Upgraded B Gas Plus Engine for Operation with Hydrogen Blended Natural Gas Fuel

• *Overview and Summary Results* •

Introduction

With funding from the U.S. Department of Energy through NREL and SCAQMD, SunLine Transit Agency initiated a project to demonstrate two buses operating on a mixture of natural gas and hydrogen (HCNG or Hythane®). SunLine asked Cummins Westport Inc. (CWI) to upgrade the CWI B Gas Plus engine rated at 230 horsepower. The work was done by Westport Innovations Inc., a parent company of CWI. Hydrogen Components Inc. of Littleton, Colorado, which led the previous Hythane® engine tests, is an advisory member of the current project team.

Previous investigations have shown that the presence of hydrogen in the natural gas enabled leaner (air/fuel) mixtures to be used, leading to reduced nitrogen oxides (NOx) emissions.

Objectives

The objectives of the engine upgrade portion of the project were to:

- determine if significant NOx reductions could still be achieved on modern engines operating closer to the lean (air/fuel) limit;
- determine the most suitable hydrogen content in the range of 15% to 30% by volume for the B Gas Plus engine, with the constraint of retaining the engine performance and efficiency;
- configure engine controls for operation on the chosen mixture; and
- calculate the overall emissions benefits.

Engine

The HCNG upgrade was developed for the CWI B Gas Plus—an in-line 6 cylinder, electronically controlled and turbocharged lean burn spark-ignited engine. The engine has a displacement of 5.9 liters and is certified at NOx+non-methane hydrocarbons (nmHC) levels of 1.8 g/bhp-hr and particulate matter (PM) of 0.01 g/bhp-hr when fitted with the standard oxidation catalyst.

Hardware modifications were limited to the fuel flow rate sensor. All other components remained unchanged.

Method

Natural gas and hydrogen blends were prepared and stored in a high-pressure storage vessel.

The fuel mixture was fed to a B Gas Plus engine that was mounted on a dynamometer. The engine was operated under steady-state conditions at four selected speeds and loads. At these operating points, engine combustion was optimized over a defined matrix for hydrogen fractions between 20 and 32%.

A 20% hydrogen content by volume was found to provide the most cost effective benefits when taking into consideration the engine and vehicle performance attributes. Range consideration was also taken into account—for example, a 20% hydrogen mixture reduces the range of a vehicle by approximately 15%, unless more storage vessels or higher-pressure vessels are used. A 20% hydrogen mixture contains 3% hydrogen by mass and 7% hydrogen by energy.

A full engine map was developed for the chosen mixture, and was verified over the steady-state AVL 8 mode cycle, which approximates the heavy-duty transient certification cycle.

Selected Results

Figure 1 shows that the power and torque curves are maintained over the full engine speed range under HCNG operation.

Figure 1

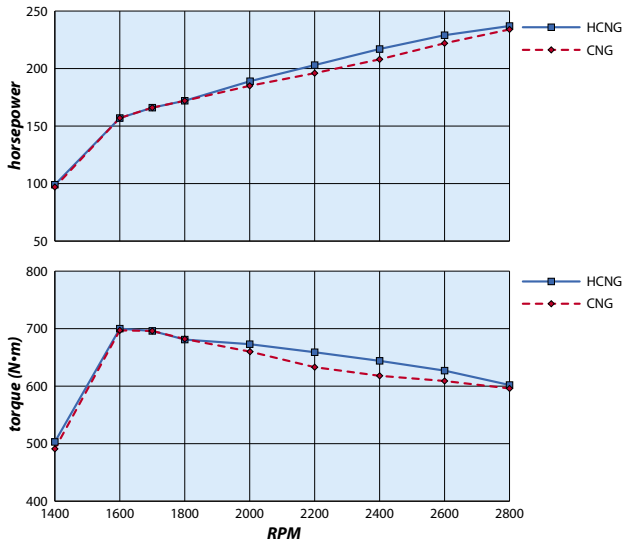
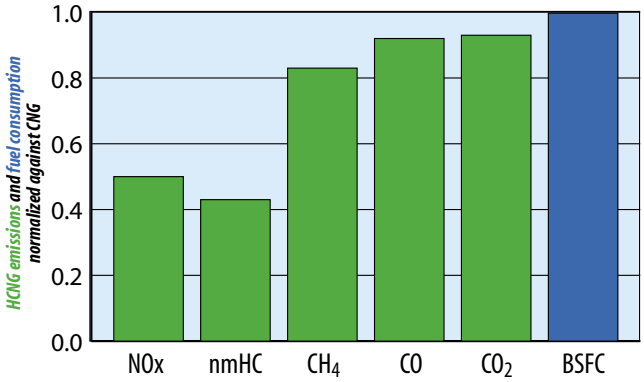


Figure 2 shows the pre-catalyst emissions results normalized compared to the original natural gas operation. It shows that NOx and nmHC emissions are reduced by 50%, while CO and CH_4 emissions are slightly reduced. As expected, CO_2 emissions are reduced by 7%, consistent with the hydrogen energy content, and with the maintained fuel consumption also shown in Figure 2.

Figure 2



The engine transient response was found to equal that of the original natural gas engine operation over a simulated transient school bus cycle. The school bus cycle simulates transient changes in engine speed and load on an engine dynamometer representing driving of an actual heavy-duty vehicle involving idle operation, gear shifts, cruise and rated power operation.

HCNG Benefits

An upgrade of Cummins Westport's engines to HCNG would allow hydrogen to become a more rapid part of the transportation fuel mix by enabling its usage in modern, electronically controlled engines. Within a short time, commercial Cummins Westport engines could be powering medium- and heavy-duty vehicles using hydrogen. This would catalyze the development of the hydrogen infrastructure needed for future vehicles powered by pure hydrogen.

Based on the results achieved in this project, it appears that substantial NOx reduction could be achieved compared to both regular natural gas operation and diesel operation. Opportunities may also exist for improved efficiency and lowered greenhouse gas (GHG) emissions.

Next Steps

As part of the SunLine demonstration, the two HCNG buses will complete a 24,000 mile (38,624 km) on-road test starting in the summer of 2003, which will include chassis dynamometer testing of the vehicles. Two control CNG buses will also be monitored for comparison.

Opportunities exist to apply HCNG to other engines as well. An upgrade to the C Gas Plus engine rated at 280hp could be developed for larger buses and trucks.

To develop a fully commercial engine, CWI will have to perform further product development tasks. For example, formal emissions certifications or verification tests should be conducted. Also, while previous demonstrations indicate that natural gas fuel system components are not affected by the presence of 3% hydrogen by mass, formal components durability testing must be completed.

A SunLine Transit Agency "SunBus" powered by HCNG.

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