Roush Enterprises E-350 LPI System

Task #4 Deliverable Report

for:

New Technology Research and Development Program

582-11-11142-3264

Submitted by:

Roush Enterprises

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May 5, 2011

The preparation of this report is based on work funded in part

by the State of Texas

through a Grant from the Texas Commission on Environmental Quality

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Abstract/Executive Summary

Roush's project goals are to design prototype Liquid Propane Injection (LPI) system hardware and develop calibration of the powertrain control module for the Ford E-350 Cutaway vehicle configuration, build prototype components and E-350 prototype vehicles for hardware design validation, and develop the calibration that runs the powertrain control module and contributes to overall emissions reductions. This program stage will result in the confirmation through emissions testing in an EPA-approved test lab that nitrogen oxide (NO_x) and other emission levels have been improved from the base E-350 gasoline versions. Anticipated emissions reductions over a comparable 2010 gasoline vehicle are 50% for NO_x, 25% for particulate matter (PM), 25% for greenhouse gases (GHG), and 15% for nonmethane hydrocarbons (NMHC). The key benefits of this technology will be reductions of 2.9 tons of NO_x, 0.62 tons of NMHC, 0.07 tons of PM, and over 4,500 tons of GHGs annually by 2012 for fleets operating in Texas' nonattainment areas, as well as support for technology using a Texas-produced alternative fuel.

Introduction / Background

In today's business environment, fleets are challenged with demands for alternative fuel technologies that reduce carbon-based fuel emissions, including NO_x, while also reducing operating costs and dependence on foreign oil. Frito Lay, out of Plano, Texas, as an example, has a need for converting much of their on-road heavy-duty delivery truck fleet to alternative fuel vehicles that reduce emissions.

Propane systems for vehicles, both past and current, have relied on outdated technology (vapor and bi-fuel) which degrade engine performance and compromise quality. Liquid propane injection (LPI) systems, both past and current, have achieved better performance, but technological advancements have been required to effectively manage the flow and pressure of liquid propane, improve upon related emissions attributes and provide a sustainable platform for fleet growth with future LPI vehicles.

Roush has been a leader in improving liquid propane injection (LPI) technology for vehicles, integrating longstanding expertise in OEM level engineering and powertrain calibration with in-house emissions development, testing and certification capabilities. Propane, as an alternative engine fuel, supports the initiative to reduce emissions such as NO_x as well as dependence on foreign oil, while providing a cost benefit over gasoline to fleets. Roush has released for sale a number of Ford-based fleet vehicle LPI applications, including the 2007 ½ - 2008 F-150, 2009 and 2010 F-250, and 2009 – 2011 E-Series Vans.

The advanced technology being developed under this grant project is intended to enable Frito Lay (Plano, Texas) and other large fleets to reduce NO_x and other emissions from their delivery vehicle fleets by enabling the testing and development of a prototype LPI system for the Ford E-350 chassis-cab with 5.4L 2V engine, including hardware and calibration, for in-vehicle testing, development and emissions reduction confirmation. This LPI system would then be certified by EPA for sale to Frito Lay and other large fleets in Texas and around the United States. The E-350 cutaway makes-up a large portion of the delivery vehicle fleets in Texas and the US overall. With the funding provided by the proposed grant, this product will be commercially available as early as the fourth quarter of this year.

This program stage will result in the confirmation through emissions testing in Ford's EPA-approved test labs that NO_x emissions and other criteria pollutant levels have been improved over the baseline E-350 gasoline versions. This stage is especially relevant for the TCEQ's NTRD program because of the significant NO_x reductions predicted from development of this technology at nearly 50% over a comparable gasoline vehicle.

Project Objectives / Technical Approach

From the grant contract Grant Activities (Scope of Work):

> *"Article 1. Objectives*
>
> *1.1 The objectives for this work are:*

1.1.1. Design, construct, and test a propane powered Ford E-350 truck.

1.1.2. Verify through testing that NO_x emissions have been reduced from gasoline version by up to 50%."

Tasks

Construct Confirmation Prototype Vehicles

From the grant contract Grant Activities (Scope of Work):

Task 4: Procure components for and construct confirmation prototype vehicles

2.4. Task Statement: The PERFORMING PARTY will procure components for and construct confirmation prototype vehicles.

Roush procured a total of four E-350 vehicles that were used exclusively for this development program. This grant project is part of an overall program for Roush that is much larger in scope than contained in the grant scope of work. Although all four E-350's have been utilized, Roush is only seeking reimbursement for two of the E-350's per the approved grant budget.

Roush updated two 2008 E-350 Duel Rear Wheel (DRW) vehicles from Advanced Prototype (AP) level design to the Confirmation Prototype (CP) level design and converted two 2011 E-350 DRW vehicles to CP level. FL01 and FL02 are the 2008 vehicles and RCT01 and RCT02 are the 2011 vehicles.

The major AP system level components consisted of the following: fuel rail system, fuel line system, fuel tank system, fuel fill system, pressure relief system, fuel rail pressure control system, electrical system, and injector pressure transducer sensor (IPTS) interface.

The 2008 E-350's FL01 and FL02 had a number of systems and components updated from AP to CP level. The first of those was the fuel supply and return lines and tee assemblies in the fuel rail system. The fuel line system had the forward and rear supply lines – 3/8", forward and rear return lines – ¼", and rear fuel line support bracket updated. Part of the fuel line system is shown in Figure 1.

Figure 1: Fuel Line System

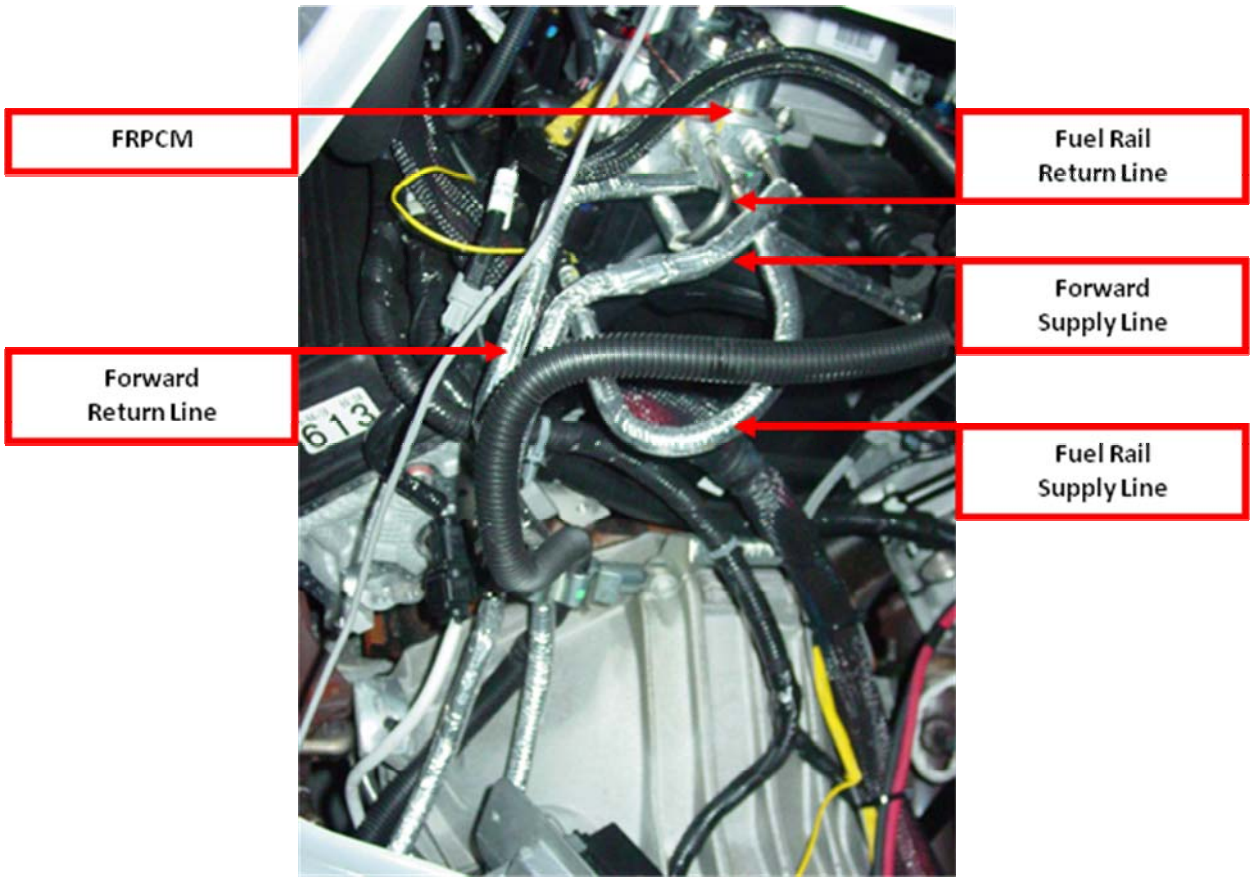
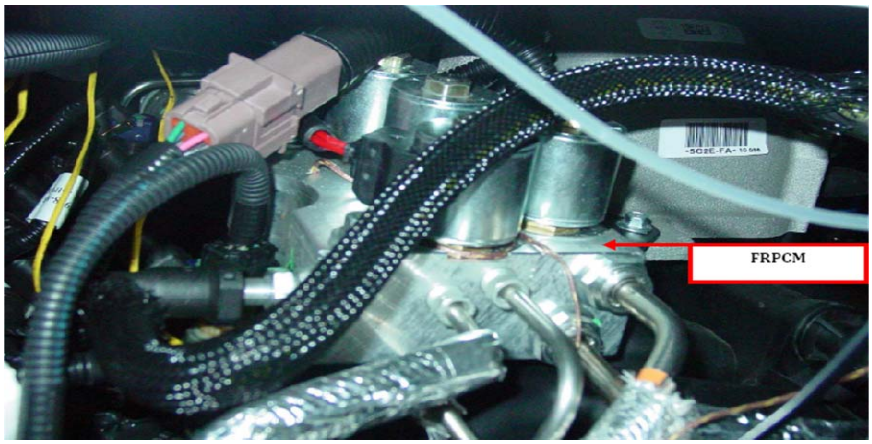


Figure 2 shows a better view of the fuel rail pressure control module (FRPCM). This module handles the routing and flow of liquid propane fuel to the fuel rails.

Figure 2: FRPCM

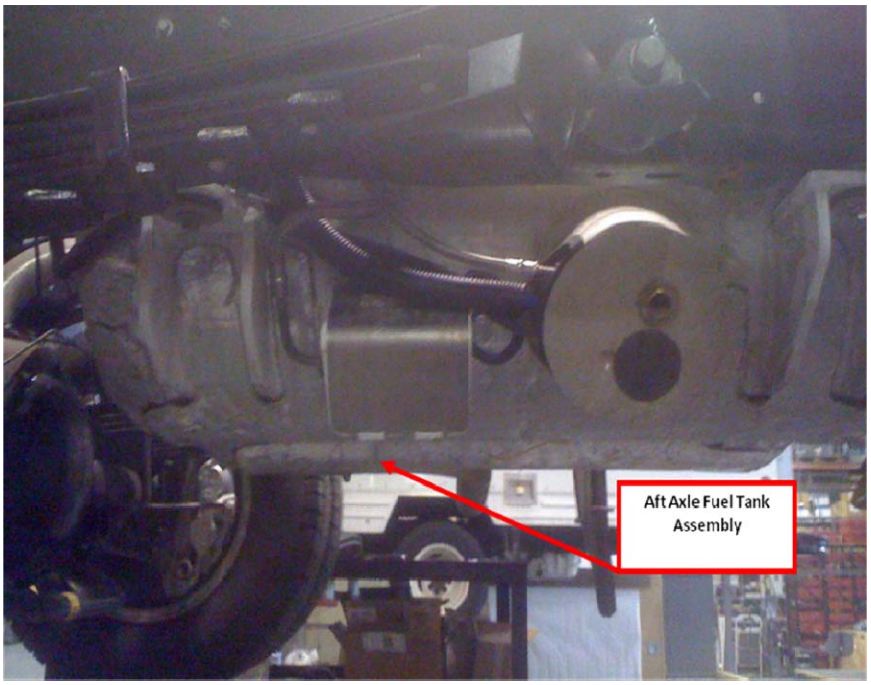


The fuel tank pressure transducer (FTPT) FTPT_ Sensor Assembly 2007-2010 model year in the FTPT sensor assembly system was also updated from AP to CP level. The FTPT sensor is shown in vehicle position in Figure 3.

Figure 3: FTPT Sensor

The fuel tank mounting and miscellaneous hardware system also saw changes. The aft axle fuel tank assembly as well as the left and right aft axle tank frame mounting brackets were updated. Figure 4 shows the aft axle fuel tank assembly in vehicle. The mounting brackets are hidden in this view.

Figure 4: Fuel Tank System



The 2007/2008 vehicle main wiring harness in the electrical system and injector pressure temperature sensor (IPTS) interface system saw changes as well. The remaining parts that were left on the vehicle at the AP level did not change in design from AP to CP level design.

In addition to the above items the following additional equipment were also installed to aid the engineers in the data gathering process:

- Laptop stand,
- Vacuum gauge,
- Mini-View gauge,
- Fuel gauge for auxiliary tanks,
- Auxiliary battery,
- Remote Display Module gauge for the auxiliary battery,
- Electric Power Box for the auxiliary battery,
- Accurate Technologies Incorporated equipment, and
- 2 additional transducers (1 in the fuel tank Pump-out Press and 1 after the Multi-Valve Supply side).

The 2011 E-350 DRW vehicles are labeled "RCT01" and "RCT02" on the upper passenger-side windshield. These two vehicles were upfitted from production to the CP level. They had the following additional equipment installed as well:

- Laptop stand,
- Horiba,
- Vacuum gauge,
- Fuel gauge,
- Smart Relay Module heads-up,
- Auxiliary battery,
- Auxiliary fuel tank,
- Remote Display Module gauge for the auxiliary battery,
- Electric Power Box for the auxiliary battery, and
- Battery chargers
- · Accurate Technologies Incorporated equipment.

From the grant contract Grant Activities (Scope of Work):

> *2.4.1. The PERFORMING PARTY will competitively procure components for the confirmation prototype vehicles. Selected suppliers will manufacture the prototype parts per the released CAD models and/or drawings and deliver the components to the PERFORMING PARTY.*
>
> *2.4.2. The PERFORMING PARTY will fit the advanced prototype vehicles with the constructed confirmation prototype level components, including new powertrain control module PCM calibration.*

The strategy and calibration used in the CP level vehicles did not change due to the AP level content conversion. No unique calibration modifications were required to make the CP vehicles function. The calibration development proceeded with the normal adjustments and tuning.

From the grant contract Grant Activities (Scope of Work):

> *2.4.3. Schedule: The PERFORMING PARTY shall complete this task within 6 months of the signed Notice to Proceed Date as issued by TCEQ.*

2.3.4. Deliverables: The PERFORMING PARTY shall submit a report to the TCEQ upon completion of this task. This report will include but is not limited to documentation, including pictures, of the completed confirmation prototype vehicles.

Discussion / Observations

Objectives vs. Results

The project objectives for these tasks and deliverables have been met. The AP level vehicles have been shown to be functionally equivalent to CP level, and have provided the engineering team with the necessary feedback to continue on with the CP level hardware design and calibration.

Critical issues

There are no critical issues documented at this time.

Technical and commercial viability of the proposed approach

The Liquid Propane Injection System, at the AP level, has shown through this stage that the E-350 vehicle is a good platform for this technology and that the assumed scope of work for this program should meet the objectives.

Scope for future work

The scope of work for the remainder of the E-350 program under the grant contract should continue as defined and under the previous assumptions.

Intellectual Properties / Publications / Presentations

The Roush LPI system uses a unique integrated system for controlling injector leakage during engine-off soak periods. Roush considers this technology to be proprietary, and has submitted notice of intent to patent. This system allows the propane in the fuel rail to be isolated from the rest of the system and vented to the evaporative emissions canister, where it is stored until the vehicle is started again. This system eliminates any propane leakage past the injectors, which historically has been a concern with liquid injection systems due to the relatively high system pressures.

Summary / Conclusions

The program tasks and deliverables as described above have been completed and it has been determined by Roush to be appropriate to proceed with the scope of work defined in the next scheduled tasks and deliverables.

Acknowledgements

Roush has an excellent working relationship with Ford Motor Company. Roush has long been a strategic partner with Ford Motor Company in the area of powertrain design, development and engine calibration, providing a strong foundation and experience level for the propane program. Leveraging that foundation, the LPI systems developed by Roush incorporate the creation of advanced calibrations and improved

hardware systems, greatly impacting the vehicles performance characteristics and its emission performance.