DOE Grant DE-EE-000-7800

Final Scientific/Technical Report

I. Overview

Federal Agency and Organization Element to Which Report is Submitted: DOE EERE

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Project Title: Innovative Dual Fuel Aftermarket Emissions Solution

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Sub-Recipient Contract: DE-FOA-0001384/001, DE-FOA-0001384/002, DE-FOA-0001384/003

Project/Grant Period (Start Date, End Date): 5/8/17 – 6/30/19

Final Scientific/Technical Report Date: 9/28/19

II. Executive Summary

Three companies, NG1 Technologies (enhanced exhaust technology), BoostBox H2 (Hydrogen fuel cell technology) and Vaztec (advanced air-intake technology), sub-recipients of DOE-EE-0007800, endeavored to combine their technologies to improve the three aspects of combustion: efficient air intake (more air pressure), efficiency combustion (hydrogen enhanced combustion), efficient exhaust (lower backpressure), to accomplish the grant objectives.

The objective of this project was to develop an advanced emission control system for Class 7 and 8 heavy-duty dual-fuel vehicles that eliminate or mitigates the negative effects of currently used diesel particulate filters (DPF) and selective catalytic reduction (SCR) emissions-treatment systems. The project combined multiple technologies that worked together to increase engine efficiency and reduce most emissions from the combustion process.

Our overall project goal was to improve fuel economy and reduce Particulate Matter (PM) emissions by 30% in Class 7 & 8 Heavy-Duty dual-fuel trucks, in doing so, eliminating or mitigating the need of the Diesel Particulate Filter Emissions After Treatment System (EATS).

Additionally, it was the team's goal to improve fuel efficiency and reduce maintenance costs to incentivize fleet operators and justify the expenditure to implement the new technologies that reduce emissions.

The majority of project testing was conducted on a 2013 Mack Pinnacle single-axle day cab (SADC) tractor equipped with an 11-liter 2012 Mack MP7 ATX engine provided by United Parcel Service (UPS). Additional testing was completed with a 2014 Mack Cummins LNG MTX, meeting project's dual-fuel objective.

We far exceeded our primary project objectives by not only reducing PM emissions by 64%, but by also reducing NO_x emissions by 77%, reducing CO_2 by 4.5%, and improving fuel efficiency by 9.94%. It should be noted that by not consuming 9.94% of fuel, ALL emissions were reduced by an additional 9.94%.

Our team was able to continue to refine our technologies (for example, installation and manufacturing techniques) and implement additional features (like Telematics to the BoostBox H2) due to this project, which help to make the overall solution to improved fuel efficiency and reduced greenhouse gas emissions devices more cost-effective and useful in the field. Additionally, the team was able to utilize testing resources that would otherwise be financially unavailable to our new companies.

Although not all aspects of the project were ultimately accomplished, and we will likely not replace EATS, this program definitively showed that the BoostBox H2 and NG1 TechFlo devices dramatically improved the performance of diesel combustion using a Hydrogen Enhanced Combustion chamber both on the track over 5000 miles of use and on a dynameter using the HHDDT profile. Such improvements will not only save fleets thousands of dollars in fuel and maintenance costs but will also provide much cleaner air and reduced greenhouse and smog creating gases.

The team was extremely encouraged by the results observed and are anticipating rapid commercialization of the team technologies to help improve overall air quality and freight costs. Our system costs would reflect less than a 15-month Return on Investment (ROI) for most participating owners of diesel-powered systems.

III. Accomplishments vs. Objectives

There were two budget periods for this project that had specific objectives (tasks) and requirements (milestones) associated with each period, with the overall project goal of achieving a 30% reduction in PM over existing baseline emissions equipment that would be standard on any commercial diesel truck produced after 2010.

Our testing was conducted using a 2013 Mack Pinnacle single axle day cab (SADC) tractor equipped with an 11-liter 2012 Mack MP7 ATX engine, with approximately 530k miles on the vehicle at the start of testing. All testing was conducted in accordance with EPA CFR49, Part 1065, SAE J2711, SAE J1264, and SAE J1321

Our team was able to complete most of the objectives of Budget Periods 1 and 2 and results are presented in the Summary of Technical Activities later in this report.

<u>Budget Period 1: Technology Testing, Data Collection, and Systems Development</u>

- Collect on-road data from proposed devices
- Testing of technologies
- Development of intake system for single cell
- Development and design of the catchment system
- Start of modeling & Flow analysis
- Test final results of proposed technologies
- Completion of Phase I testing

- Milestone 1: Collection of emissions data on NG1 and BoostBox H2 separately and together

We were able to successfully collect emissions test data with the NG1 TechFlo combined with the BoostBox H2 and have shown positive results for reduction in PM, $NO_{x,}$ and CO_2 in accordance to the goal as measured by third party company infoWedge.

- Milestone 2: Combine Boost Box H2 with NG1 on a single-cylinder testbed

Testing of a single-cylinder diesel engine was conducted as a baseline for the development of the Vaztec air intake solution. The baseline engine tests were conducted on a stock engine using a laboratory dynamometer. Particulate and gaseous emissions were measured by third party company infoWedge.

BoostBox H2 successfully implemented electronic flow control for their hydrogen system to adjust the volume of hydrogen for this smaller engine application.

While baseline tests were accomplished in accordance to this goal, the team was not able to integrate the Vaztec advanced air intake system into a new engine design, therefore, we were not able to test all three technologies together.

- Milestone 3: Design Mapping software to optimize the fuel mixture

This required the development of a custom-engineered electronic control module and software that will recognize the combined technologies in optimizing vehicle performance. The team contacted Mack Trucks in seeking their assistance. Unfortunately, Mack was not able to support changes to the programming due to proprietary and legal restrictions of their intellectual property incorporated in the systems. The team then contacted OTR Performance; then PDQ Performance; then CZero, seeking a custom design fuel mapping software program needed for optimizing fuel mixture. No solutions were found that fit within the time and cost parameters of this grant, therefore the team was not able to complete this objective.

- Milestone 4: Demonstrate a reduction of particulate matter (PM) of at least 30% relative to baseline

Testing on the dynamometer at Penn State showed an 11% reduction in PM, while infoWedge performed continuous PM measurements during a 5000-mile track test at Mesilla Valley Transportation, utilizing the BF Goodrich proving track in Texas, showed a 64% reduction in PM - far in excess of project objectives.

Budget Period 2: Finalize System Design, Prototype and Test

- Test centrifuge effects
- Completion of modeling & flow analysis of centrifuge
- Completion of a prototype catchment system
- Compare spin catchment designs
- Chassis dyno and emissions testing
- Final Society of Automotive Engineering (SAE) testing
- Development of marketing strategy & commercialization
- Market launch

- Milestone 1: Determine if the NG1 system alone has enough space claim to create the required centrifugal effect to completely spin particulates to secondary catchment chamber or if a mechanical centrifuge is required

A spin catchment system was designed and fabricated through the team partner in North Carolina, however, resources and priority were given to refining and optimizing the existing NG1 and BoostBox H2 technologies given the 64% improvement in PM measurements. This objective was not completed as the spin catchment system was not required to achieve the 30% minimum PM reduction.

- Milestone 2: Chassis dyno testing and emissions collecting

Chassis dynamometer testing was completed by Penn State University. After benchmark testing, we were able to successfully collect emissions test data with the NG1 TechFlo combined with the BoostBox H2 and have shown positive results for reduction in PM, NO_x, and CO_2 in accordance to the project goal.

- Milestone 3: Complete spin catchment system

A spin catchment system was designed and fabricated through the team partner in North Carolina, however, resources and priority were given to refining and optimizing the existing NG1 and BoostBox H2 technologies given the 64% improvement in PM measurements. This objective was not completed within the timeframe of the project.

- Milestone 4: Complete testing of all technologies on diesel truck engine in on-road application

Only the NG1 (enhanced exhaust technology) and Boost Box H2 (Hydrogen Fuel Cell Technology) were able to be combined for on-road testing. Unfortunately, the team was unable to integrate the Vaztec (advanced air-intake) technology into the systems. infoWedge performed continuous PM measurements during a 5000-mile track test at Mesilla Valley Transportation, utilizing the BF Goodrich proving track in Texas, which showed a 64% reduction in PM. Additionally, between official testing cycles, the tractor provided by UPS was driven and monitored from State College, PA to El Paso, TX to Laramie, WY, to State College, PA. This objective was successfully completed.

IV. Publicly Available Scientific and Technical Information (STI)

There is no publicly available material that is duplicated in this report.

V. Summary of Technical Project Activities

Through the project, the team conducted several rounds of testing with the NG1 and BoostBox H2 technologies in four primary areas as summarized below.

1. Testing by Mesilla Valley Transportation Solutions was a long-duration track test of over 5,000 miles that comprised two major aspects of test: A/B fuel efficiency comparison of our test vehicle with a baseline vehicle under the same track conditions; and continuous emissions monitoring.
2. Testing by Penn State was a short duration track test combined with dynamometer testing where they were primarily monitoring fuel efficiency and emissions before and after hydrogen conditioning of the engine.
3. Single-Cell Testing was an experimental development project to attempt to integrate NG1 and BoostBox H2 technologies with a new concept in air intake design from Vaztec that would eliminate valves and valve stems in the engine and to monitor fuel efficiency and emissions.
4. Over-the-road testing was conducted on various vehicles and the primary grant test vehicle to evaluate long term fuel efficiency utilizing the NG1 and BoostBox H2 technologies.

Detailed third party reports provided in the links at the end of each section.

Testing with Mesilla Valley Transportation Solutions (MVST)

The test consisted of 5000 miles on the test vehicle to quantify the savings over time and break-in period of the technologies. Testing was conducted at a steady-state speed of 65 miles-per-hour on the BF Goodrich 9-mile test track near Pecos, Texas. Testing analyzed fuel consumption (reported by MVTS) and emissions measurement (reported by InfoWedge).

The test vehicle was a 2013 Mack Pinnacle single-axle day cab (SADC) on loan from United Parcel Service (UPS). The truck had 530,440 miles at the commencement of testing. Service and repairs were made to the truck prior to testing to ensure consistent, reliable performance throughout the test.

A second vehicle was used as a comparison for fuel economy tests, which was a 2015 Volvo SADC with 194,170 miles. Details of which can be found in the detailed report. Test procedures followed MVTS 2-truck procedures and utilized sophisticated data acquisition systems, fuel flow meters, and numerous sensors to accurately quantify changes in fuel consumption.

Two 53' dry-vans trailers were provided by the MVT fleet and were closely inspected prior to testing. Trailer tires were Wide Based Singles (WBS). Trailers were equipped with GreenWing trailer skirts and loads were secured to the floor and sides of the trailers. Total gross vehicular weight was 45,000 pounds.

Test results showed to be accurate and reliable, proven by the start/finish fuel economy value difference of -0.01% when the primary test truck was returned to nearly the same condition.

MVTS Test Results – 77% Reduction in NO_x. 64% Reduction in PM.

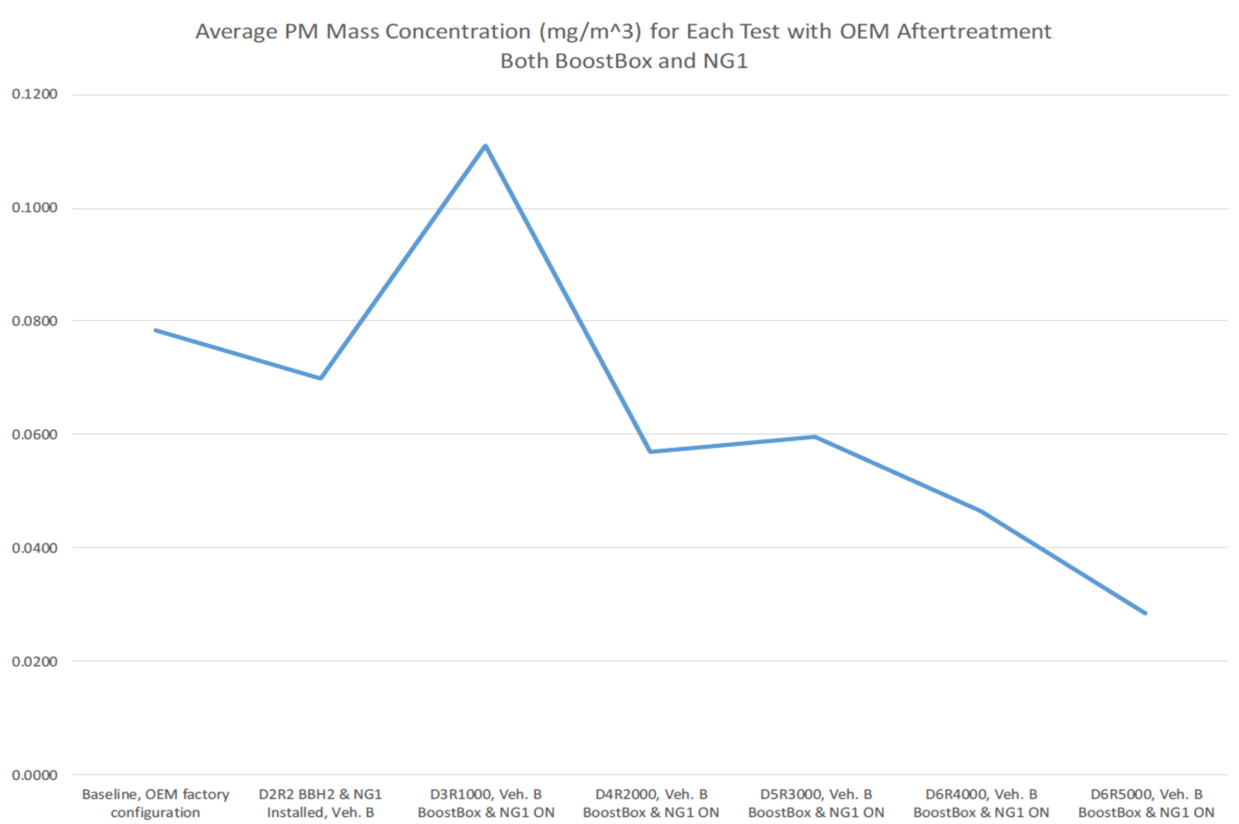
If was shown that at a steady-state 65 mpg track test, the fuel efficiency was not statistically different from the start to end of testing versus the comparable vehicle. Even though the test vehicle achieved a 10.14% improved fuel efficiency during the testing period, the second comparable vehicle also exhibited a similar improvement. Following testing, it was learned the engine of the primary test truck (Mack MP-7) used a multi-burst fuel injection system that may have prevented the BoostBox H2 system from performing to its optimal extent. Given the previously stated issues related to modifying software related to fuel injection and combustion parameters, the team was not able to achieve significant relative fuel savings.

Emissions results showed a 64% reduction particulate matter (PM) emissions per mile over the course of testing. As can be seen in the table and graph below, the average mass concentration of PM in the exhaust steadily reduced from the baseline level to the point that, at the 5000-mile test it was 64% lower than the already low baseline. The 5000-mile average NO_x concentration was 77% lower than the baseline average.

"Test results indicate that adding the retrofit devices and using them for 5000 miles at highway conditions resulted in a PM concentration reduction of approximately 64% at the tailpipe for this vehicle. The already low baseline PM concentration of 0.0784 mg/m3 was reduced to 0.0283 mg/m3. Also, NO_x emissions were reduced by approximately 77%, from 72.2 ppm down to 16.6 ppm. Unfortunately, your fuel efficiency contractor measured a slight reduction in fuel efficiency of between 0.01% and 1.34%." – Andrew Burnett, infoWedge

"All tests controlled or recorded parameters that could conceivably change emissions independently of the BoostBox and NG1 retrofit devices (weather conditions, driver influence, etc.). No outside influences that could have affected emissions anywhere near the observed levels were identified. Therefore, we conclude that the emissions reductions were caused primarily by your retrofit devices." – Andrew Burnett, infoWedge

Baseline vs. BoostBox H2 & NG1	MPG	mi/kg fuel	mi/mol e fuel	Date	Approx Test Time	Averaging Data Start	Averaging Data End	Averaging Time (mins)	Avg. PM mg/m^3	Avg. NOx ppm	Avg. O2 %	Avg CO2 calc'd%	% Excess air	Exhaust Flow mol/mi	Avg PM mg/mol exh	Avg PM mg/mi
Baseline, OEM factory configuration	7.1	2.15	0.48	16-Jan	6:10	8:59:02	10:06:29	67.45	0.0784	72.2	7.82	8.39	61.10	400.0	0.00192	0.76736
D2R2 BBH2 & NG1 Installed, Veh. B	7.3	2.20	0.49	16-Jan	10:06	12:56:18	14:03:46	67.46	0.0699	53.4	7.60	8.54	58.37	383.5	0.00171	0.65636
D3R1000, Veh. B BoostBox & NG1 ON	7.3	2.20	0.49	17-Jan	20:31	23:27:10	0:34:39	67.48	0.1110	53.7	7.48	8.62	56.87	379.9	0.00272	1.03204
D4R2000, Veh. B BoostBox & NG1 ON	8.1	2.46	0.54	18-Jan	14:31	17:50:11	18:57:39	67.46	0.0569	35.9	7.17	8.82	53.29	333.4	0.00139	0.46382
D5R3000, Veh. B BoostBox & NG1 ON	7.9	2.37	0.53	19-Jan	8:00	10:58:10	12:05:37	67.45	0.0596	38.6	7.30	8.74	54.73	348.5	0.00146	0.50798
D6R4000, Veh. B BoostBox & NG1 ON	7.8	2.34	0.52	20-Jan	1:50	4:20:59	5:28:28	67.48	0.0464	25.2	7.47	8.62	56.78	358.1	0.00114	0.4066
D6R5000, Veh. B BoostBox & NG1 ON	8.5	2.57	0.57	20-Jan	16:51	18:48:35	19:56:04	67.48	0.0283	16.6	7.13	8.85	52.77	317.4	0.00069	0.21999
% Reduction from baseline to 5000 mi									**64%**	**77%**						**71%**
D7R5390, Veh. B Stock exhaust stack (NG1 OFF), DPF/SCR Bypas	8	2.42	0.54	21-Jan	13:11	3:07:08 AM	4:14:36 AM	67.48	0.2421	512.0	8.49	7.95	69.95	375.6	0.00592	2.22485
D7R5260, Veh. B Boostbox Off, NG1 ON, DPF/SCR Bypass	8	2.40	0.53	21-Jan	7:57	12:27:21 AM	1:34:49 AM	67.46	0.2096	494.9	8.05	8.25	63.94	364.6	0.00513	1.86929
D6R5130, Veh. B BoostBox & NG1 ON, DPF/SCR Bypass	8.1	2.45	0.54	20-Jan	10:27	9:55:04 PM	11:02:33 PM	67.47	0.2140	492.2	8.09	8.22	64.45	359.0	0.00523	1.87918
% Reduction from engine-out to tailpipe (both retrofits ON)									**12%**	**4%**						**16%**
% Reduction from engine-out to tailpipe (only NG1 ON)									**13%**	**3%**						**16%**



MVTS BB H2 NG1 5000-mile test

infoWedge_Boost-BoxNG1-1pager

infoWedge_Boost-BoxNG1-initialPMResults

NTKSummary20180302-01

Testing at Pennsylvania State University (Penn State)

The goal was to analyze and publish test results from the vehicle testing at Pennsylvania State University Larson Transportation Institute between October 31, 2017 – November 7, 2019. The NG1 Project Team along with BoostBox traveled to Penn State University to perform a chassis dynamometer test and a track test on the 2012 Mack MP7 UPS aftermarket equipped project truck donated by United Parcel Service. An institutional validated aftermarket data was generated using vehicle analytics, chassis dynamometer and fuel cycle testing on the vehicle test track. Both fuel and emissions will be captured during the aftermarket testing events.

Penn State Test Results – 9.94% Fuel Savings, 4.5% Reduction in CO_2,12% Reduction in NO_x, 11% Reduction in PM.

The first test iteration performed was the chassis dynamometer specific to emissions collection. The chassis dynamometer testing was performed generally in accordance with EPA CFR49, Part 1065 and SAE J2711 as practically determined by the Emissions Testing Protocol developed by Penn State University. The chassis dynamometer-based tests were conducted at an inertia load of 30,000 lb., as recommended by the sponsor. The emissions results show steady improvement from baseline in particulate matter (PM) emissions over the course of testing. As can be seen in the attached table and graphs, the average mass concentration of particulate matter PM in the exhaust steadily reduced from the baseline level to the point that, chassis dynamometer test was 11% lower than the already low baseline level. The NOx concentration was 12% lower than the baseline average. The concentration of CO_2 in the exhaust steadily reduced from the baseline level to the point that chassis dynamometer test was 4.5% lower than the already low baseline level. The fuel economy results on the chassis dynamometer show an improvement from baseline stock equipped truck to aftermarket NG1 TechFlo Pipe and BoostBox equipped truck of a 9.94% fuel improvement over the course of testing.

Comparisons of Emissions and Fuel Economy Results on Dynamometer

Table 4. Comparison of emissions and FE results for stock diesel and conditioned diesel with both technologies functioning, HHDDT cycle- (October, 2017, November 2018)

	Test #	Mileage, mpg	CO_2, gm/mi	CO, gm/mi	THC, gm/mi	CH_4, gm/mi	NO_x, g/mi	PM, g/mi
HHDDT Stock, Diesel	1	6.64	1407	0.27	0.06	0.01	2.51	0.005
	2	6.64	1406	0.30	0.01	0.00	2.43	0.006
	Average	6.64	1407	0.29	0.04	0.01	2.47	0.006
HHDDT with NG1 stack and Boostbox on	1	7.16	1353	0.13	0.08	0.0	2.15	0.005
	2	7.16	1347	0.19	0.09	0.0	2.25	0.008
	Average	7.16	1350	0.16	0.09	0.0	2.20	0.007

The second test iteration performed was the track test specific to fuel economy only. The track test constant speed tests were conducted with a gross vehicle load of 30,000 lb. to be consistent chassis dynamometer-based tests that were conducted at an inertia load of 30,000 lb., as recommended by the sponsor. A water tanker filled with enough water to achieve the gross load was used for the tests.

The tractor-tanker combination was run at constant speeds of 30 mph and 40 mph around the 1-mile test track at Penn State. The fuel consumption was noted for completing two runs around the track. This was repeated four times and average numbers were calculated. The test was also conducted in both clockwise and counterclockwise directions on the track to minimize effects of wind and grade on the results. The tractor was tested in the condition and configuration as delivered to the test track by the sponsor. Warm-up consisted of driving the tractor for 30 minutes.

The fuel economy results of the track test show a fuel improvement from baseline stock truck to aftermarket conditioned truck; result of NG1 TechFlo Pipe and BoostBox H2 equipped unit (5,000 mile track test at Mesilla Valley), of 15% fuel improvement at 30 miles an hour interval and 16% fuel improvement at 40 miles an hour interval over the course of testing.

Comparisons of Fuel Economy Results - Baseline Truck vs. Condition Truck (5,000 miles Aged)

Table 2. Comparison of constant speed on-track fuel economy test results for diesel fuel-Baseline vs. conditioned engine (October, 2017, November 2018)

	Speed	Mileage, mpg		Average fuel, mpg/mpdge
		CCW	CW	
Baseline	30 mph	13.00	13.20	13.10
	40 mph	11.42	11.90	11.66
Conditioned engine	30 mph	11.0	11.5	11.25
	40 mph	9.62	9.92	9.77

NG1 Report - Dyno based

NG1 Report - Track based

NG1 UPS_truck_Diesel_report

Penn State Report

Single-Cell Evaluations

The goal was to perform fuel and emissions testing on a one-cylinder stock engine in generating a baseline average during the Single Cell Testing. The testing protocol was to consist of baseline testing of stock one-cylinder engine, including Tier 3 and Tier 4 stock exhaust pipes, the use of the aftermarket equipment; NG1 TechFlo and BoostBox H2. The testing event was to cover two-day engine testing at VazTec Engine Laboratory that included fuel cycle testing along with the collection of particulate matter (PM) and nitroxide (NO_x) and carbon dioxide (CO_2) emissions with test data being collected by infoWedge.

BoostBox H2 developed a mechanism to reduce the hydrogen production for a single-cylinder engine. This mechanism was further refined when the system was used at the VazTec facility to create a baseline of a single cell diesel engine.

The data generated from the use of the stock diesel engine in the course of performing the Baseline Single Cell Test resulted in reductions of particulate matter (PM) and nitroxides (NO_x). As shown in the data table below, a 17.67% PM reduction was realized when compared to the incumbent stock exhaust (Tier 4) using the combined technologies of NG1 TechFlo and BoostBox H2. The combined technologies, when compared to the Tier 3 exhaust offering, produced an 11.63% reduction in PM. The average NO_x levels were also reduced 4.95% with NG1 TechFlo respectfully with the combined technologies averaging 5.28%.

VazTec Engine Laboratory - 17.67% Reduction in Particulate Matter

Muffler Type	Boost Box	PM mg/m3	NO_x ppm	Average PM	Average NO_x	NO_x vs Tier 4	NO_x vs Tier 3	PM vs Tier 4	PM vs Tier 3
Tier 4	W/O	6.94	304						
Tier 4	W/O	6.25	302	6.595	303				
Tier 4	W	7.22	296			2.31%		-9.477%	
Tier 3	W/O	6.01	277						
Tier 3	W/O	6.28	294	6.145	285.5				
Tier 3	W	5.42	280				3.78%		11.80%
NG1 TechFlo	W/O	6.25	288			4.95%	-0.88%	5.23%	-1.71%
NG1 TechFlo	W	5.43	287			5.28%	-0.53%	17.665%	11.63%

VazTec Engine Laboratory - 3.5% Fuel Savings specific to Brake Specific Fuel Consumption

Muffler Type	Boost Box Status	Fuel Usage g/min	Corrected HP	BSFC (g/min)/HP	Average BSFC	Vs Tier 4 %	Vs Tier 3 %	Vs NG1 %
Tier 4	W/O	28.1	7.347496	3.824432				
Tier 4	W/O	26.1	7.148364	3.651185				
Tier 4	W/O	26.2	7.212107	3.63278	3.7028%			
Tier 4	W	25.8	7.147882	3.609461		2.5208%		
Tier 3	W/O	25.3	6.893617	3.670062				
Tier 3	W/O	26	7.17135	3.625538	3.6398%			
Tier 3	W	24.2	6.676581	3.62461			0.4163%	
NG1 TechFlo	W/O	25.5	7.548189	3.378294				
NG1 TechFlo	W/O	26.1	7.380084	3.536545	3.5015%	5.4377%	3.8000%	
NG1 TechFlo	W	25.9	7.429003	3.486336				
NG1 TechFlo	W	25.35	7.212964	3.514505	3.5114%			-0.2853%

Fuel consumption rate was used to calculate mass emissions from the engine. Using the combustion equation for Ultra Low Sulfur Diesel (ULSD) and the measured mass flow rate of the fuel, the mass flow rates for each of the measured pollutants in the exhaust can be calculated. The fuel usage was monitored via an elevated digital scale supporting the gas tank. The fuel usage is then normalized to provide brake specific fuel consumption. The multiple results of each configuration are then averaged. The percentage comparisons are between the averaged Break Specific Fuel Consumption (BSFC).

The project team confirmed a particulate matter (PM) reduction was realized during the single-cell baseline test. Regarding the evaluation on the impact of combining the NG1 and BoostBox H2 technologies on particulate matter (PM) emissions, it is probably most relevant to look at the difference between the most modern of the non-retrofit configurations (i.e., Tier 4) to the NG1 & BoostBox H2 configuration.

"Keeping in mind that neither the influence of simply removing the muffler nor of the parasitic load the BoostBox H2 would impose on the engine have yet been accounted for, the apparent reduction in PM of almost 18% (from about 0.36 g/bHP-hr with Tier 4-only to about 0.30 g/bHP-hr with the NG1/BoostBox combination) is quite large" – Andrew Burnett – infoWedge

infoWedge_Vaztec-Baseline-InitialResults

Over-the-Road tests

The goal was to operate multiple vehicles equipped with the NG 1 TechFlo exhaust solution combined with the BoostBox H2 Hydrogen technology for the testing of fuel use and emissions reductions using city route and over the road methods of traveling the same distance to and from a predetermined location every day.

The team has proven the technologies on a fleet in one of the harshest applications possible with a large fleet in the Memphis area, which is also home to some of the worst roads in the country. Our system was installed on two vehicles – one that was primarily line haul (250+ miles point to point) and one that was Pickup and Delivery (typically less than 20 miles between points).

In the on-road testing in Memphis, TN between October 2016 through Jun 2019, the team observed consistency in the data as observed from the Society of Automotive Engineers (SAE J1264) test performed when compared to the previous reporting period in fuel economy using both the NG1 TechFlo exhaust and BoostBox H2, when compared to the OEM stock solution. We observed an increase in fuel economy using the TechFlo exhaust on Class 8 vehicles performing city routes and over the road. The combining of NG1 TechFlo exhaust and BoostBox hydrogen technology provided a greater than 10% improvement in fuel economy on pre-emission (earlier than 2006) trucks when compared to the individual component data and overall OEM stock equipped vehicle. This appears to be consistent over the course of 33 months of data.

We installed shock monitors on our boxes to see just what our systems were experiencing and very unexpectedly, we regularly were seeing system shocks over 20g. That's 20 times the force of gravity! The largest shock was at 37g. Even in these conditions, our systems survived the application and functioned. After discussions with a master mechanic in the area, he said that unlike most failures of Class 8 trucks (turbos, alternators, etc.), he sees cracked front springs, axle damage, and other violent impact issues from driving in the area. We have been pleased with the durability of our systems under these conditions.

VI. Products and Collaborations Developed through Award

During the grant process, the BoostBox H2 team deferred all salaries, and as a result, was able to use funds to develop a telemetric platform (outside the grant) and integrated that system onto the UPS Grant Vehicle as an upgrade to the existing platform. This allowed the team to remotely monitor the performance of the BoostBox H2 system and provide real-time feedback to the driver or the fleet owner.

Through the grant funds, the team was able to engage many interns and engineers that would have otherwise been unavailable. Most notably of those, is the work done with Manufacturing Works of Wyoming and the University of Wyoming, the University of Colorado and the University of North Dakota. Their engineering interns have been instrumental in completing the design documentation necessary for volume production ramp and in-process functional testing of the BoostBox H2 products. Through this interaction, the BoostBox H2 team helped to educate engineering students in the nuances of product design – in a real-world application. A total of 6 interns worked our systems as part of their senior or graduate projects. The result was a mechanical design package of our system that is ready and will hold up to ISO/TUV auditing standards.

Additionally, graduate students at the University of North Dakota used the BoostBox H2 as their graduate project to develop a final system-wide functional tester that has now been implemented in manufacturing. The students enhanced their understanding of the concepts of GD&T (Geometric Dimensioning and Tolerance), statistical process control, C_{pk} analysis, process flow, and DFMAT (Design for Manufacturability and Testing). They have also gained a real-world understanding of product certification bodies, like Underwriters Laboratory (UL), Vehicle Certification Agency UK (VCA) and CE-Mark and the importance that that third-party verification plays in product design. Two of the engineers have applied to BoostBox H2 for a full-time position when they graduate, and one of the engineers has been employed by our contract manufacturer to work as a manufacturing/test engineer in our production cell.

At least three individuals were permanently hired through direct interactions with this project, and the project involved collaboration with many organizations including:

- UPS, Inc.
- Volvo Trucks North America
- Pennsylvania State University (Penn State)
- Mesilla Valley Transportation Solutions
- infoWedge
- Mesilla Valley Transportation, Inc
- Penske Truck Rental
- University of Colorado
- Colorado State University
- University of Wyoming
- University of North Dakota
- Manufacturing Works of Wyoming
- University of California - Riverside
- Cascade Tek
- C-Zero
- Carbon Blu
- Cobra Engineering

- ORT Performance
- PDQ Performance
- Element Materials Testing, Inc.
- E-Instruments
- Sparton, Corp
- A&J Transport, Inc.
- Vehicle Certification Agency, Ltd (UK)
- Avvid Corp
- EFI Analytics
- DMR Group, LLC
- Society of Automotive Engineering (SAE)

VII. Computer Modeling

There was no computer modeling involved in this project

VIII. Conclusion / Go-To-Market

The team has proven the NG1 and Boost Box H2 technologies capable of delivering both fuel saving and emissions reduction. As recorded in various testing throughout the grant, we have achieved a 9.94% improvement in fuel efficiency, a 64% reduction in particulate matter (PM), a 77% reduction in NO_x, and a 4.5% reduction in CO_2.

The overreaching goals of the project and the team members were to:

- Reduce Particulate Matter (PM) Emissions
- Improve Fuel Economy
- Reduce Consumption of Fossil Fuels
- Health improvements for people suffering from chronic lung ailments and the public in general
- Reduce Greenhouse Gasses: Carbon dioxide ($CO_{2)}$, Oxides of Nitrogen ($NO_{x)}$
- Change the image of Diesel Fuel from a "black smoke" emitter to a "clean alternative"
- Lower Operating and Maintenance Costs
- Improve Vehicle Performance
- Better Durability
- Reduce Operating Noise Decibels

Our technologies have been proven to support fleet sustainability goals of better fuel efficiency and lower emissions from after-market devices.

As part of the go-to-market strategy, the team has been networking with marketing outlets such as Bloomberg News, CEO Money, the Entrepreneurial Podcast Network, and the magazines Overdrive, Motor Trend, Fleet Owner, and Line Haul to set the stage for a "Breaking News" type of national coverage. Press releases will be issued through multiple outlets to spread the word.

Lastly, in the execution of our go-to-market strategy, BoostBox H2 recently signed distribution agreements to bring the BoostBox H2 product into Australia, New Zealand, Philippines, South Korea, Singapore, and Israel.

It is anticipated that given the test results shown in this grant initiative, additional markets will be opened in the USA.