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New Technology Research & Development Program
Grant Contract 582-5-70807-0006

Tasks 2, 4 & 5 Deliverable Report
Final Report

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New Technology Research & Development Program
Forklift Engine Retrofits for Low Emissions

Grant Contract 582-5-70807-0006

Final Report
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Project overview

This project was on improving emissions on forklift trucks. Forklift trucks did not have emissions controls until January 2004 when the Environmental Protection Agency required lift trucks to meet emissions standards. In January 2007, the EPA put stricter emission requirement in place, along with more rigorous testing procedures. As there are approximately 36,000 forklifts in Texas and 27,000 are in non-attainment or near non-attainment areas, most of which have uncontrolled emissions this represents a large potential for NOx reduction in Texas metro areas. This project was to plan, test and certify existing emissions controls suitable for pre 2004 forklift engines. This was successful in accomplishing that goal. The ECS forklift retrofit is now available on the market. We are waiting the decision by the California Air Resources Board and will forward this information to The Texas Commission on Environmental Quality when it becomes available.

This project with a partner brought into the marketplace a certified kit, that can be used to retrofit forklifts manufactured prior to 2004 and significantly reduce the NOx emissions of the trucks. The certification would be by the California Air Resources Board through an Executive Order and the executive order would permit the installation of an O2 controller, O2 sensor and a catalytic muffler on the forklift engine for the purpose of reducing NOx and provide NOx credits to the owner of the lift truck. This feedback fuel control could reduce the NOx by at least 60%. In previous test the NOx reduction has been as high as 90% on a different set of engines – new Nissan 4 cylinder 2-liter engines.

Potential fuel system partners who were interested in the aftermarket forklift clean emission retrofit were contacted and partnership agreements were developed and agreed upon with 2 of the suppliers, NETT and Lubrizol. Certification plans were drafted and submitted to the California Air Resources Board for approval and emissions test were conducted according to the testing protocol at an emissions lab acceptable to CARB. Only one company completed the entire process. This company was Lubrizol now known as Emissions Control Systems or ECS. The emission test were conducted according to EPA test procedures at the approved Lab. This lab was Carnot Emissions Services of San Antonio, Texas. The test program was run twice because the unstable operation of the engine in the first test. The coefficient of variance in the first test was felt to be too high due to the use of a used engine that had over 6000 hours of operation. The final results of the testing were submitted to CARB by ECS and they requested requesting a CARB executive order allowing the use of the control system as a retrofit for quantifiable emission reduction programs. We are waiting for CARB's response, which we expect in the early Fall 2007.

Partners

Fuel system providers were contacted by phone and email to seek potential partners. The partners who showed interest included Engine Control Systems – ECS. ECS is large catalysis and fuel controller manufacturer, that provides fuel controllers in

the European markets including a forklift company Linde, which has a small US market share. Other partners were NETT, also a catalyst and controller manufacturer, Safe Controls was vary interested and is an alternative fuel controller manufacturer, aka Autotronics. Precision Governors showed interest at the beginning of the project but decided not to participate. Also Motive Ventures, an amalgamator of components had some interest in being a partner but was unable to participate due to other commitments. Toward the end of the project only ECS and NETT were actively involved in the certification plan and testing program.

Both Safe Controls and Motive Ventures dropped out of the project early. Safe Controls because they were bought out by Zenith Fuel System and were not able to accept any new projects. Motive Ventures dropped out because they were a small organization and had other projects to focus their attention on. NETT stayed with the program as a partner, but at the end of the project they were unable to produce the aged hardware to test. Therefore their system was never tested. The difficulty with NETT was the test protocol required the emission testing of a new de-greened fuel system (catalyst and O2 sensors) and a system with 2,500 hours of field operation on it to represent an aged system. NETT had a working fuel system they shipped to the test lab, but were unable to produce a fuel system with 2,500 hours of operation on it before the project came to a close in May of 2007. They could not locate a customer with high enough usage to accumulate the 2500 operation hours for the aged system in the time frame of the project. This project did not have enough funds to run durability test in a test cell where the engine could be run 24 hours a day, which would cost about $60,000. ECS was successful in meeting the project requirements as they were able to furnish both new and aged systems needed for testing. In addition they were prompt in filing a complete certification plan with CARB that included the needed test protocol. ECS was ready to test when the test lab and engine was available and we were able to complete the entire program with them.

Project Results

The engine selected for testing was the GM 4.3 liter V6. This is a 6-cylinder version of the GM 5.7L V8 and has been used for many years in both small and large GM pick up trucks along with forklifts. However the forklift version is a little bit different and this required that we obtain an engine out of forklift. ECS had already received approval for their system in the 4 cylinder 1.6-3L engines and was seeking certification of the system in the larger engines. The larger class 7 forklifts use engines 80-100hp range and the GM 4.3L at 90hp fits this market segment nicely. However it provides some packaging problems in a forklift truck. One of the problems is; its height gets in the way of the rear deck of the forklift. The height of the engine is made acceptable by using a shorter - lower manifold (it’s referred to as a marine manifold by the technicians who work on the motor. This solves the height problem but the engine is reported to have poor fuel distribution with the low manifold. The second problem was with 2 exhaust manifolds and one O2 sensor. The control system would meter only one exhaust stream and would need to assume that the other one was similar, which it may not be correct with poor fuel distribution. This could explain some of the variation in the emissions

control with the first test engine. This was a difficult engine to control and the control system controlled it successfully.

The project produced a verification plan acceptable to CARB and in the plan was included an emissions test protocol shown below:

CARB APPROVED TEST PROTOCOL FOR THE ECS TermiNOx SYSTEM

Step	Description
1	Perform a compression test on the engine prior to installation to check for loss of compression in any of the cylinders. The pressure of each cylinder should meet manufacturer's minimum specifications.
2	Install the GM 4.3L V6 test engine in a test cell compliant with C2 and transient test cycle requirements. • Install a pressure regulator between the fuel cylinder and the engine vaporizer to insure constant fuel pressure supply. Install a full cylinder of an appropriate LPG motor fuel in accordance to ARB requirements as defined in the verification procedure part 2783 (d). • The fuel pressure for each test is to be recorded. • The specific test fuel and source is to be documented in the final report.
3	• Install a new oil filter and bring engine oil level to "full" using approved engine oil. • Check coolant level and inspect for any leaks. • Inspect fuel system, replace diaphragm and clean fuel system of any deposits. If any sticking of the diaphragm is determined, the vaporizer is to be replaced. • Perform a complete tune up - install a new PCV valve, air filter, spark plug set, ignition wires and distributor points if so equipped. Set engine timing to factory settings. • Inspect exhaust manifolds for any signs of cracks. • Make any required engine repairs. • Check idle and adjust idle screw. • Check engine top end power and adjust power valve. • All tests to be performed with an appropriate LPG motor fuel in accordance to ARB requirements as defined in the verification procedure
4	Install three thermocouples in baseline exhaust system (no catalyst) at the following locations: • approximate location of catalyst inlet or muffler inlet. • 1-2 inches downstream of exhaust manifold on left bank of engine. • 1-2 inches downstream of exhaust manifold on right bank of engine.
5	Insure all calibrations are current (propane analyzer, NOx analyzer, torque meter, etc.). Check signal-conditioning systems. Validate CVS gaseous sampling systems using propane recovery techniques.
6	• Set backpressure and intake restriction to the engine manufacturer's desired level or other suitable level defined by ECS in the absence of an OE specification. <u>Operate engine for at least 3 hours or longer to promote break-in and stabilization.</u> • Operate engine at rated speed and load for approximately 10 minutes, then power validate engine and produce peak torque curve for engine. • Stabilize engine through a suitable period of running to insure emissions and performance stability. Check the vaporizer to insure the diaphragm is not sticking.
7	Conduct "full throttle" torque map from low to high-idle to document engine performance.
8	Conduct LSI steady state D2 testing in triplicate for engine baseline configuration in accordance to ARB verification protocol requirements. Measure HC, CO, CO2, and NOx. Provide separate and combined measures of HC and NOx. <u>Test results must comply to ARB requirements for acceptable variability.</u> If engine is stable, proceed to next step.
9	LSI cycle baseline deleted- Robin to confirm acceptability.

10	Install TermiNOx system using aged oxygen sensor and catalyst. An ECS technician will be present to assist and to insure the system is installed in accordance to ECS requirements. Install two thermocouples, one at converter muffler inlet or just ahead of the inlet, and one at converter muffler outlet.
11	A second oxygen sensor and readout is to be installed on the rich engine bank and used by ECS staff to insure a suitable setting of the oxygen sensor connected to the TermiNOx system installed on the lean bank of the engine. The second oxygen sensor combined with CO readings will allow ECS technical staff present to determine the correct bias of the air/fuel ratio setting (accomplished by direct A/F setting of TermiNOx or shiming of vaporizer diaphragm) to insure that CO emissions do not increase with the aged oxygen sensor. The air/fuel ratio setting and use of any shims to obtain it will be employed with future in-field installations.
12	Evaluate air fuel ratio over individual D2 steady state modes to determine correct bias of the air fuel ratio setting of the TermiNOx system. The correct setting will insure that carbon monoxide emissions do not increase over the C2 steady state modes. This air fuel ratio setting will be recorded and included in TermiNOx installation Manual for GM4.3L engines to be retrofit in the future to insure compliant emissions. The procedure is more fully described below**. When the settings have been finalized, conduct three repeats of the D2 cycle with the aged TermiNOx configuration.
13	Conduct LSI transient testing in triplicate for TermiNOx aged configuration in accordance to ARB verification protocol.
14	Testing of de-greened TermiNOx system deleted- Robin to confirm acceptability.
15	Prepare brief report of data for each configuration in tabular form. Include data in Final report to include all engine testing.

**Further description of procedure in step 12 in Table 4.2-2.

I. The TermiNOx with aged oxygen sensor and catalyst will be set to stoichiometric air fuel ratio.
II. D2 test modes will be run in order of highest weighting to lowest. During each mode, the steady state CO readings (ppm) will be compared to those obtained for this mode in the baseline testing as described in Step 8 in table 4.2-2 above.
III. If the CO reading for the aged TermiNOx system in a given mode of the D2 test cycle is less than the CO reading for the baseline test, proceed to the next mode.
IV. If the CO reading for the aged TermiNOx system in a given mode of the D2 test cycle is greater than the CO reading for the same mode of the baseline test, then the air-fuel ratio setting of the aged TermiNOx system is to be biased one increment towards a lean of stoichiometric A/F setting and repeat the CO measurement for this mode.
V. This procedure is to be used for each D2 test mode in order of its weighting until the ECS technician is satisfied with that the air-fuel ratio setting is correct to insure no increase in CO will occur over the D2 test.
VI. The final A/F setting and any diaphragm shims used are to be recorded for submittal to ARB under the verification.

Two sets of emission test were required because of instabilities in the engine power level with the first test. The source of these variations in power was not identified. Also there were high CO levels measured with the first set of test due to a poorly operating engine. The engine had over 6000 hours of operation, as CARB required the use of a used engine, so its poor operation was not unexpected. In the first set of test the fuel system was set to minimum NOx , which resulted in a 99.5% reduction of NOx, but an unacceptable increase in CO. As fork lifts are often used indoors the high CO was judged unacceptable. A second set of test was conducted with a new "used" engine. Also CARB had switched from the steady state C2 testing to transient testing and steady state D2 testing. This required modifications of the testing plan.

The test result for the transient test cycle using the ECS controller is as follows. :

Summary of 40 CFR 1048 App.II

Composite Speed Cycle Transient Results

NO CATALYST - AS FND						
	BSCO	**BSCO2**	**BSHC**	**BSNOx**	**BS(THC+NOx)**	**BSFC**
Test ID	**g/kW-hr**	**g/kW-hr**	**g/kW-hr**	**g/kW-hr**	**g/kW-hr**	**kg/kW-hr**
AVG(3 test)	30.19	806.66	2.30	9.51	11.81	0.288

WITH ESC CATALYST						
AVG(3 test)	3.35	826.86	0.19	3.78	3.97	0.278

%Reduction	**88.9**	-2.5	91.7	**60.2**	66.4	3.3

The coefficient of variance (standard deviation/average) was found to be quite acceptable on the test and CARB has reported that results are acceptable. It should be noted that ECS feels that the system is capable of much higher NOx reductions with other engines and this conclusion is consistent with previously testing that the Railroad Commission has preformed with 4-cylinder, 2 liter Nissan engine using the ECS controller.

The testing of the system using the EPA steady state D2 test cycle showed the following results:

LSI D2 Emissions		As Found	TermiNOx System	Percent Change
BSCO	g/kW-hr	30.06	0.80	97
BSHC	g/kW-hr	2.40	0.05	98.1
BSNOx	g/kW-hr	16.38	5.05	69.2
BS(THC+Nx)	g/kW-hr	18.79	5.10	72.9

These results are consistent with the transient testing The test lab, Carnot Emission Services, reported the following comment on the system in their final report of project 236B June 2007:

> "The performance of the ECS system was sensitive to the two adjustment screws related to idle and rated fuel air mixture ratios. Substantial NOx and CO emissions reductions were demonstrated with the ECS TerminNOx system utilizing an aged catalyst and O2 sensor. With the installation of a properly calibrated TermiNOx system it was possible to meet the emission targets as required for the project."

Certification plans

As of June 20, 2007 ECS has submitted an updated application requesting CARB verification as a Level 2 technology for engines above 3L to 8.2L. We are waiting for decision from CARB on the emission level of the system.

Summary

The project completed its goal in getting a CARB approved forklift retrofit available for owners and dealers to purchase. ECS has been a valuable partner in this project, however NEET was not able to meet one of the basic project requirements of producing an aged system for testing after months of promising that they could. Safe Controls, an El Paso company was in transition of being purchased during the project and was not able to obtain their new management commitment to the forklift retrofit market. However testing of their fuel system in previous project showed that their system is quite effective in reducing NOx.

The result of this project is that there is now a system available that reduces NOx by over 60% in the worst case and by over 90% in more typical cases for Pre 2004 propane forklifts. The system is certified for 1.6 to 3 liter 4 cylinder engines and has applied for approval for 3 liter to 8.2 liter engines which it is expected to receive.