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Presented at the 2005 SAE Powertrain & Fluid Systems Conference & Exhibition, October 2005, San Antonio, Texas

2005-01-3766

Achievement of Low Emissions by Engine Modification to Utilize Gas-to-Liquid Fuel and Advanced Emission Controls on a Class 8 Truck

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ABSTRACT

A 2002 Cummins ISM engine was modified to be optimized for operation on gas-to-liquid (GTL) fuel and advanced emission control devices. The engine modifications included increased exhaust gas recirculation (EGR), decreased compression ratio, and reshaped piston and bowl configuration. The emission control devices included a deNO$_x$ filter and a diesel particle filter. Over the transient test, the emissions met the 2007 standards.

In July 2004, the modified engine was installed into a Class 8 tractor for use by a grocery fleet. Chassis emission testing of the modified vehicle was conducted at the National Renewable Energy Laboratory's (NREL) Renewable Fuels and Lubricants (ReFUEL) facility. Testing included hot and cold replicate Urban Dynamometer Driving Schedule (UDDS) and New York Composite (NYComp) cycles and several steady-state points. The objective of the testing was to demonstrate the vehicle's with the modified engine.

Average vehicle NO$_x$ emissions from the UDDS cycle were 6.20 g/mi and 4.26 g/mi from cold and hot runs, respectively, with nitrogen dioxide (NO$_2$) emissions ~50% of the total NO$_x$ emissions. Over the NYComp cycle, the cold start emissions were 12.75 g/mi and the hot start emissions were 7.74 g/mi. The carbon monoxide (CO), hydrocarbons (HC), and PM emissions were very low, with average PM less than 0.005 g/mile for hot starts over both cycles.

The test inertia weight was varied from 46,000 lbs to 63,000 lbs to 80,000 lbs on a random basis for repeated hot-start cycles. The NOx emissions varied from 3 to 5 g/mi over the UDDS cycle and from 6 to 8 g/mi over the NYComp cycle.

Steady-state testing was also performed at repeated cruise conditions ranging from 10 to 60 mph. Average NO$_x$ emissions on a g/mi basis were the highest for this test matrix at 6.7 g/mi during 10 mph cruise conditions, ~3 g/mi over 20, 30, 40, and 50 mph cruises, and ~1.8 g/mi during 60 mph cruise conditions.

The results from this testing showed that the modified engine and emission control systems performed effectively in vehicle operation. The technology performed as expected on two very different test cycles and a range of steady-state speed and load points. The longer-term durability of the technology will be measured after six months with additional chassis testing.

INTRODUCTION

GTL fuel can be substituted for diesel fuel in a variety of applications, including as a direct replacement for conventional diesel fuel. Recent studies have shown the emission reduction potential of GTL fuel when used as a replacement for conventional diesel fuel, often combined with advanced emission control systems.[1-3]

Other applications of GTL fuel include using its properties to achieve further emission reductions. Fuel properties—such as a very high paraffin content, very high cetane number, and near zero sulfur content—make GTL fuel unique compared to even highly treated conventional diesel fuels. These fuel properties may allow for engine modifications to increase emission reductions over those possible with the neat fuel alone. A proof-of-concept study on a Power Stroke engine showed the emission reduction potential of engine modification and advanced emission control systems.[4]

This project built upon previous project successes to modify a heavy-duty engine, incorporate advanced emission control systems and install it into a Class 8 truck. The drivability of the modified engine and emission control systems was proven through chassis dynamometer testing.

COMPONENTS

A systems approach was used to complete the engine modifications and incorporate the emission control systems. Two engine systems were designed in this project and installed into vehicles. Only one of these vehicles was tested on the chassis dynamometer. Each component will be discussed below.

FUEL – Shell Global Solutions (US) Inc provided the GTL fuel for this project. Details about the fuel production have been published previously.[5] Southwest Research Institute in San Antonio, TX, analyzed the fuel, results are in Table 1. The Shell GTL Fuel used in this project met all the ASTM D975 fuel property specifications. To illustrate the differences between the Shell GTL Fuel and a conventional diesel fuel, the properties for a CARB specification diesel fuel have been included in Table 1.

Table 1. Measured fuel properties for Shell GTL Fuel.

Property	Method	Shell GTL Fuel	CARB Specification Diesel Fuel[6]
Density, g/mL	ASTM D4052	0.7841	0.8312
Kinematic Viscosity @ 40ºC, mm^2/s	ASTM D445	3.509	2.539
Flash Point, ºC	ASTM D93	89.4	70
Pour Point, ºC	ASTM D97	-3	-27
Sulfur, ppm	ASTM D5453	<1.0	70
Distillation, ºC	ASTM D86		
IBP		205	183
T10		246	
T50		299	253
T90		331	315
FBP		342	346
Ash, mass%	ASTM D482	<0.001	<0.001
Heat of Combustion, Btu/lb	ASTM D240		
Gross		20,275	18,145
Net		18,894	16,878
Carbon/Hydrogen Ratio	ASTM D5291	2.13	1.92
Cloud Point, ºC	ASTM D2500	0	-15
Scuffing Load BOCLE, g	ASTM D6078	5,750	2,750
HFRR, Wear Scar, mm	ASTM D6079	0.390	0.590
Aromatics, mass%	ASTM D5186		
Monoaromatics		<1.0	10.7
Polynuclear Aromatics		<1.0	1.4
Total Aromatics		<1.0	12.1
Hydrocarbon Types, vol%	ASTM D1319		
Aromatics		0.8	12.4
Olefins		0.7	1.3
Saturates		98.5	86.3
Gum Content, mg/100mL	ASTM D381	8.5	
Cetane Number	ASTM D613	>76.0	56
Copper Corrosion	ASTM D130	1A	
Carbon Residue, mass%	ASTM D524	0.04	

ENGINE – The engine selected for this project was a 2002 Cummins ISM engine. The base engine met the 2.5 g/BHP-hr NO_x+HC and 0.1 g/BHP-hr PM emission standards. Table 2 provides details of the test engine.

Table 2. Base engine description.

Manufacturer	Cummins
Model and Year	ISM 2002
Displacement	10.8 L
Cylinders	In-line 6 cylinder
Horsepower	370 hp
Peak Torque	1,450 ft-lb
Other Features	Cooled EGR Variable Geometry Turbocharger

Ricardo, Inc. in Chicago IL performed the engine modifications. A summary of these modifications was presented at the 2003 DEER Workshop.[6] The modifications included redesigned combustion bowl, higher EGR, altered injector spray angle, NO_x reduction catalyst (NRC) and diesel particle filter (DPF). The combination of these engine modifications and emission control systems resulted in a 44% reduction in the NO_x emission and over 90% reduction in PM emissions with a 4.4% fuel economy penalty over the heavy-duty transient test (FTP).

EMISSION CONTROL SYSTEM – Cleaire Advanced Emission Controls® designed the aftertreatment system for this project. The system has been extensively tested for performance and durability.

The aftertreatment system is composed of the following sub-systems:

- Catalysts – two catalyst assemblies in parallel, each consisting of an inlet section, an NRC, a DPF, and an outlet section
- Fuel handling and injection – fuel injector, injector block, fuel pump, pressure regulator, fuel filter, various fittings and lines
- Controller and sensors – the Cleaire MLC® and sensors for determining the operating condition of the engine and the exhaust conditions.

Figure 1 shows a schematic of the system. Two parallel paths were used for this engine because of the backpressure sensitivity of the EGR system. The NRC sub-system operates as follows:

- Fuel is drawn directly from the vehicle fuel supply system in such a manner to ensure that it will not interfere with engine operation.
- A pump pressurizes the fuel to approximately 60 psig and drives it through a fuel filter to the injector.
- The fuel injector is held in a fuel-cooled mount attached to the exhaust pipe. The fuel pressure is held constant by a pressure regulator downstream of the injector. A fuel shut-off valve is installed upstream of the pump as a safety device to prevent accidental fuel leaks in the unlikely event of hose damage. This safety valve shuts off the flow of fuel if the pressure drops below a pre-set level of approximately 15 psig.

Sensors monitor the engine and exhaust conditions. The software inside the MLC calculates the amount of fuel to inject and then sends the appropriate electrical signal to the injector.

Ricardo developed the fuel injection strategy during the engine development phase. The exhaust gases and supplemental fuel react on the NRC to remove NO_x from the exhaust. Particulate matter is collected in the DPF, where it is oxidized via catalytic reactions. The catalytic coating on the DPF also oxidizes HC, CO, and unused supplemental fuel.

VEHICLE – The engine and aftertreatment system modifications were proven on the engine dynamometer using the FTP. The next step in this project was to install the engine into a vehicle. The vehicle selected for this project was a Class 8 delivery truck from the Ralphs Grocery fleet in Riverside, CA. Chassis details are given in Table 3.

Table 3. Chassis Description.

Manufacturer	Freightliner
Model and Year	1995 FTL-D11264ST
Transmission Model	TDA RM9-125AS

The modified engine was installed in the 1995 Freightliner chassis. Several modifications to the existing parasitic systems were necessary, including new wiring harnesses and a new radiator/charge air cooler system.

VEHICLE TEST FACILITY – NREL's ReFUEL Laboratory conducted chassis dynamometer testing. A process and instrumentation diagram is illustrated in Figure 2. The vehicle was mounted to a 380 hp DC electric chassis dynamometer with twin 40" rolls as shown in Figure 3.

Figure 1. Schematic of the Cleaire Aftertreatment System. The exhaust lines are not drawn to scale and the connection between MLC and injector, and MLC and engine sensors are not shown.

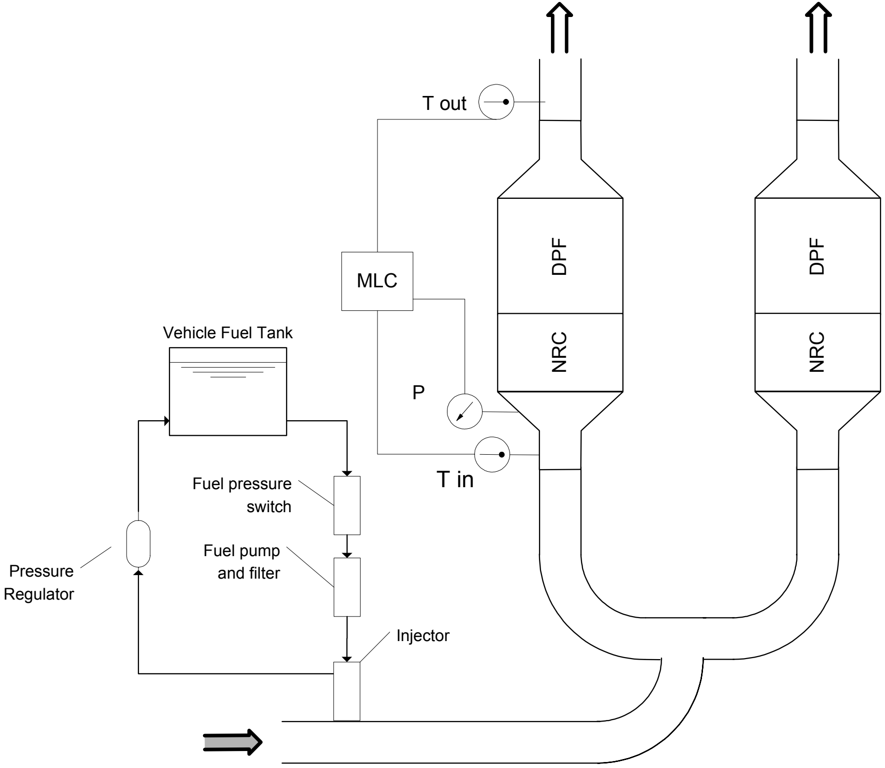


Figure 2. Schematic of NREL's ReFUEL Chassis Dynamometer Test Cell.

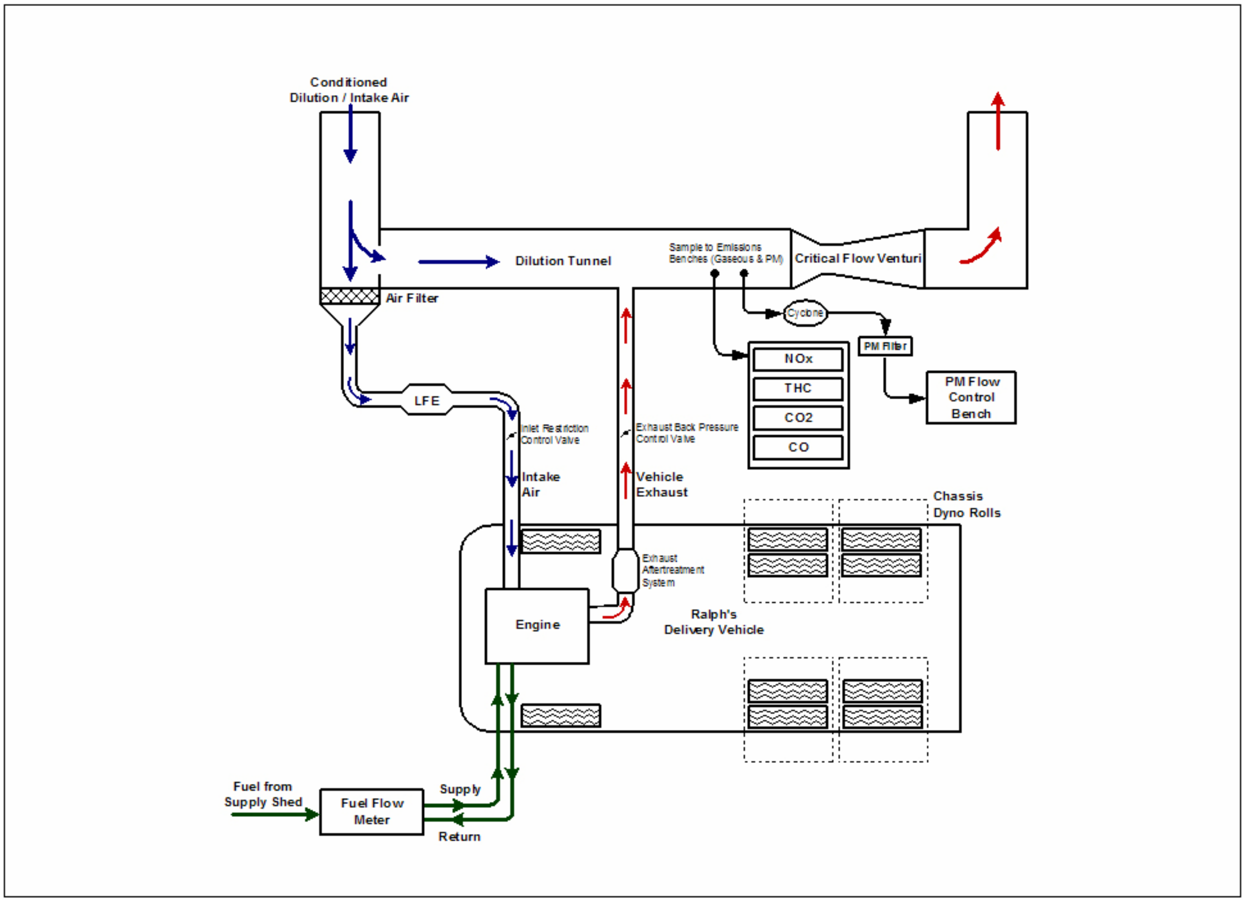
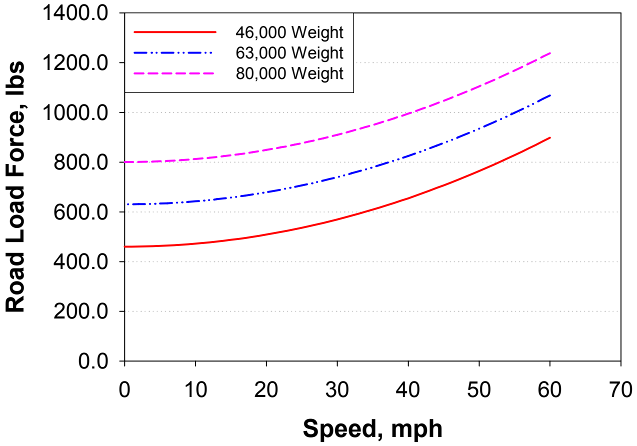


Figure 3.Test vehicle mounted on NREL ReFUEL chassis dynamometer.

The absorption capability of the dynamometer was used to simulate road load conditions and vehicle inertia. The road load function of the vehicle, including aerodynamic drag and friction losses, was estimated from standard equations. Vehicle inertias of 46,000 lbs, 63,000 lbs, and 80,000 lbs were simulated for testing. Figure 4 shows the coast down curves of the vehicle at each inertia weight due to the estimated road load functions.

Figure 4. Estimated road load for Ralphs vehicle on NREL chassis dynamometer.



All emissions sampling was based on the full-scale dilution method with constant volume sampling for mass flow measurement.[8] Dilution air and intake air was HEPA filtered and conditioned for temperature and humidity control. Gaseous emissions were continuously sampled and analyzed using standard practices: non-dispersive infrared analyzers (NDIRs) for CO and CO_2, flame ionization detection (FID) for HC, and photochemiluminescence (CLD) for NO_x.

Particulate matter emissions were quantified on a gravimetric basis by collecting samples on Teflon membrane filters. The PM sampling, conditioning, and weighing practices are designed for measurement of 2010 level emissions. Measures were taken to mitigate the effects of static charge buildup, filter contamination, and equilibrium instability. All filter handling, conditioning, and weighing was conducted in a Class 1000 clean room/environmental chamber with precise control over temperature and humidity. Filters were weighed with a Sartorius microbalance with a readability of 0.1µg. The microbalance is installed on a specially designed table to eliminate variation in measurements due to vibration. These procedures are designed to achieve a standard deviation of 2.5µg for repeated weighing of a filter and 0.25µg for repeated weighing of a standard calibration weight.

Fuel was delivered to the vehicle through a Pierburg fuel metering system (Model PII514-300) capable of volume and mass flow measurement. The metering system also maintains a constant fuel temperature during testing.

CHASSIS TEST CYCLES – Two transient and two steady state cycles were selected for testing. The transient test cycles were the UDDS and the NYComp. These cycles were selected to represent the real world driving encountered by the Ralphs vehicles, including freeway and arterial driving, and low-speed driving around the distribution yard at the Ralphs facility. Figures 5 and 6 show the schematics of the UDDS and NYComp cycles, respectively.

Figure 5. Schematic of UDDS cycle.

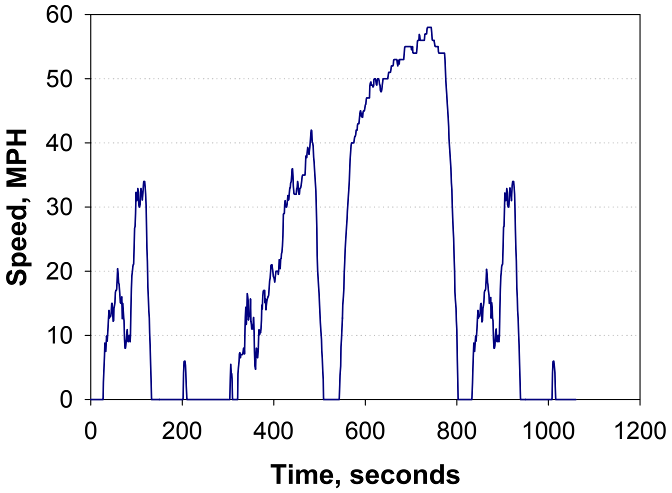
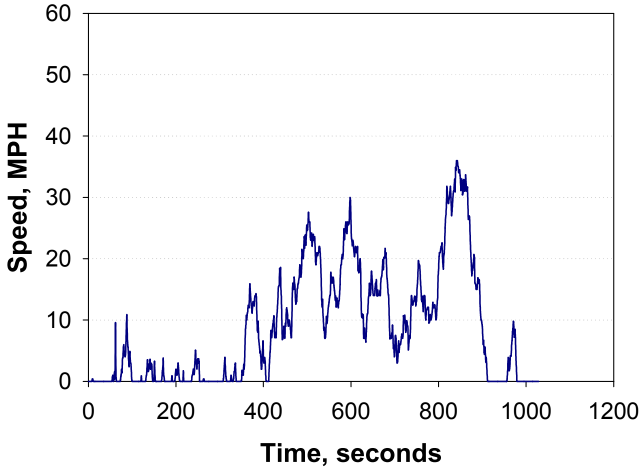


Figure 6. Schematic of NYComp cycle.



The steady-state test cycles included a "cruise" cycle and a "modal" cycle. In the "cruise" cycle, the vehicle was operated at a constant speed from 10 mph to 60 mph in 10 mph increments. The "modal" testing was based on the 8-mode steady state engine test.

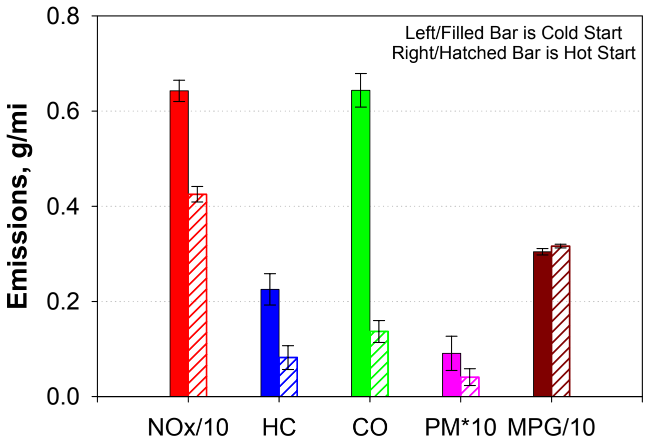
RESULTS

TRANSIENT TESTING – Testing was conducted at three inertia settings. The vehicle was tested at 63,000 lbs, 46,000 lbs, and 80,000 lbs. The test weight of 63,000 lbs represents the average of the vehicle curb weight (CWT – 46,000 lbs) and gross vehicle weight (GVW – 80,000 lbs). Heavy-duty vehicles are typically tested at the average of the CWT and GVW; real world vehicles operate under a variety of conditions. For example, the Ralphs vehicles typically leave the facility with a full trailer, make 3 to 4 stops during a shift, and return empty or nearly so.[9] To understand the impact of loading on emissions, testing was also conducted at 46,000 lbs and 80,000 lbs.

In the following figures, the error bars are 95% confidence intervals determined through an analysis of variance technique. An overlap of the error bars should not be used to determine statistical significance. The significance of any changes will be discussed in the text. Emission test results are given in Appendix 1.

Figure 7 shows the average emissions over the hot and cold start for the UDDS cycle at 63,000 lbs inertia. Note the emissions are scaled for display purposes. All regulated emissions are higher for cold start than hot start. These differences are statistically significant. The NO_x emissions were 51% higher and CO emissions were approximately 380% higher during cold start versus hot start runs. As expected, the fuel economy is slightly greater (approx. 4%) during the hot starts than the cold starts. This difference is also statistically significant.

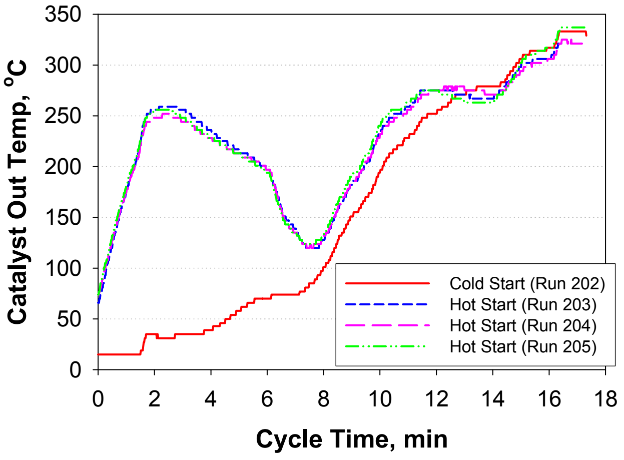
Figure 7. Average hot and cold start emissions over UDDS cycle at 63,000 lbs inertia.



Repeated hot start test runs over the UDDS cycle were performed with the NO_x analyzer operated in NO_x mode and then in NO mode. The difference between the average NO_x and average NO emissions yielded the calculated NO_2 emission rate over the UDDS cycle. For this series of transient drive cycle tests, the NO_2 emissions were roughly 50% of the total NO_x emissions. This is in agreement with previous work with DPFs.[2,10]

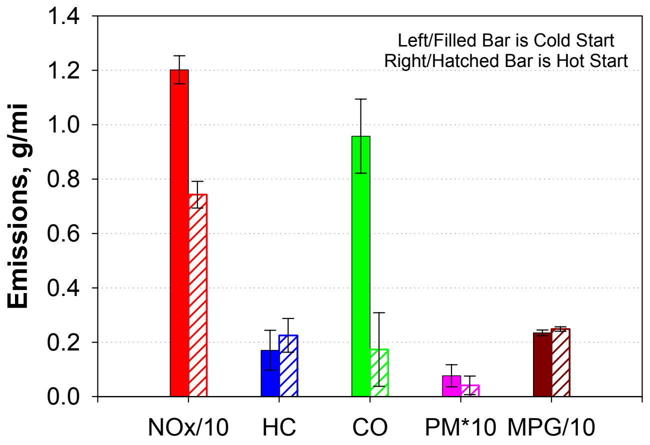
The temperatures in the aftertreatment system were continuously monitored during testing. Figure 8 illustrates the difference in catalyst out temperature over the UDDS cycle. The testing occurred on a single day and shows how the catalyst temperature changes between cold and hot starts.

Figure 8. Catalyst out temperature shown over replicate UDDS cycles on a single day.



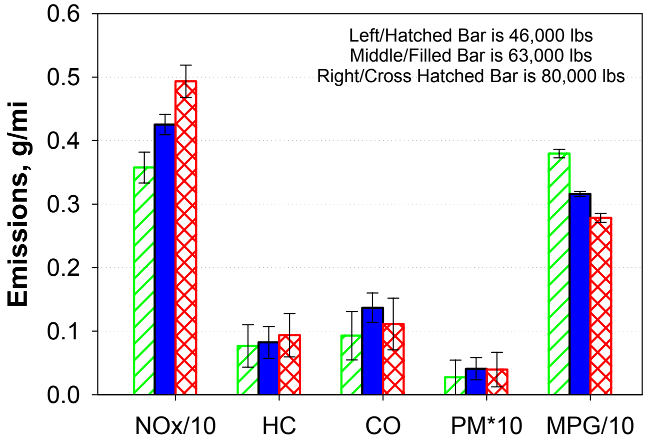
Similar significant cold start versus hot start emissions differences for NO_x and CO were evident over the NYComp cycle (Figure 9). Differences in HC and PM emissions were not statistically significant. The higher fuel economy (approx. 6%) over the hot starts was statistically significant compared to the cold starts.

Figure 9. Average cold and hot start emissions over the NYComp cycle at 63,000 lbs inertia.



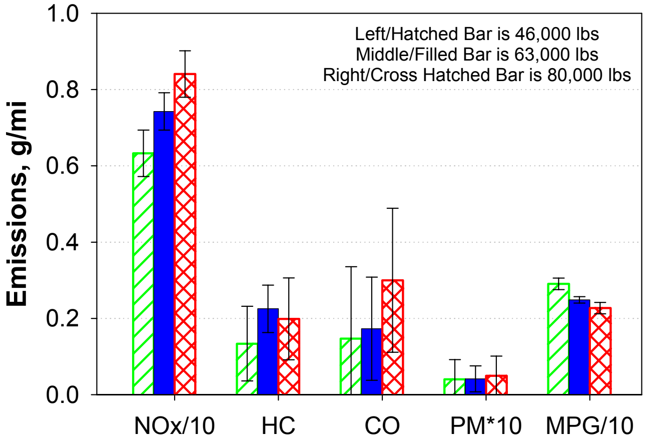
The impact of inertia on emissions from the UDDS cycle was determined by replicate hot start tests at each test inertia weight. Figure 10 shows how the different inertia weights impacted the regulated emissions and fuel economy. No significant differences were observed in the CO, HC, and PM emissions with the changes in inertia. The increase in NO_x emissions and decrease in fuel economy with increase in inertia was statistically significant. Change in simulated vehicle inertia weight from empty (46,000 lbs) to full (80,000 lbs) resulted in an increase of approximately 38% in NO_x emissions (g/mi) and 36% increase in fuel consumption (g/mi).

Figure 10. Impact of inertia on emissions and fuel economy over the UDDS cycle, hot starts only.



Similar emissions and fuel economy trends are observed with changing vehicle inertia weight over the NYComp drive cycle (Figure 11). Like the UDDS cycle, the PM emissions did not change significantly with inertia, showing the efficacy of the DPF over varying simulated vehicle loads for these cycles. The NO_x emissions increased 28% on average and fuel consumption went up 34% when comparing results performed at GVW inertia (80,000 lbs) versus CWT inertia (46,000 lbs).

Figure 11. Impact of Vehicle Weight on Emissions and Fuel Economy Over the NYComp Cycle, Hot Starts Only.

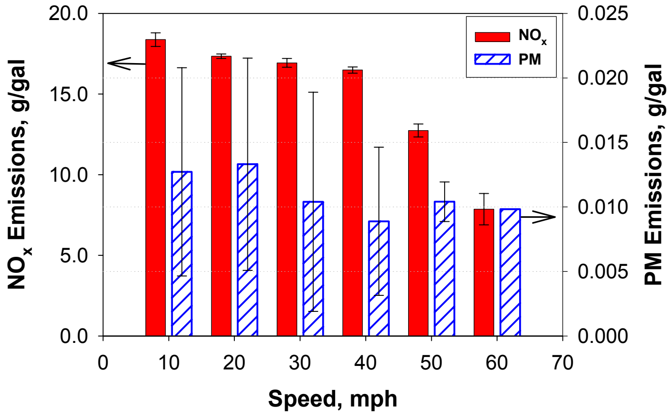


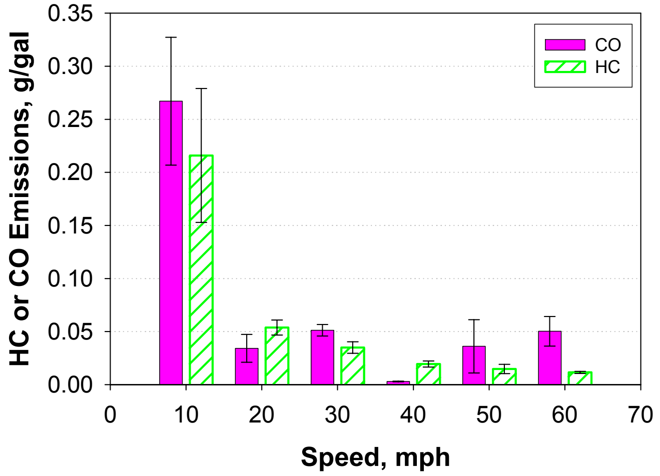
The vehicle performed as expected over both transient cycles. No performance issues were noted over the cold or hot starts or at the various inertial settings.

STEADY-STATE TESTING – To complement the transient testing, the vehicle was tested over two steady state cycles. These cycles were selected for the purpose of ensuring the drivability of the vehicle. In the following figures, the error bars are one standard deviation.

The results from the “cruise” testing were plotted on a fuel specific basis (g/gal). Figure 12 shows the regulated emissions over repeated “cruise” conditions. A simple regression analysis of the emissions revealed that the decrease in NO_x emissions with increasing speed is significant. The corresponding PM emissions do not change significantly with changes in speed. It is also evident from the figure that HC and CO emissions are noticeably higher during 10 mph operation than the higher cruise speeds tested, although the absolute emissions are very low for diesel engines.

Figure 12. Regulated emissions over “cruise” conditions. The top graph shows NO_x and PM emissions. The bottom graph shows HC and CO emissions.

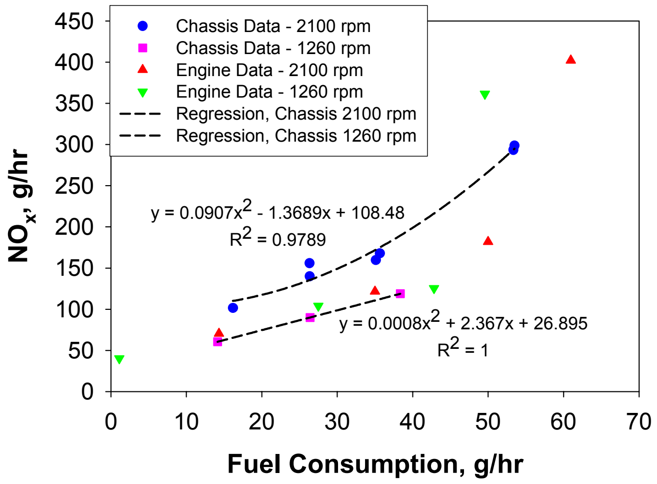




The “modal” testing tried to simulate the engine 8-mode steady state test. The fueling and emission data from the engine dynamometer test were taken and used to construct the chassis “modal” testing. Engine speed was monitored and matched to previous engine test data, while load was increased with the dynamometer. NO_x emissions results at varying load points are presented in Figure 13. The engine steady modal testing at constant speed and varying load points shows NO_x increasing in a linear manner with load under low to medium load conditions, with the NO_x increase becoming more steep (nearly an exponential curve) at high load levels.

Figure 13 shows that there is good agreement between the engine and chassis NO_x emissions at the lower speed (1260 rpm). Higher load points at 1260 rpm were not performed on the chassis dynamometer due to cooling limitations of the vehicle. The agreement deviates somewhat at the higher speed mode (2100 rpm), with the fuel specific NO_x emissions from chassis modal testing being significantly higher than the levels measured under corresponding engine test conditions, although the general curve trend upward with engine load is very similar. Reasons behind this discrepancy at high speed are still being investigated.

Figure 13. Comparison of “modal” data for chassis and engine dynamometer testing.



As with the transient testing, the vehicle did not exhibit any performance issues during the steady state testing.

CONCLUSIONS

A 2002 Cummins ISM engine was modified to operate on GTL fuel and advanced emission control systems. The engine modifications included increased EGR, optimized bowl design, and optimized ECM algorithms. A Cleaire NRC and DPF were used to produce low emissions during the engine FTP.

Once the engine modifications were complete, and the engine met the performance goals, it was installed into a Freightliner body and chassis tested. The purpose of the chassis testing was to show drivability over transient and steady-state operation, as well as to evaluate fuel economy and emissions performance under vehicle driving conditions that more closely simulate duty cycles in the field.

NREL’s ReFUEL laboratory collected the chassis emissions over the UDDS and NYComp transient cycles and two steady-state cycles—a “modal” and a “cruise” cycle. Emissions were consistently higher on a g/mi basis over the low-speed NYComp cycle compared to the UDDS cycle. The influence of vehicle weight was tested through varying inertial weights during testing. As expected, the lightest vehicle test weights produced the lowest emissions and highest fuel economy.

The test weight is not commonly varied during chassis dynamometer testing, which follows from light-duty certification practice. However, in studying commercial vehicles, it may be more important to study the effects of being fully loaded. There is an economic incentive to maximize payload, to study part-load conditions, and to reflect the fact that commercial vehicles are often limited by volume rather than mass.

Steady-state testing revealed the significant changes in emissions rates at different cruise speeds. The changes in the fuel specific NO_x emissions were significant between 10 mph and 60 mph. No significant changes in the fuel specific PM emissions were observed over the same range of cruise speed conditions. The engine 8-mode test was roughly replicated on the chassis dynamometer. Agreement between the NO_x emissions was good at the lower speed, but deviated at the higher speed.

Overall, this vehicle, with a modified engine and advanced emission control system, met drivability expectations over two transient test cycles and two steady state test cycles. At the conclusion of the dynamometer testing, the vehicle was returned to the fleet to undergo a six-month operability study. At the time of this writing, the vehicle had completed three months of testing and was able to meet the fleet requirements for operation.

ACKNOWLEDGMENTS

The authors thank the Department of Energy's Office of Energy Efficiency and Renewable Energy, FreedomCAR and Vehicle Technologies Program, Fuels Technology Subprogram.

DEFINITIONS

ASTM: American Society for Testing and Materials
ºC: Degrees Celsius
CFR: Code of Federal Regulations
CO: Carbon monoxide
CO_2: Carbon dioxide
CWT: curb weight
DC: direct current
DPF: Diesel particle filter
EGR: exhaust gas recirculation
EPA: Environmental Protection Agency
FTP: Federal Test Procedure
g/BHP-hr: grams per brake horsepower hour
g/gal: grams per gallon
g/mL: grams per milliliter
g/mi: grams per mile
GTL: Gas-to-liquid
GVW: gross vehicle weight
HC: Hydrocarbons
HEPA: High Efficiency Particle Abatement
hp: horsepower
lbs: pounds
µg: microgram
mm^2/s: square millimeters per second
mph: miles per hour
NO: Nitrogen monoxide
NO_2: Nitrogen dioxide
NO_x: Nitrogen oxides
NRC: NO_x Reduction Catalyst
NREL: National Renewable Energy Laboratory
NYComp: New York Composite
PM: Particulate matter
ppm: parts per million
psig: pounds per square inch, gauge
ReFUEL: Renewable Fuels and Lubricants
UDDS: Urban Dynamometer Driving Schedule

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APPENDIX A-1

Emission Test Results – UDDS Cycle

Inertia Weight	Date	Run	Start	Distance	CO_2	NO_x	THC	CO	PM	Fuel Economy
lbs.		**#**	**(Hot/Cold)**	**miles**	**g/mi**	**g/mi**	**g/mi**	**g/mi**	**g/mi**	**MPG**
63,000	7/21/2004	186	Cold	5.38	2800	5.84	0.17	0.54	N/A	3.23
63,000	7/21/2004	187	Hot	5.42	2785	4.38	0.11	0.11	0.0119	3.19
63,000	7/21/2004	188	Hot	5.45	2746	4.11	0.11	0.11	0.0048	3.21
63,000	7/21/2004	189	Hot	5.40	2750	4.02	0.11	0.11	0.0045	3.20
63,000	7/23/2004	197	Cold	5.39	2885	5.92	0.31	0.70	N/A	3.08
63,000	7/23/2004	198	Hot	5.37	2789	3.95	0.12	0.13	0.0037	3.18
63,000	7/30/2004	201	Cold	5.35	3084	6.82	0.22	0.71	0.0133	2.89
63,000	8/3/2004	206	Cold	5.28	3096	6.71	0.27	0.63	0.0060	2.97
63,000	8/3/2004	207	Hot	5.37	2936	4.14	0.09	0.11	0.0048	3.13
63,000	8/3/2004	208	Hot	5.37	2909	4.04	0.10	0.11	0.0033	3.18
63,000	8/3/2004	209	Hot	5.34	2933	4.22	0.09	0.12	0.0032	3.13
63,000	8/5/2004	225	Hot	5.43	2900	4.52	N/A	0.18	0.0171	3.17
46,000	8/5/2004	226	Hot	5.49	2345	3.57	0.07	0.11	N/A	3.92
46,000	8/5/2004	227	Hot	5.43	2398	3.57	0.07	0.06	0.0024	3.74
80,000	8/5/2004	228	Hot	5.23	3360	4.86	0.10	0.09	0.0056	2.78
46,000	8/5/2004	229	Hot	5.41	2371	3.47	0.05	0.07	0.0027	3.72
80,000	8/5/2004	231	Hot	5.25	3301	4.90	0.08	0.15	0.0054	2.81
63,000	8/5/2004	232	Hot	5.39	2831	4.04	0.07	0.12	0.0032	3.23
63,000	8/10/2004	235	Hot	5.36	2888	4.19	0.11	0.17	0.0023	3.17
63,000	8/10/2004	236	Hot	5.34	2930	4.37	0.07	0.12	N/A	3.16
63,000	8/16/2004	248	Hot	5.36	2930	4.23	0.06	0.15	0.0017	3.07
46,000	8/16/2004	249	Hot	5.48	2363	3.70	0.04	0.13	0.0016	3.76
80,000	8/16/2004	250	Hot	5.24	3397	5.01	0.05	0.09	0.0014	2.75
63,000	8/16/2004	251	Hot	5.23	2942	4.19	0.04	0.10	0.0050	3.12
63,000	8/16/2004	252	Hot	5.30	2889	2.19*	0.05	0.09	0.0016	3.18
63,000	8/16/2004	253	Hot	5.21	2920	4.47	0.05	0.12	0.0016	3.14
63,000	8/16/2004	255	Hot	5.30	2908	2.33*	0.03	0.16	0.0013	3.15
63,000	8/16/2004	256	Hot	5.23	2853	4.45	0.04	0.18	0.0014	3.21
63,000	8/16/2004	257	Hot	5.27	2879	2.34*	0.04	0.12	0.0015	3.19
63,000	8/19/2004	259	Cold	5.36	3055	6.73	N/A	0.62	N/A	N/A
63,000	8/23/2004	269	Hot	5.43	2889	4.29	0.04	0.15	0.0022	3.14
46,000	8/23/2004	270	Hot	5.49	2340	3.63	0.06	0.11	0.0022	3.86
80,000	8/23/2004	271	Hot	5.29	3297	5.04	0.06	0.13	0.0014	2.81
63,000	8/23/2004	272	Hot	5.37	2886	4.29	0.04	0.19	0.0048	3.13
63,000	**Average**		**Cold**	**5.35**	**2984**	**6.40**	**0.24**	**0.64**	**0.0096**	**3.04**
63,000	**Average**		**Hot**	**5.35**	**2875**	**4.23**	**0.07**	**0.13**	**0.0042**	**3.16**
80,000	**Average**		**Hot**	**5.25**	**3339**	**4.95**	**0.07**	**0.12**	**0.0035**	**2.79**
46,000	**Average**		**Hot**	**5.46**	**2363**	**3.59**	**0.06**	**0.10**	**0.0022**	**3.80**

* NO_x analyzer in NO mode

Avg. NO_2			**NO g/mi**	**NO_2 g/mi**	**NO_2:NO_x Ratio**
63,000	**Average Hot 8/16**		**2.29**	**2.08**	**0.48**

APPENDIX A-1, CONTINUED.

Emission Test Results – NYComp Cycle

Inertia Weight	Date	Run	Start	Distance	CO_2	NO_x	THC	CO	PM	Fuel Economy
lbs.		**#**	**(Hot/Cold)**	**miles**	**g/mi**	**g/mi**	**g/mi**	**g/mi**	**g/mi**	**MPG**
63,000	7/22/2004	192	Hot	2.49	3452	7.26	0.19	0.17	0.0024	2.53
63,000	7/22/2004	195	Hot	2.51	N/A	N/A	N/A	N/A	0.0034	2.46
63,000	7/22/2004	196	Hot	2.54	3344	7.03	0.21	0.24	0.0031	2.57
63,000	8/2/2004	202	Cold	2.53	3580	12.72	0.19	1.00	N/A	2.53
63,000	8/2/2004	203	Hot	2.51	3501	8.19	0.17	0.16	0.0122	2.50
63,000	8/2/2004	204	Hot	2.52	3461	7.92	0.16	0.23	0.0039	2.57
63,000	8/2/2004	205	Hot	2.52	3594	8.07	0.22	0.20	0.0033	2.46
63,000	8/3/2004	212	Hot	2.52	3597	7.86	0.246	0.12	0.0031	2.43
63,000	8/3/2004	213	Hot	2.54	3541	7.54	0.21	0.18	0.0034	2.38
63,000	8/4/2004	216	Hot	2.51	3686	7.17	0.34	0.16	0.0051	2.40
46,000	8/4/2004	217	Hot	2.58	2964	6.33	0.28	0.21	0.0031	2.90
80,000	8/4/2004	218	Hot	2.54	3950	8.45	0.47	0.46	0.0043	2.26
80,000	8/4/2004	219	Hot	2.51	3908	8.32	0.23	0.19	0.0062	2.21
46,000	8/4/2004	220	Hot	2.58	2919	6.26	0.21	0.16	0.0034	2.80
63,000	8/4/2004	221	Hot	2.56	3391	7.32	0.34	0.21	0.0023	2.63
80,000	8/4/2004	222	Hot	2.55	3796	7.95	0.32	0.28	0.0035	2.36
46,000	8/4/2004	223	Hot	2.59	2690	5.89	0.14	0.10	0.0047	3.04
63,000	8/10/2004	233	Cold	2.54	3752	12.56	0.13	1.12	0.0110	2.33
63,000	8/16/2004	247	Cold	2.51	3902	11.72	0.13	0.85	0.0130	2.14
63,000	8/17/2004	258	Cold	2.52	3627	N/A	N/A	0.67	0.0029	2.40
63,000	8/23/2004	264	Cold	2.57	3790	11.25	0.17	1.13	0.0037	2.31
63,000	**Average**		**Cold**	**2.53**	**3730**	**12.06**	**0.16**	**0.95**	**0.0077**	**2.34**
63,000	**Average**		**Hot**	**2.52**	**3508**	**7.60**	**0.23**	**0.19**	**0.0042**	**2.49**
80,000	**Average**		**Hot**	**2.53**	**3885**	**8.24**	**0.34**	**0.31**	**0.0046**	**2.28**
46,000	**Average**		**Hot**	**2.58**	**2858**	**6.16**	**0.21**	**0.16**	**0.0038**	**2.91**