also chosen over other conditions due to the greater fuel consumption rate at higher loads. The data was then complied for the average inputs and outputs at the different engine speeds, as seen in Tables 3 & 4. The average horsepower, torque, exhaust composition, and fuel consumption was then broken down in Figures 4-7 to illustrate 95% confidence intervals for the mean.

Table 2: Test Modes

Mode	**1**	**2**	**3**
RPM	3500	3000	2500
Torque %	100	100	100
Number of Runs	7	7	7

Table 3: Recorded Inputs

Engine Speed (RPM)	Fuel Consumption (GAL/HR)	Air Intake Flow (CFM)	Air Intake Temp (F)	Coolant Flow (GPM)	Coolant Temp (F)	Coolant Pressure (PSI)
3500	0.99	34.19	71	4.3	131.24	7.29
3000	0.861	30.54	71	2.82	123.86	6.71
2500	0.694	25.54	71	1.67	110.67	7.16

Table 4:Recorded Outputs

Engine Speed (RPM)	Horsepower	Torque (FT-LBS)	Exhaust Flow (CFM)	Exhaust Temp (F)	Coolant Flow (GPM)	Coolant Temp (F)	Coolant Pressure (PSI)
3500	14.29	21.43	92.33	998	4.3	169.31	6.89
3000	12.82	22.44	81.4	978	2.82	160.68	6.35
2500	11.05	23.21	67.37	965	1.67	152.8	6.73

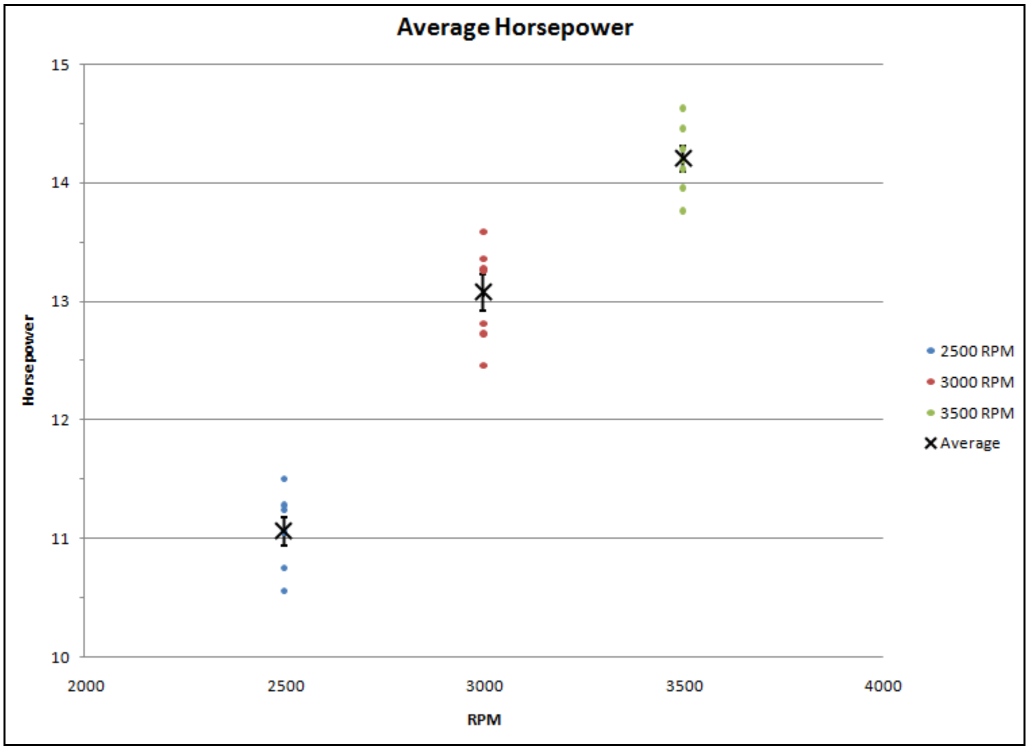

Figure 4: Average Horsepower vs. rpm at full load. X represent mean horsepower with 95% confidence intervals for the mean shown.

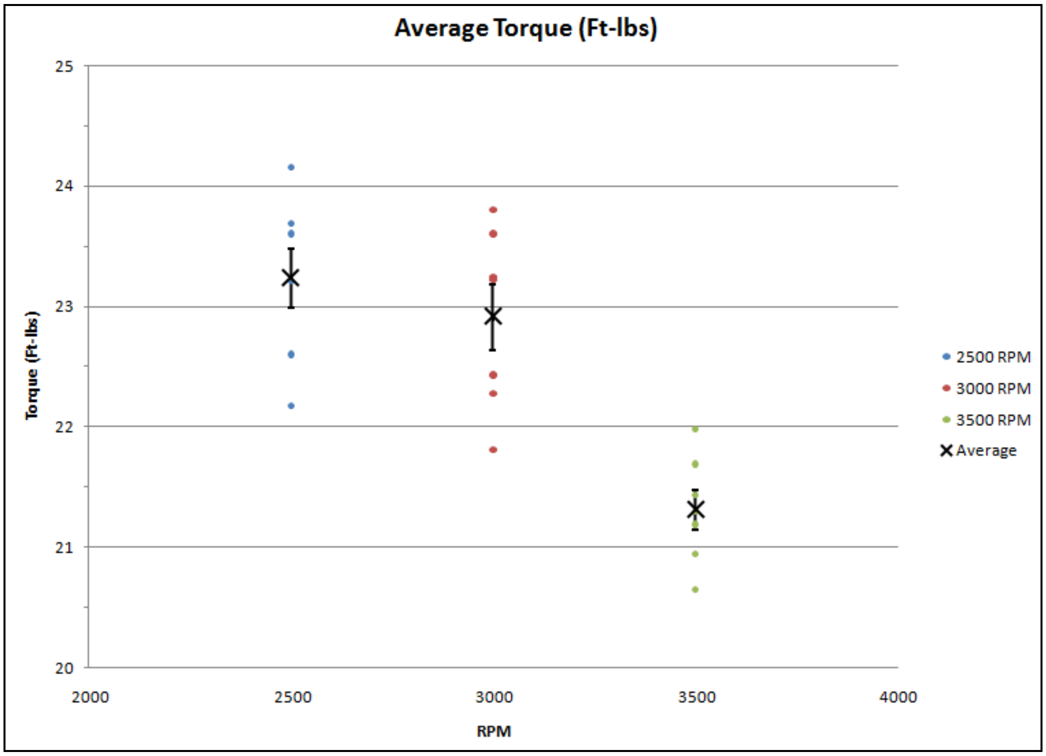

Figure 5: Average Torque vs. rpm at full load. X represent mean torque with 95% confidence intervals for the mean shown.

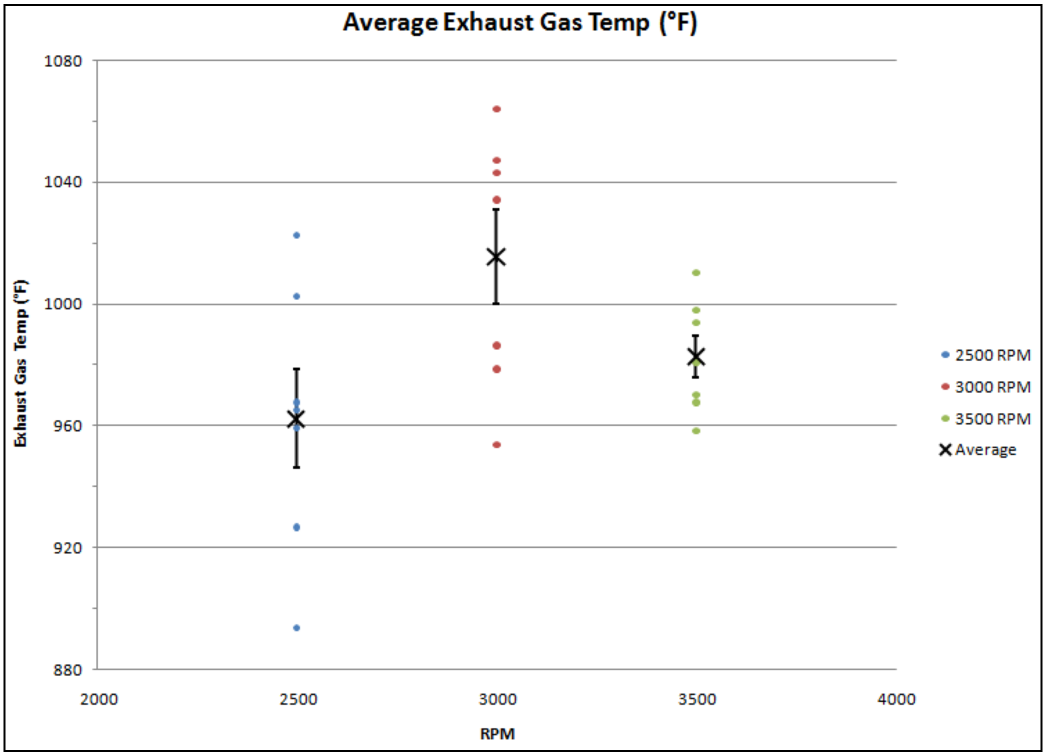

Figure 6: Average Exhaust Gas Temp vs. rpm at full load. X represent mean exhaust gas temp with 95% confidence intervals for the mean shown.

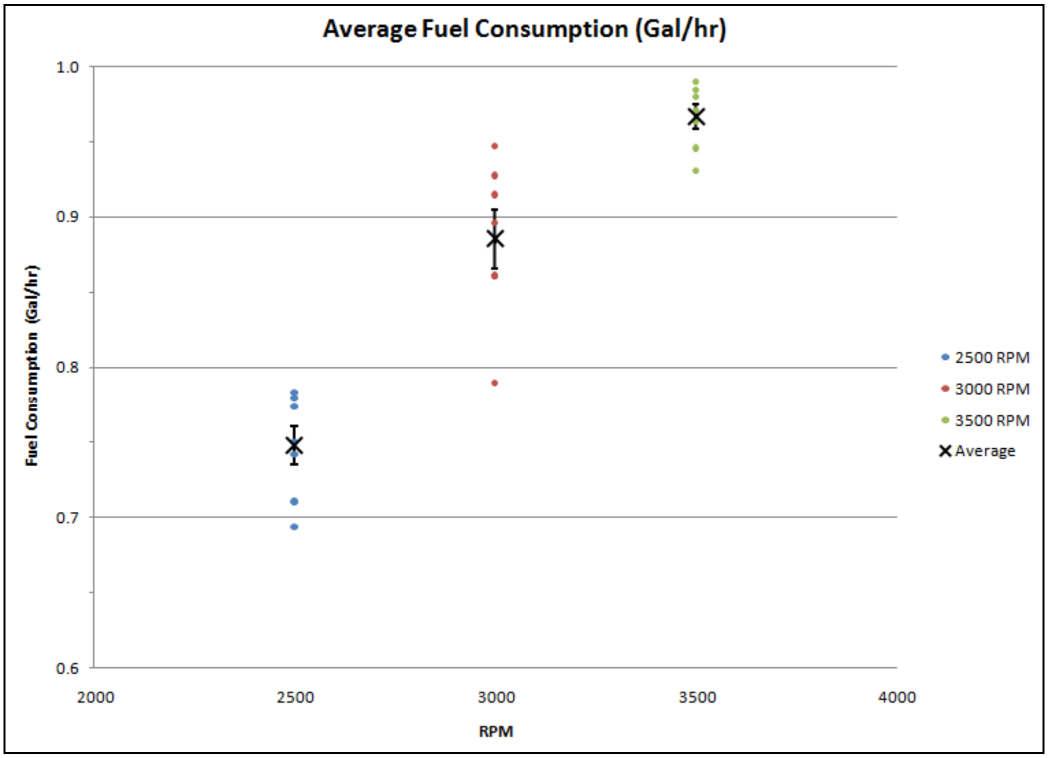

Figure 7: Average Fuel Consumption vs. rpm at full load. X represent mean fuel consumption with 95% confidence intervals for the mean shown.

After gathering all the data during each run, the average overall engine efficiency for each RPM range and load was calculated. This was done by relating the energy content in the fuel consumed to the overall power output by the engine. Understanding the baseline engine efficiency for each RPM range will help illustrate any positive or negative changes while testing the hydrogen assist generator. The average overall baseline efficiency reached 26.84%.

Table 5: Calculated Engine Efficiencies for Each Run

	3500 RPM	**3000 RPM**	**2500 RPM**
Run 1	0.2638	0.2579	0.2636
Run 2	0.2658	0.2702	0.2608
Run 3	0.2697	0.2887	0.2722
Run 4	0.2684	0.2677	0.2766
Run 5	0.2702	0.2651	0.2781
Run 6	0.2728	0.2722	0.2684
Run 7	0.2691	0.2709	0.2636
Average	**0.2685**	**0.2675**	**0.2691**
Standard Deviation	**0.0030**	**0.0094**	**0.0068**

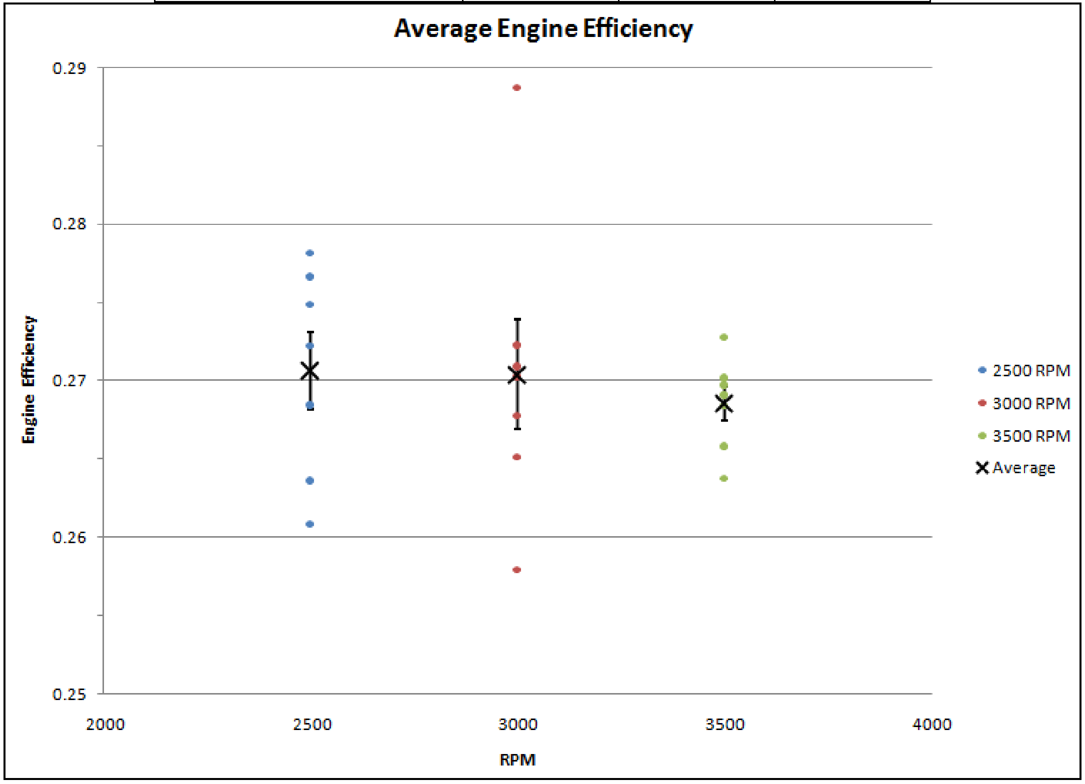

Figure 8: Average Engine Efficiency vs. rpm at full load. X represent mean efficiency with 95% confidence intervals for the mean shown.

After the initial baseline tests were completed, an energy balance was calculated to understand how the energy content from the fuel consumed was distributed throughout the engine. Since the overall baseline efficiency of the engine was 26.84%, it must be known that energy had dissipated in areas other than the dynamometer. There was heat rejection by means of the exhaust, coolant (assuming ethylene glycol), and other content losses due to free convection to the room. The total energy content lost to the exhaust, coolant, and dynamometer was then subtracted from the total average energy content from the fuel consumed. Theoretically the value should be zero, but because of the additional heat loss from the engine, the result shows a slight error.

Table 6: Energy Balance from Inputs and Outputs

Input	2500 RPM (BTU)	3000 RPM (BTU)	3500 RPM (BTU)
Energy Content of Fuel Consumed	34588.50	41262.86	45019.05
Outputs			
Heat Rejection to Exhaust	10058.89	12903.49	13855.10
Heat Rejection to Coolant	9240.97	13849.67	17612.85
Energy absorbed by Dyno	9353.99	11138.75	12088.50
Summation of Energy Outputs	28653.85	37891.91	43556.45

Table 7: Energy Balance Showing Content Loss

	2500 RPM (BTU)	3000 RPM (BTU)	3500 RPM (BTU)
Total Energy Content In	34588.50	41262.86	45019.05
Total Energy Content Out	28653.85	37891.91	43556.45
Other Energy Content Loss	**5934.65**	**3370.95**	**1462.60**
	17.16% Loss	**8.17% Loss**	**3.25% Loss**

Exhaust Composition

During the engine testing, a sample probe was installed into the exhaust system to take exhaust composition readings. The readings were from a Nova five gas diesel emission analyzer. The individual gases monitored are CO, CO_2, HC's, O_2, NO_x(NO+ NO_2). The results are also important to the baseline testing, because it will allow any changes in exhaust composition to be noticed while testing other emission reducing techniques, such as the hydrogen assist. Below are the average exhaust gas samples for each RPM range, and the corresponding graphs in Figures 9a-e. The more noticeable trends are the increases in O_2 and NO emissions and the decreases in CO_2 emissions as the engine RPM increases from 2500 to 3500.

Table 8: Average Exhaust Composition

	O2 (%)	CO2 (%)	HC's (PPM)	NO2 (PPM)	NO (PPM)
2500 RPM	5.393	11.813	4.964	257.929	3.518
3000 RPM	6.073	11.318	3.393	240.786	7.250
3500 RPM	7.671	10.231	3.923	255.648	13.538

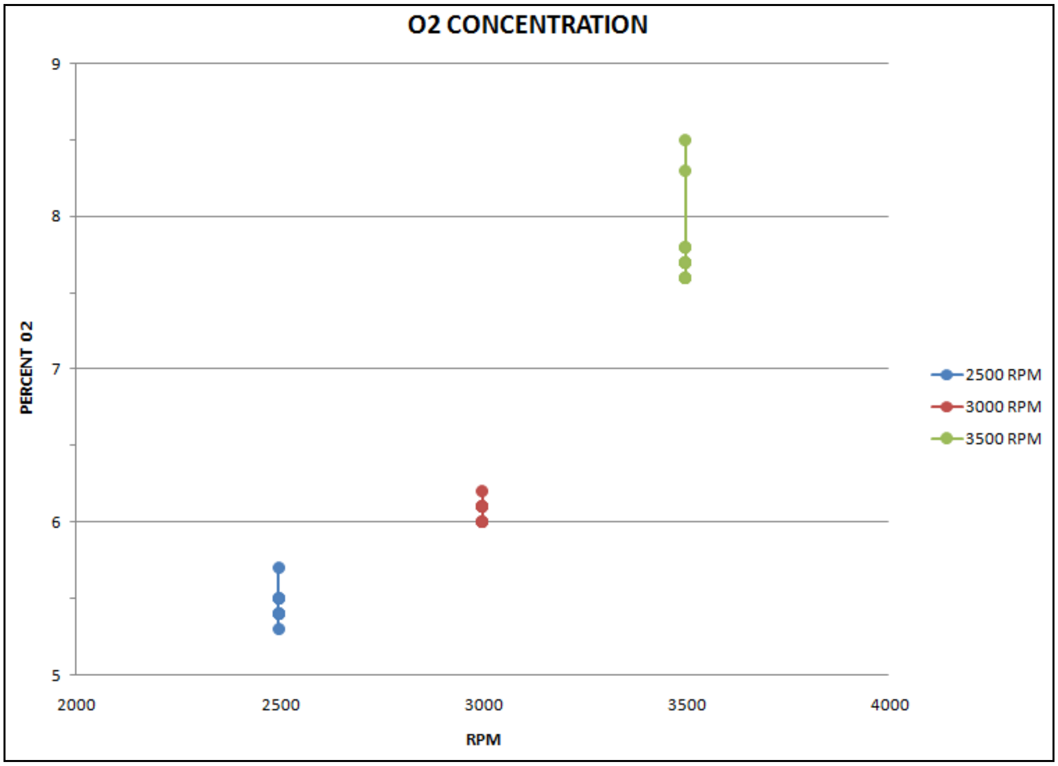

Figure 9a: O_2 Readings for designated RPM

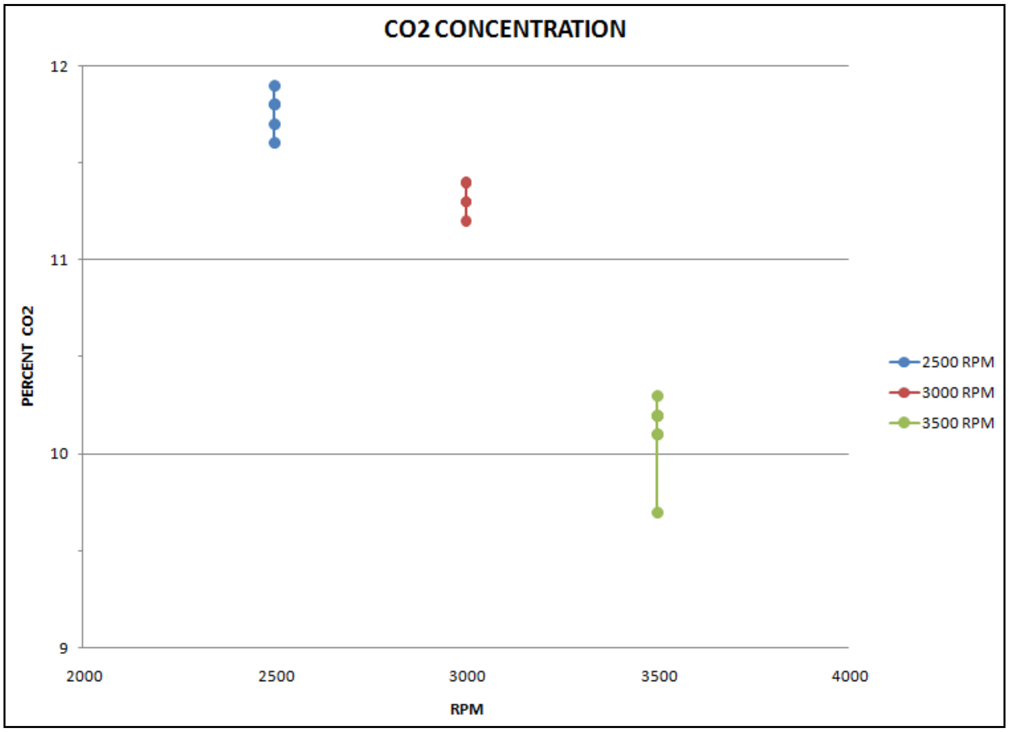

Figure 9b: CO_2 Readings for designated RPM

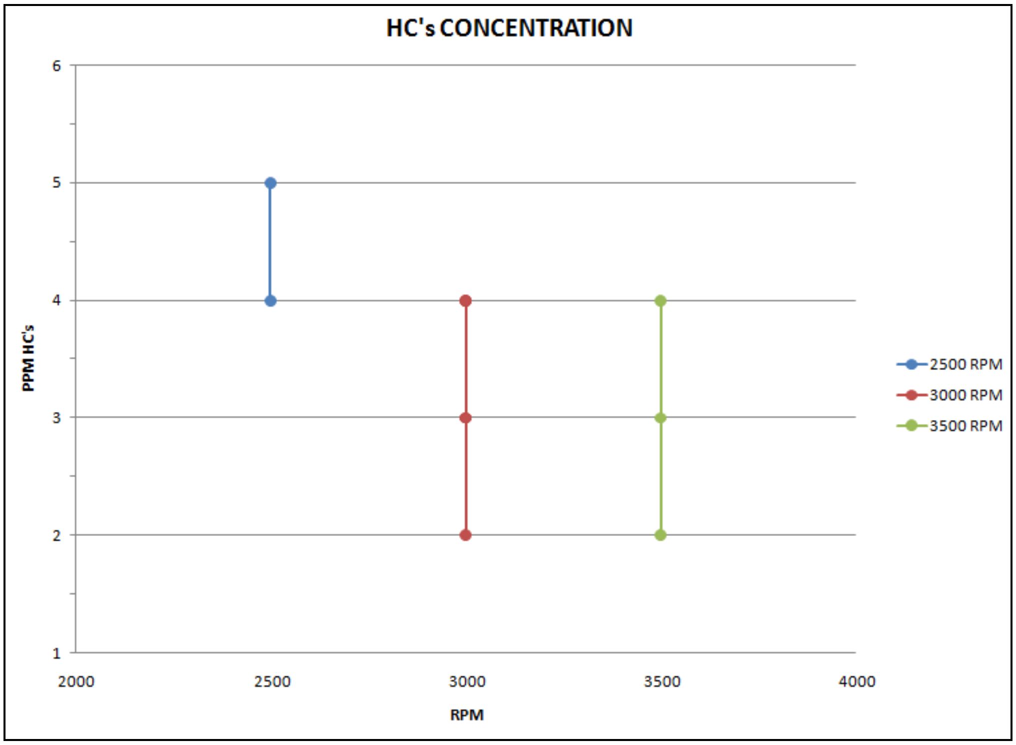

Figure 9c: HC’s Readings for designated RPM

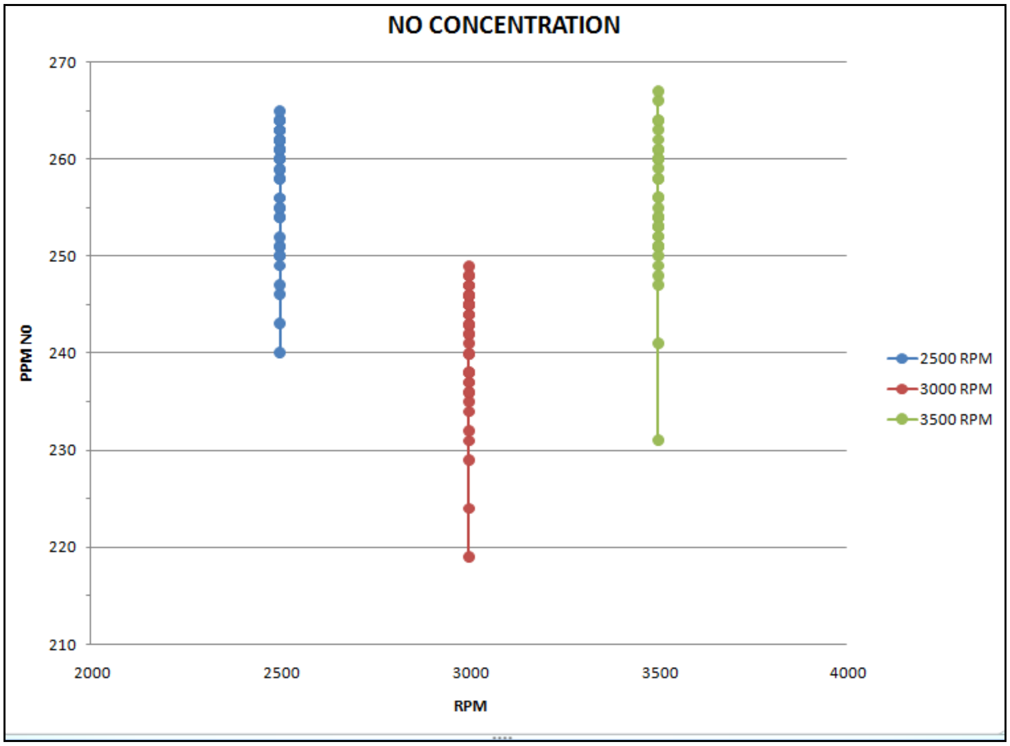

Figure 9d: NO Readings for designated RPM

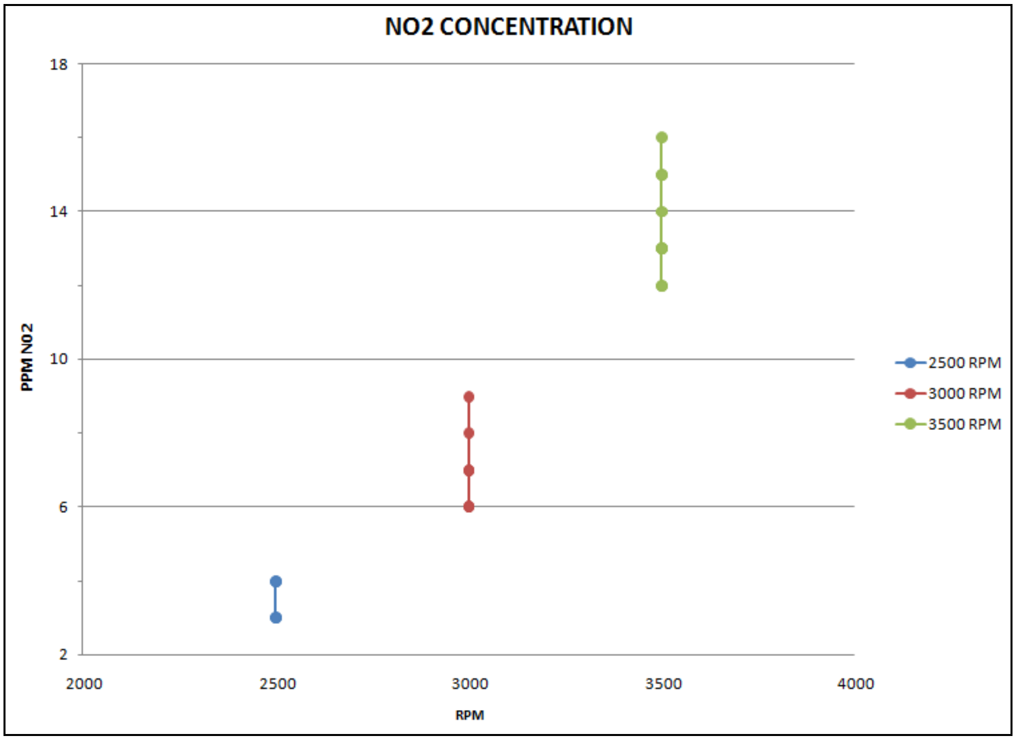

Figure 9e: NO_2 Readings for designated RPM

Hydrogen Assist

After the baseline results of the diesel engine were analyzed, the testing could begin on the hydrogen assist. In order to have accurate results the testing procedure was identical to the baseline tests consisting of multiple 20 minute runs that exert a 100% load at different RPM ranges, also shown in Table 6. Only this time the hydrogen assist generator was installed, which required an electrical source to operate. This is because the hydrogen assist uses electrolysis to produce hydrogen. The housing was hooked up to the 12 volt battery and outlet side of the generator was routed into the intake. Since the hydrogen generator must have an electric source, the power consumption was monitored to measure the energy loss. The data compiled for the average inputs and outputs at the different engine speeds are shown in Tables 2 & 3. The average horsepower, torque, exhaust composition, and fuel consumption was then broken down in Figures 10-13 to illustrate 95% confidence intervals for the mean.

Table 9: Test Modes

Mode	**1**	**2**	**3**
RPM	3500	3000	2500
Torque %	100	100	100
Number of Runs	7	7	7

Table 10: Recorded Inputs

Engine Speed (RPM)	Fuel Consumption (GAL/HR)	Air Intake Flow (CFM)	Air Intake Temp (F)	Coolant Flow (GPM)	Coolant Temp (F)	Coolant Pressure (PSI)
3500	0.945	32.36	71	3.71	134.37	10.16
3000	0.873	29.30	71	2.87	126.45	10.24
2500	0.767	24.76	71	1.77	113.16	9.43

Table 11: Recorded Outputs

Engine Speed (RPM)	Horsepower	Torque (FT-LBS)	Exhaust Flow (CFM)	Exhaust Temp (F)	Coolant Flow (GPM)	Coolant Temp (F)	Coolant Pressure (PSI)
3500	14.21	21.64	85.50	966.95	3.72	176.16	9.35
3000	13.44	23.53	79.33	1001.41	2.88	174.73	9.45
2500	11.61	24.40	66.60	992.36	1.78	172.40	8.72

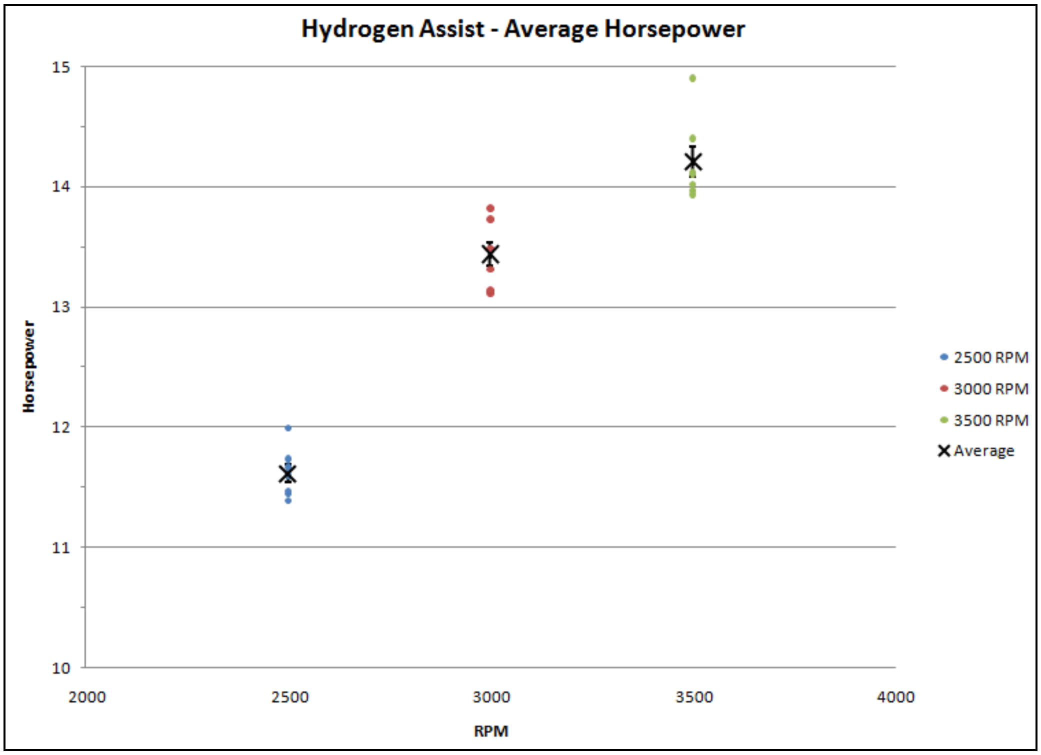

Figure 10: Average Horsepower vs. rpm at full load. X represent mean horsepower with 95% confidence intervals for the mean shown.

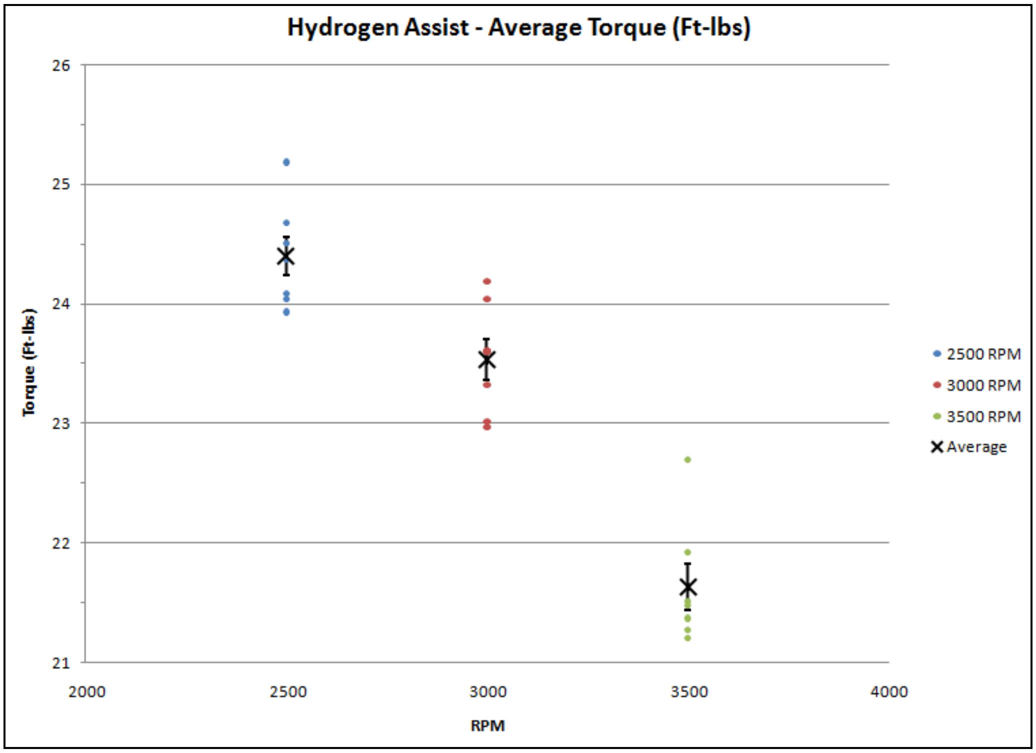

Figure 11: Average Torque vs. rpm at full load. X represent mean torque with 95% confidence intervals for the mean shown.

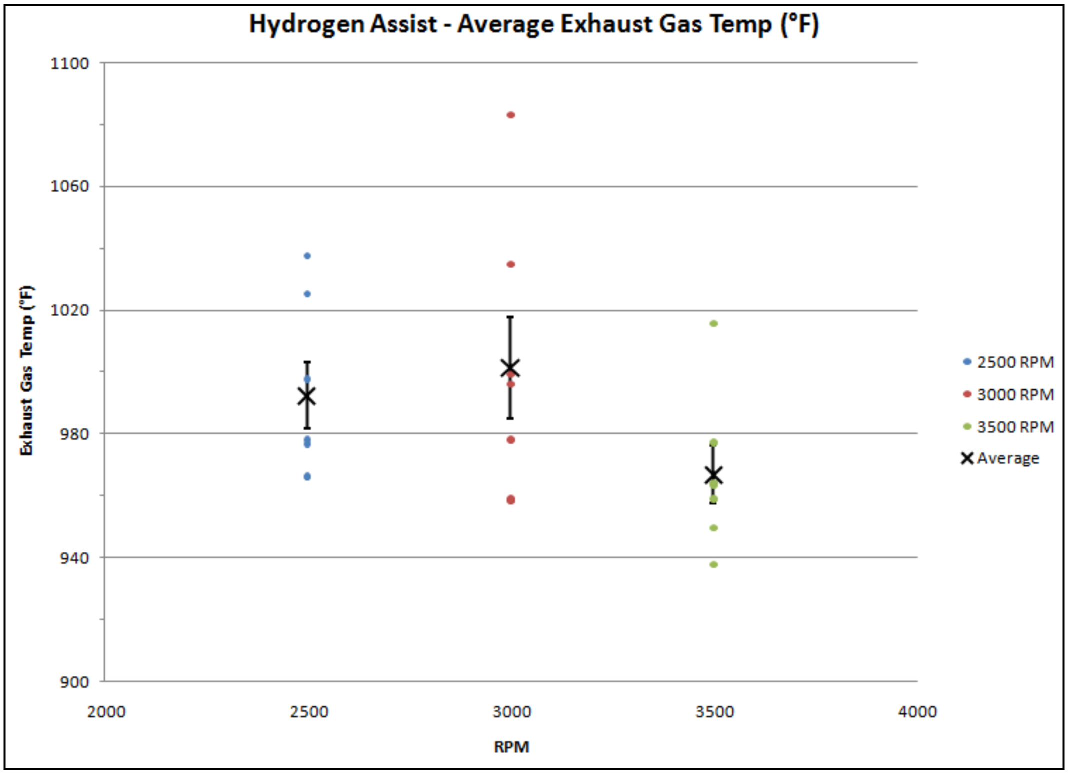

Figure 12: Average Exhaust Gas Temp vs. rpm at full load. X represent mean exhaust gas temp with 95% confidence intervals for the mean shown.

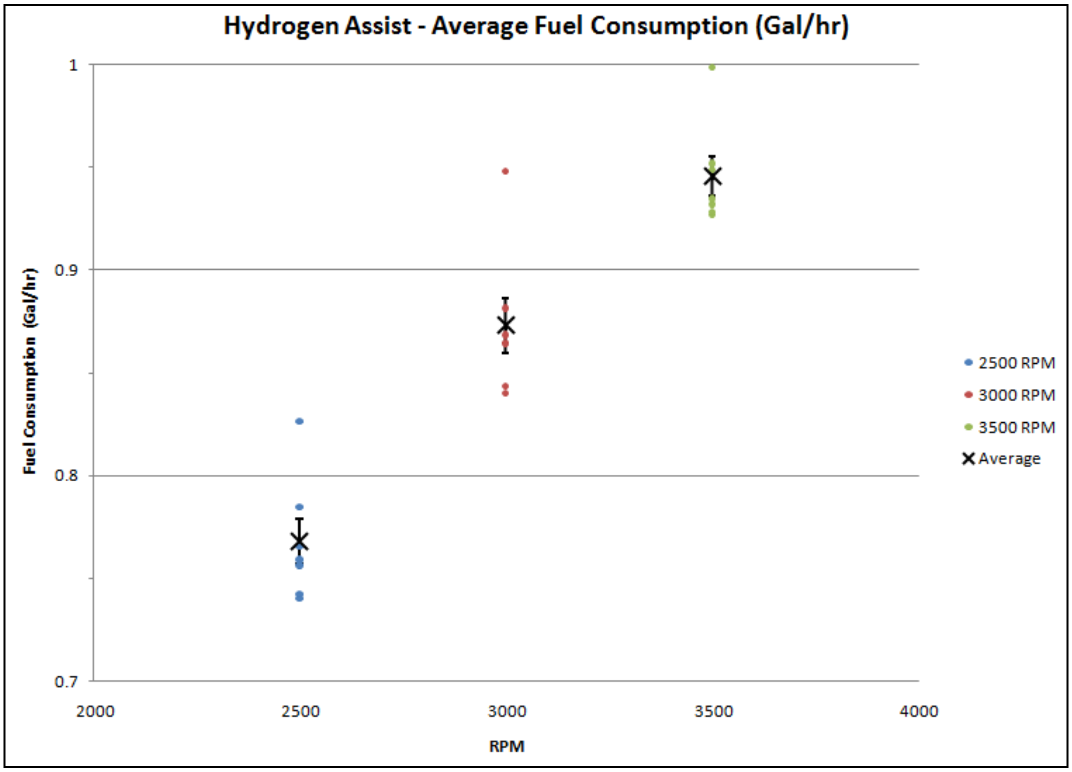

Figure 13: Average Fuel Consumption vs. rpm at full load. X represent mean fuel consumption with 95% confidence intervals for the mean shown.

Similar to the baseline tests, after gathering all the data during each run, the average overall engine efficiency for each RPM range and load was calculated. Although, this time the power consumption from the hydrogen generator was subtracted from the output power of the engine. The engine efficiency for each RPM range, after the power consumption was subtracted is shown below. The average overall baseline efficiency reached 27.35%.

Table 12: Calculated Engine Efficiencies for Each Run

	3500 RPM	3000 RPM	2500 RPM
Run 1	0.2692	0.2628	0.2614
Run 2	0.2729	0.2806	0.2779
Run 3	0.2745	0.2809	0.2764
Run 4	0.2715	0.2796	0.2761
Run 5	0.2664	0.2776	0.2726
Run 6	0.2696	0.2799	0.2790
Run 7	0.2721	0.2816	0.2626
Average	**0.2709**	**0.2776**	**0.2723**
Standard Deviation	**0.0027**	**0.0066**	**0.0073**

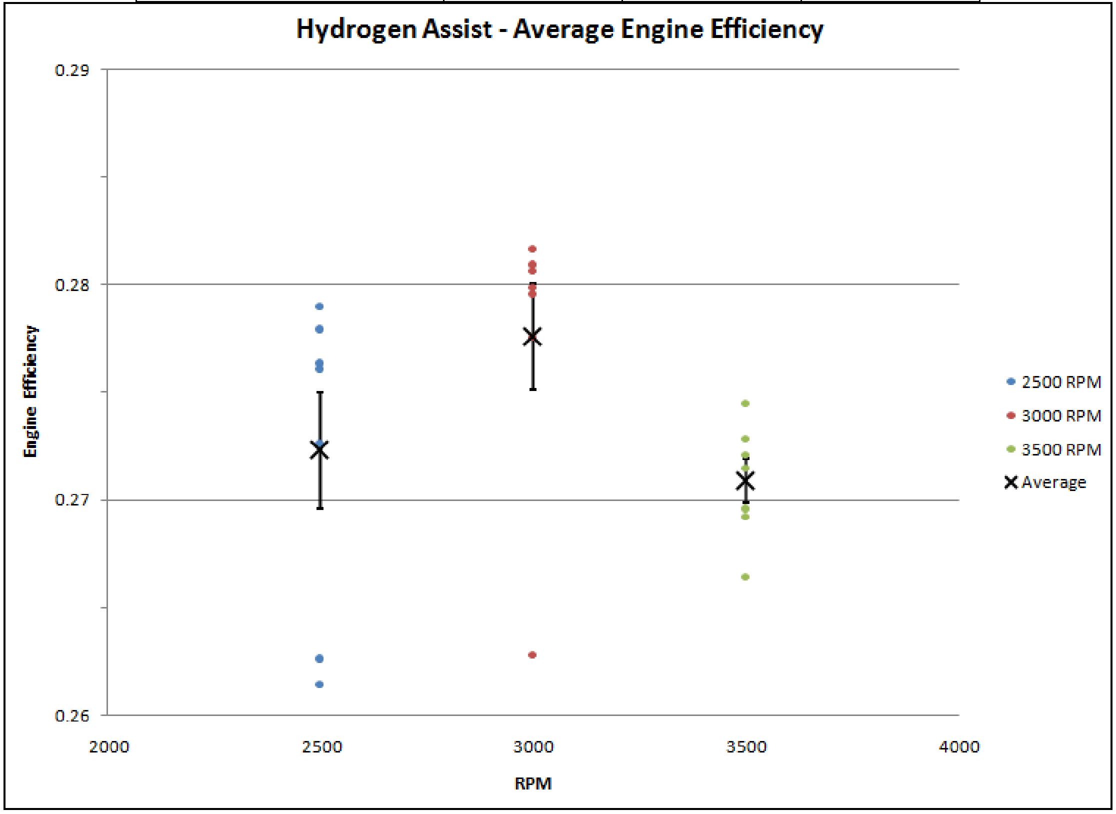

Figure 14: Average Engine Efficiency vs. rpm at full load. X represent mean efficiency with 95% confidence intervals for the mean shown.

Similarly to the baseline tests, an energy balance with the hydrogen assist was calculated. The total energy content lost to the exhaust, coolant (assuming ethylene glycol), and dynamometer is calculated and then subtracted from the total average energy content from the fuel consumed. The result shows error from the heat lost through the engine.

Table 13: Energy Balance from Inputs and Outputs

Input	2500 RPM (BTU)	3000 RPM (BTU)	3500 RPM (BTU)
Energy Content of Fuel Consumed	35739.03	40625.34	43969.61
Outputs			
Heat Rejection to Exhaust	10137.13	12105.43	12680.14
Heat Rejection to Coolant	12873.48	16010.19	17538.93
Energy absorbed by Dyno	9884.98	11433.05	12077.34
Summation of Energy Outputs	32895.59	39548.67	42296.41

Table 14: Energy Balance Showing Content Loss

	2500 RPM (BTU)	3000 RPM (BTU)	3500 RPM (BTU)
Total Energy Content In	35739.03	40625.34	43969.61
Total Energy Content Out	32895.59	39548.67	42296.41
Energy Content Loss	**2843.44**	**1076.67**	**1673.20**
	7.96% Loss	**2.65% Loss**	**3.81% Loss**

Exhaust Composition

Below are the average exhaust gas samples for each RPM range while using the hydrogen assist, and the corresponding graphs in Figures 9a-e. The averages can be directly compared to the baseline exhaust readings to see any increase or decrease with the addition of the hydrogen generator.

Table 15: Average Exhaust Composition

	O2 (%)	CO2 (%)	HC's (PPM)	NO2 (PPM)	NO (PPM)
2500 RPM	6.605	10.768	3.897	225.359	11.949
3000 RPM	6.612	10.833	2.808	236.154	10.115
3500 RPM	7.541	10.196	3.744	249.744	15.167

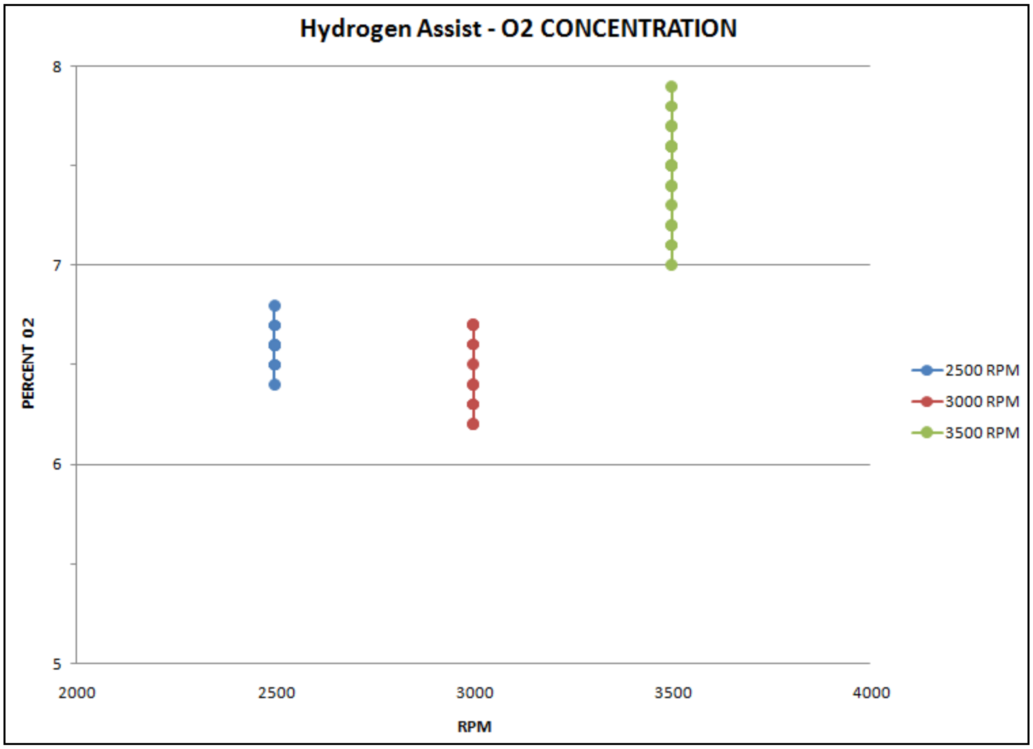

Figure 15a: O_2 Readings for designated RPM

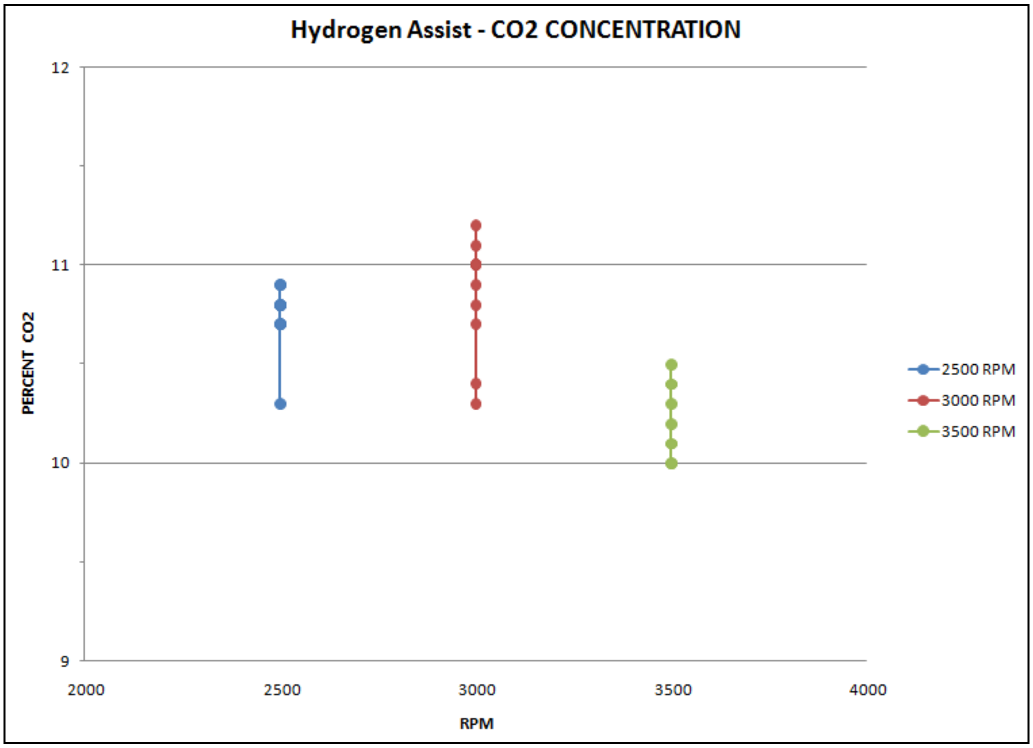

Figure 15b: CO_2 Readings for designated RPM

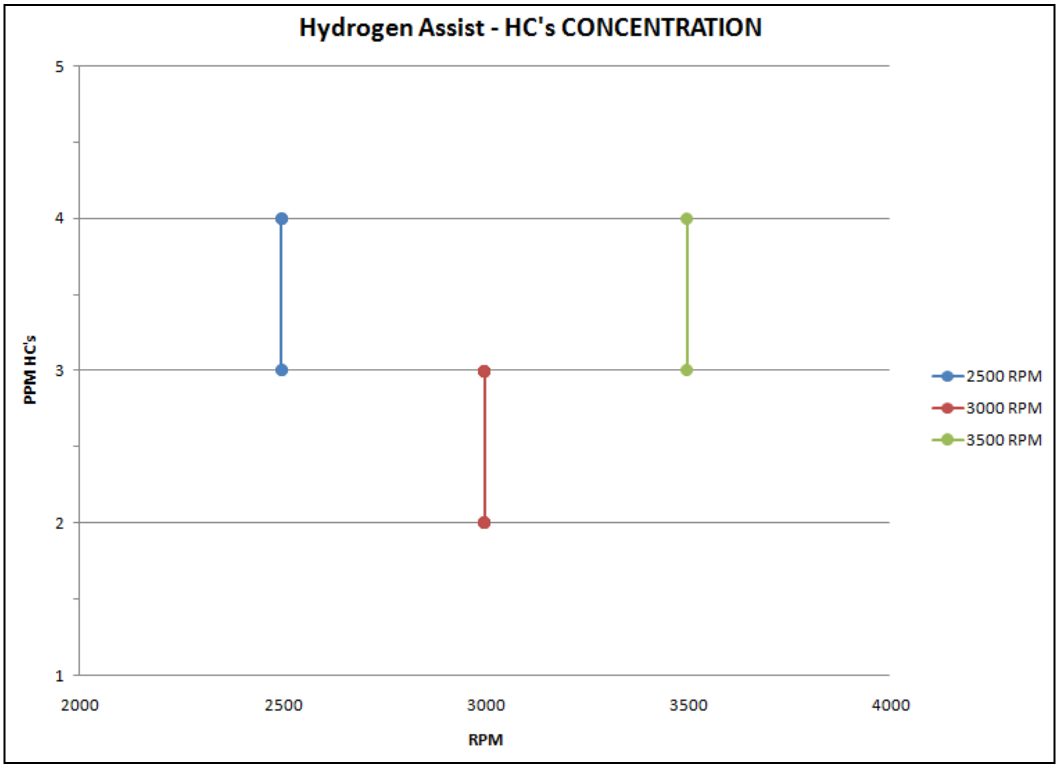

Figure 15c: HC’s Readings for designated RPM

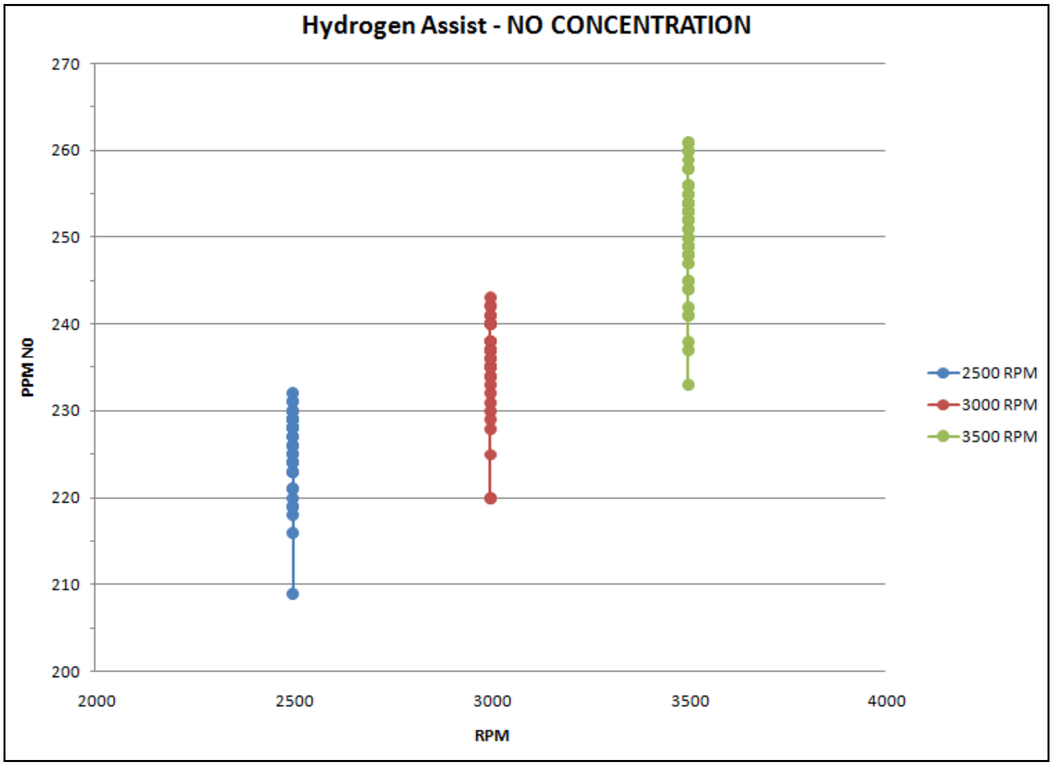

Figure 15d: NO Readings for designated RPM

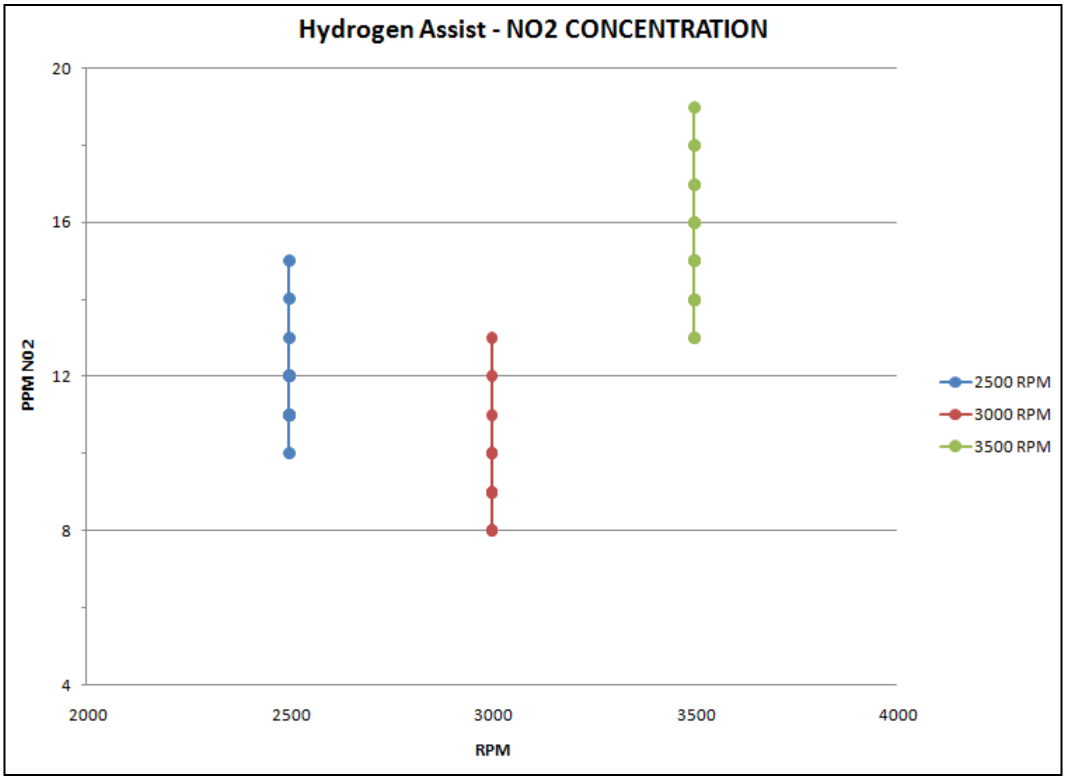

Figure 15e: NO_2 Readings for designated RPM

Comparison

After both sets of test were completed, the data was compiled and analyzed. All the calculations were made assuming that each test mode was conducted at the same steady state conditions for both the baseline and hydrogen assist tests. Below in Tables 16-18 contain the mean values and comparisons for horsepower, torque, fuel consumption, efficiency, and exhaust temp at each designated RPM. The tables contain the differences between overall mean values for the baseline diesel runs and the hydrogen assisted runs. A t-distribution test was conducted to conclude that differences exist between the baseline tests and the hydrogen assisted tests. The values calculated below .05 can be concluded with 95% confidence that there is a difference between the two sets of data. There was a slight increase in efficiency from the addition of the hydrogen generator. The .51% overall average efficiency increase led to slight increase in horsepower and torque, while maintaining around the same fuel consumption rates.

Table 16: Comparisons at 2500 RPM

2500 RPM	**Horsepower**		**Torque (Ft-lbs)**		**Fuel Consumption (Gal/hr)**		**Efficiency**		**Exhaust Temp (°F)**	
	Diesel	**H2**	**Diesel**	**H2**	**Diesel**	**H2**	**Diesel**	**H2**	**Diesel**	**H2**
Run 1	11.244	11.993	23.604	25.184	0.780	0.827	0.264	0.261	967.551	1037.317
Run 2	11.052	11.453	23.208	24.045	0.775	0.740	0.261	0.278	959.219	976.655
Run 3	11.052	11.673	23.209	24.509	0.742	0.759	0.272	0.276	965.037	997.459
Run 4	10.753	11.396	22.601	23.934	0.711	0.742	0.277	0.276	926.773	966.017
Run 5	10.559	11.605	22.173	24.371	0.694	0.766	0.278	0.273	893.787	977.909
Run 6	11.503	11.737	24.156	24.680	0.783	0.756	0.268	0.279	1022.385	1025.045
Run 7	11.281	11.470	23.691	24.087	0.750	0.785	0.275	0.263	1002.581	966.148
Average	**11.063**	**11.618**	**23.235**	**24.402**	**0.748**	**0.768**	**0.271**	**0.272**	**962.476**	**992.364**
Difference	**0.555**		**1.167**		**0.020**		**0.002**		**29.888**	
T-Test	**0.002**		**0.002**		**0.271**		**0.667**		**0.154**	

Table 17: Comparisons at 3000 RPM

3000 RPM	Horsepower		Torque (Ft-lbs)		Fuel Consumption (Gal/hr)		Efficiency		Exhaust Temp (°F)	
	Diesel	**H2**	**Diesel**	**H2**	**Diesel**	**H2**	**Diesel**	**H2**	**Diesel**	**H2**
Run 1	13.366	13.822	23.604	24.191	0.947	0.948	0.258	0.263	1063.951	1083.139
Run 2	12.731	13.727	22.282	24.042	0.861	0.882	0.270	0.281	986.536	1034.954
Run 3	12.466	13.485	21.818	23.603	0.789	0.865	0.289	0.281	954.083	996.367
Run 4	13.281	13.483	23.242	23.606	0.896	0.869	0.271	0.280	1034.160	999.367
Run 5	13.269	13.315	23.222	23.319	0.915	0.864	0.265	0.278	1043.246	978.208
Run 6	12.819	13.117	22.435	22.969	0.861	0.844	0.272	0.280	978.853	958.589
Run 7	13.590	13.144	23.799	23.011	0.928	0.841	0.268	0.282	1047.191	959.222
Average	**13.075**	**13.442**	**22.915**	**23.535**	**0.885**	**0.873**	**0.270**	**0.278**	**1015.432**	**1001.407**
Difference	**0.367**		**0.620**		**-0.012**		**0.007**		**-14.025**	
T-Test	**0.069**		**0.086**		**0.622**		**0.125**		**0.555**	

Table 18: Comparisons at 3500 RPM

3500 RPM	Horsepower		Torque (Ft-lbs)		Fuel Consumption (Gal/hr)		Efficiency		Exhaust Temp (°F)	
	Diesel	**H2**	**Diesel**	**H2**	**Diesel**	**H2**	**Diesel**	**H2**	**Diesel**	**H2**
Run 1	14.288	14.904	21.434	22.698	0.990	0.998	0.264	0.269	998.009	1015.839
Run 2	14.119	14.403	21.192	21.924	0.971	0.952	0.266	0.273	970.114	977.506
Run 3	13.963	14.122	20.946	21.511	0.946	0.927	0.270	0.275	958.393	963.684
Run 4	14.458	13.975	21.690	21.272	0.985	0.928	0.268	0.271	993.894	959.192
Run 5	13.766	14.025	20.651	21.370	0.931	0.949	0.270	0.266	967.645	949.934
Run 6	14.629	13.936	21.980	21.206	0.980	0.932	0.273	0.270	1010.138	938.117
Run 7	14.199	14.107	21.301	21.480	0.965	0.935	0.269	0.272	980.867	964.365
Average	**14.203**	**14.210**	**21.314**	**21.637**	**0.967**	**0.946**	**0.269**	**0.271**	**982.723**	**966.948**
Difference	**0.007**		**0.324**		**-0.021**		**0.002**		**-15.774**	
T-Test	**0.967**		**0.236**		**0.115**		**0.144**		**0.204**	

The exhaust composition was also compared after the addition of the hydrogen assist generator. In some areas it did lead to cleaner emissions. There was a noticeable decrease in CO_2 and HC's emissions, and an average of .37% increase in O_2. Below in Tables 17 & 18 contain the exhaust composition information, and their differences between the baseline runs and hydrogen assisted runs.

Table 17: Comparison of Exhaust Composition at Designated RPM

	Diesel	**H2**	**Diesel**	**H2**	**Diesel**	**H2**	**Diesel**	**H2**	**Diesel**	**H2**
	O2 (%)	**O2 (%)**	**CO2 (%)**	**CO2 (%)**	**HC's (PPM)**	**HC's (PPM)**	**NO2 (PPM)**	**NO2 (PPM)**	**NO (PPM)**	**NO (PPM)**
2500 RPM	5.393	6.605	11.813	10.768	4.964	3.897	257.929	225.359	3.518	11.949
3000 RPM	6.073	6.612	11.318	10.833	3.393	2.808	240.786	236.154	7.250	10.115
3500 RPM	7.671	7.541	10.231	10.196	3.923	3.744	255.648	249.744	13.538	15.167

Table 18: Differences of Exhaust Composition at Designated RPM ([-] indicates decrease)

	O2 (%)	**CO2 (%)**	**HC's (PPM)**	**NO2 (PPM)**	**NO (PPM)**
2500 RPM	1.212	-1.045	-1.067	-32.570	8.431
3000 RPM	0.538	-0.485	-0.585	-4.632	2.865
3500 RPM	-0.130	-0.035	-0.179	-5.905	1.628

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