INL/EXT-07-13321

U.S. Department of Energy

FreedomCAR & Vehicle Technologies Program

CARB Executive Order Exemption Process for a Hydrogen-fueled Internal Combustion Engine Vehicle – Status Report

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Prepared by Electric Transportation Applications

April 2008

Idaho National Laboratory
Operated by Battelle Energy Alliance

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Prepared for the
U.S. Department of Energy
Assistant Secretary for Energy Efficiency and Renewable Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

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ABSTRACT

The CARB Executive Order Exemption Process for a Hydrogen-fueled Internal Combustion Engine Vehicle was undertaken to define the requirements to achieve a California Air Resource Board Executive Order for a hydrogen-fueled vehicle retrofit kit. A 2005 to 2006 General Motors Company Sierra/Chevrolet Silverado 1500HD pickup was assumed to be the build-from vehicle for the retrofit kit. The emissions demonstration was determined not to pose a significant hurdle due to the non-hydrocarbon-based fuel and lean-burn operation. However, significant work was determined to be necessary for Onboard Diagnostics Level II compliance. Therefore, it is recommended that an Experimental Permit be obtained from the California Air Resource Board to license and operate the vehicles for the durability of the demonstration in support of preparing a fully compliant and certifiable package that can be submitted.

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1. INTRODUCTION

The CARB Executive Order Exemption Process for a Hydrogen-fueled Internal Combustion Engine (HICE) Vehicle work for the Advanced Vehicle Testing Activity (AVTA) was contracted with Roush Industries (Roush). Roush provides integrated automotive engineering services in disciplines ranging from body, chassis, and powertrain engineering through comprehensive testing, noise vibration harness engineering, and specialty manufacturing services. Roush assumed that the vehicle to be certified was the HICE pickup truck developed by ETEC in support of the U.S. Department of Energy's AVTA testing of HICE vehicles. California Air Resource Board (CARB) Executive Order personnel were consulted via correspondence presented in Appendix A. Using responses to this correspondence and incorporating Roush experience with vehicle certification and CARB Executive Order submissions (through Roush Performance Products division), the strategy for submission of a certification application presented in this report was developed by John Fleming, Roush Program Manager. This report describes the work performed to date to obtain CARB certification for the conversion of a gasoline engine base vehicle to a HICE vehicle.

2. BASE TRUCK INFORMATION

The base, build-from truck utilizes a General Motors factory KL5 CNG option 6.0L engine, which is heavy duty engine certified and engine dynamometer emissions tested instead of chassis roll emissions tested. The following list presents truck information for two trucks previously converted to hydrogen fuel use. These trucks were certified to Environmental Protection Agency (EPA) heavy duty engine standards and procedures.

2005 Chevrolet Silverado 1500HD	2006 GMC Sierra 1500HD
VIN Number: 1GCGC13U95F889816	VIN Number: 1GTGC13U06F160945
Engine Family: 5GMXH06.0583	Engine Family: 6GMXH06.0583
Evap Family: 5GMXR0223998	Evap Family: 6GMXR0223998
EPA Cert Number: GMX-CFF-LEV-05-03	EPA Cert Number: GMX-HDG-06-01

The 2005 truck was not original equipment manufacturer built with the KL5 option engine; it was updated with the KL5 option cylinder heads during conversion, which explains the different EPA Certification Number (i.e., EPA Cert Number).

3. EXECUTIVE ORDER CERTIFICATION REQUIREMENTS

CARB requires use of an original CARB-certified vehicle as the build-from vehicle to certify a retrofit system. The appropriate certified vehicle would fall under Executive Order A-006-1340 (see Appendix B) for 2006.

Currently, no formal CARB process is in place for certifying hydrogen-fueled vehicles. CARB has discussed grouping hydrogen with alternative fuel conversions. To date, no new vehicle manufacturer or retrofit company has received an Executive Order from CARB for hydrogen-fueled, on-road vehicles.

Specific CARB requirements applicable to alternate fuel retrofit systems are presented in Appendix C. In addition to all other standards and requirements, this Regulatory Order specifies the following:

- Use of a fuel lock-off valve to prevent fuel delivery while engine is shut off
- No drivability degradation from base vehicle
- Onboard diagnostics from base vehicle must not be impaired
- Creation of a supplemental emissions control information label
- Creation of a new vacuum schematic if different from base vehicle
- Owners manual supplement
- Manufacturer and installer retrofit record keeping
- Complete documentation of the retrofit system and installation procedure
- Complies with exhaust emission levels equivalent to those of the base-certified vehicle
- If approval is granted on a passenger car, light-duty truck, or medium-duty vehicle, it would automatically qualify the system for use in heavy duty engines without additional testing (assuming the use of similar emission control systems)
- Full coverage warranty for 3 years or 50,000 miles
- A cost-limited extended warranty for 7 years or 70,000 miles.

4. TAILPIPE AND EVAPORATIVE EMISSIONS TESTING REQUIREMENTS

The build-from vehicle falls under CARB Category II (i.e., vehicles with gross vehicle weight registered less than or equal to 14,000 lb and not originally certified to a chassis dynamometer-based exhaust emission standard).

> **From the Final Order, Attachment A, Section 5(c):**
>
> For durability, bench-test and emission-data vehicles in Category II, test vehicles shall have accumulated a total mileage greater than 4,000 miles and less than 10,000 miles with the original fuel system prior to emission testing. If the manufacturer chooses to use the option as described in l(b) (e) for pre-1994 model year vehicles, then the 10,000-mile limit shall not be applicable. A test vehicle's engine and emission control system shall be equipped and calibrated as certified. The vehicle shall then be tested for exhaust and, if applicable,

evaporative emissions using the test procedures set forth in the “California Exhaust Emission Standards and Test Procedures for 1988 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles.” The inertia weight setting shall be equal to the average of the vehicle's curb weight and gross vehicle weight rating and road load horsepower based on the frontal area of the vehicle without modifications, as determined in “California Exhaust Emission Standards and Test Procedures for 1988 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles,” Section 9.b. The test results shall be defined as the baseline emission rates. After the baseline emission rates have been measured, the retrofit system shall be installed.

(i) The procedures outlined in paragraphs 5(b)(iii) through 5(b)(vi) shall be used with the following modifications: "useful life" shall equal 120,000 miles for vehicles in Category II: the durability or bench-test vehicle's emission rates of regulated pollutants measured at 4,000 + 100 miles after the installation of the retrofit system shall not exceed 1.10 times the baseline rates; the deteriorated exhaust emissions of regulated pollutants projected to 120,000 miles shall not exceed 1.3 times the baseline emissions; and the deteriorated evaporative emissions of regulated pollutants projected to 120,000 miles shall not exceed the baseline emissions plus 0.5 grams.

For the assumed build-from vehicle, the only emissions testing requirement is a Federal Test Procedure (FTP CVS75) and highway comparison to the baseline vehicle. No evaporative emissions test is required due to use of a closed fuel system and non-hydrocarbon fuel.

5. ONBOARD DIAGNOSTICS LEVEL II COMPLIANCE

The largest hurdle in receiving an Executive Order for a hydrogen fuel retrofit system is maintaining compliance with the current CARB Onboard Diagnostics Level II (OBDII) standards. These requirements are outlined in the following OBDII Final Regulation Orders:

- Title 13, California Code Regulations, Section 1968.2, Malfunction and Diagnostic System Requirements for 2004 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines (OBDII)
  http://www.arb.ca.gov/regact/obd02/fro1968-2.pdf

- Title 13, California Code of Regulations, Section 1968.5, Enforcement of Malfunction and Diagnostic System Requirements for 2004 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines
  http://www.arb.ca.gov/regact/obd02/fro1968-5.pdf.

The HICE vehicle used to develop certification requirements utilizes a diagnostic tool to check and clear fault codes. However, this system is not compliant with current requirements for powertrain control module OBDII regulations in the following ways:

- The system does not meet the standardized requirement (SAE J1978) for generic scan tool communication

- The system is not compliant with standard SAE J1979 parameter identifiers monitoring

- The system is deficient in OBDII monitoring requirements

- The system has not been tested for, nor demonstrated compliance with, CARB requirements.

5.1 Generic Scan Tool Use

Current hydrogen fuel conversions typically use an add-on or piggy-back engine control unit. This is required to provide the unique electronic drivers required for supporting the Quantum hydrogen fuel injectors universally used for HICE vehicles. The HICE certification vehicle utilizes aftermarket engine control unit hardware. This hardware has never been used in an OBDII-compliant program and requires low-level (OBDII) driver development and hardware changes to become compliant. Following these changes, a significant amount of software development also will be required. One issue experienced with these particular vehicles is the fact that the build-from vehicle utilizes the J1850 messaging protocol, which is not supported by the aftermarket engine control unit. A message translator module is used to communicate between the aftermarket engine control unit and the rest of the stock vehicle modules (e.g., ABS, body, and dash). Additional software development will be required in the translator module to enable use of a generic scan tool.

5.2 Parameter Identifiers Monitoring

CARB requires a standard list of parameter identifiers for querying information from the powertrain control module that would need to be resolved. These include “Freeze Frame”-stored engine parameters for diagnosing malfunction indicator lamp illumination. A significant amount of software development will be required for the HICE certification vehicle to achieve parameter identifiers monitoring compliance.

5.3 Onboard Diagnostics Level II Monitoring

CARB requires monitoring all emissions related sensors and emission components. A Roush letter to CARB dated September 18, 2006 (see Appendix A), addresses the following OBDII monitors:

- **Catalyst monitor—**Not applicable because catalytic converters are removed. A letter explaining the decision to remove the converters was sent to CARB on August 30, 2006 (see Appendix A).

- **Misfire monitor—**Not applicable because no hydrocarbons are emitted during misfire and no catalysts will be damaged from misfire. CARB questioned whether a misfire monitor would still be desired for detecting degraded performance. However, because a misfire has no emissions impact, the monitor is not a regulatory requirement.

- **Evaporative system monitor—**Not applicable because there is no evaporative fuel system and the fuel system is sealed.

- **Fuel system monitor—**This monitor is required as emission of nitrogen oxides is influenced by the fuel/air ratio. A richer than requested mixture would increase nitrogen oxides. Because the hydrogen fuel management system is running open loop with no feedback from heated exhaust gas oxygen sensors or universal exhaust gas oxygen sensors, the conventional way of monitoring fuel shifts does not apply. Roush proposed a monitor to CARB that monitors the closed loop idle control to determine if a rich fuel shift has occurred. CARB was reluctant to agree to its use and requested that reliability of using universal exhaust gas oxygen sensors to monitor fuel shifts be investigated. Hydrogen fueled vehicles currently operating in Vancouver, Canada, as part of the AVTA’s fleet testing of HICE vehicles have universal exhaust gas oxygen sensors installed for the purpose of monitoring the durability of the sensor in a hydrogen environment.

- **Oxygen sensor monitor—**Not applicable because the system does not utilize O_2 sensors for fuel control. However, this would be required if universal exhaust gas oxygen sensors are used as inputs for the fuel system monitor.

- **Secondary air monitor—**Not applicable because the system does not utilize secondary air.

- **EGR system monitor—**Not applicable because the system does not utilize exhaust gas recirculation.

- **PCV system monitor—**Not required because hydrogen fuel contains no hydrocarbons; therefore, there will be no fuel-related crankcase vapor detrimental to the atmosphere. However, the positive crankcase ventilation system is still present on the vehicle.

- **Engine cooling monitor**—This monitor checks for a stuck open thermostat. Because the additional cold start fueling is based on engine coolant temperature at startup and decays away with time, no fueling would be modified for a non-functional thermostat. Spark is not modified for engine coolant temperature; therefore, the monitor is not applicable.

- **Cold start emissions reduction strategy monitor—**Not applicable.

- **Air conditioning system monitor**—Not applicable.

- **Variable valve timing monitor—**Not applicable.

- **Direct ozone reduction system monitor—**Not applicable.

- **Comprehensive component monitor—**HICE certification vehicle software performs the basic functions of this monitor. Additional sensor rationality checks will be required for full compliance. These checks will require significant software development.

6. EXPERIMENTAL PERMIT

During discussions with CARB, Roush was encouraged to seek an experimental permit allowing use of HICE vehicles in California. This permit would allow acquisition of data from the HICE certification vehicle and provide an opportunity to further mature the OBD compliance. The time period for using an experimental permit is likely limited to a maximum of 2 years.

The following list of items needed for applying for an experimental permit was provided by CARB (see Appendix D):

- Brief description of proposed vehicle modifications, including the following:

  - Purpose of the modification

  - Basic theory of operation and functional characteristics

- Defined test program for obtaining pertinent data on driveability, fuel economy, and emission effects as applicable

- Statement indicating which, if any, emission control components are removed or modified

- Make, model, year, and license number or vehicle identification number of vehicle(s) modified (if modifications are to a heavy-duty vehicle, include the engine serial number)

- Statement indicating disposition of the modified vehicle(s) at the end of the test program. Vehicles would either need to be updated to full OBD compliance or removed from road use in California.

Additional experimental permit information requested from Roush by CARB includes the following:

- In the near term, is there a plan to certify the hydrogen vehicles in California?

- Provide details on the durability test plan (i.e., components and emissions)

- Provide details on plan to develop a CARB-compliant OBDII System

- Length of test program

- Number of test vehicles

- Purchaser or owner of hydrogen kits or converted vehicles (in California)

- Acknowledgment from vehicle owner/operator that the permit will be valid for a fixed period of time, after which the vehicles would need to be converted back to the original certified configuration, shipped out of California, or converted to a certified hydrogen system.