NHTSA'S FOUR-YEAR PLAN FOR HYDROGEN, FUEL CELL AND ALTERNATIVE FUEL VEHICLE SAFETY RESEARCH

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ABSTRACT

The National Highway Traffic Safety Administration's (NHTSA's) program for hydrogen, fuel cell, and alternative fuel vehicles is focused on providing critical safety information on hydrogen-powered fuel cell and internal combustion engine (ICE) vehicles. Safety information is vital to support the launch of the FreedomCAR Program, a cooperative automotive research partnership between the U.S. Department of Energy (DOE) and the U.S. Council for Automotive Research (USCAR), whose members include Ford Motor Company, General Motors Corporation, and DaimlerChrysler Corporation. FreedomCAR was announced in January 2002 by Energy Secretary Spencer Abraham, and is designed to advance the development of fuel cell vehicles and hydrogen fuel infrastructure. The program was initiated as part of the President's goal to reduce U.S. dependence on foreign oil, improve vehicle efficiency, and reduce vehicle emissions. The President's Hydrogen Fuel Initiative, announced in 2003, expands on the FreedomCAR Program to make fuel cell vehicles a practical and cost-effective choice for large numbers of Americans by 2020. The President's proposed federal budget for fiscal year 2006 includes tax incentives for the purchase of fuel cell vehicles. NHTSA's safety initiative will complement these efforts by conducting risk assessment studies of hydrogen fueled vehicles, and developing test and evaluation procedures for safety assessment using suitable performance criteria. The risk assessment studies will quantify potential failures that could indicate unsafe conditions.

Corollary efforts by NHTSA address fuel economy and international harmonization of global technical regulations (GTR) for hydrogen vehicles. The agency will assess gasoline equivalency for fuel cell vehicles, and analyze potential increases to fleet fuel economy. NHTSA will also work with its international counterparts to determine the content of regulations pertaining to fuel cell and internal combustion engine (ICE) hydrogen vehicles.

This paper describes the safety issues that have been identified as unique to hydrogen-powered vehicles and the approach and timeline that NHTSA will pursue to address these issues.

INTRODUCTION

Ensuring that hydrogen ICE and fuel cell powered vehicles provide a level of safety comparable to that of other vehicles currently in use in the United States requires a substantial research effort. Hydrogen-powered vehicles will utilize many advanced and unique technologies that have not been tested in the transportation environment. Many manufacturers, however, are substantially investing in producing and marketing these vehicles in the near future. Very little data are available concerning their safe performance because so few exist; they are typically prototypes handled by specially trained personnel. As these vehicles are deployed in the fleet, the safety of hydrogen as a fuel and the safety of alternative fuel vehicles in crashes becomes an issue of significant concern. A failure to adequately address safety concerns in the earliest stages of development could have a negative impact on the deployment of this new technology.

APPROACH

Following the announcement of the FreedomCar program in 2002, NHTSA began collecting information on the status of hydrogen vehicle technology and drafting a plan to address hydrogen and fuel cell safety for passenger vehicles.

An agency-wide working group was established to coordinate activities in the areas of international harmonization, research, regulation, and enforcement relative to hydrogen fueled vehicle safety. This group also coordinates activities with the Department of Transportation (DOT) Hydrogen Fuels Working Group, which consists of representatives from all modes of DOT, and with the Department of Energy, the FreedomCar and Fuels Codes and Standards Technology Team, and the Office of Science and Technology Policy's Hydrogen and Fuel Cell Interagency Task Force.

In the fall of 2002, NHTSA began meeting with vehicle manufacturers to discuss hazards, risks, and safety considerations particular to hydrogen-fueled vehicles. As of January 2005, NHTSA had met with five manufacturers to discuss these issues. In June 2004, NHTSA obtained clearance from the Office of Management and Budget to send a letter to ten vehicle manufacturers requesting that they voluntarily provide written information on their safety strategies. In July 2004, NHTSA published its research plan, which was developed in part from the interchange conducted with industry over the previous year and a half, in the Federal Register for public comment. These documents, and the manufacturer and public responses to them, may be downloaded from the DOT docket. [1]

PROBLEM DEFINITION

The unique safety challenges presented by hydrogen and fuel cell vehicles fall into four broad categories:

First, the characteristics of hydrogen as an energy carrier differ from those of conventional vehicle fuels like diesel and gasoline. Hydrogen also has unique handling requirements, as compared to other alternative fuels, such as natural gas (CNG). Hydrogen is colorless, odorless, burns without producing a visible flame or radiant heat, and is difficult to contain. It has a minimum ignition energy an order of magnitude lower than that of other hydrocarbon fuels (.02 millijoules) and a much wider flammability range (4 to 75 percent volume in air). The quenching gap, which is the largest passage that can prevent flame propagation when filled with a flammable mixture, is smaller than that of methane, propane, and gasoline, requiring tighter tolerances to prevent flame propagation. Unlike CNG, hydrogen can cause significant deterioration in fuel system components by diffusing into steel and other metals, causing a phenomenon known as "hydrogen embrittlement." As a result, the metal will break or fracture at a much lower load or stress.

Second, hydrogen storage methods are different from storage methods for other fuels. One of the main safety concerns is the safe onboard storage of hydrogen. There are a variety of very different technologies used for storing the hydrogen fuel, from very high pressure gas storage, to cryogenic liquid, solid metal hydrides that require complex thermal management systems for charging and discharging hydrogen, liquid chemically bonded forms that produce highly alkaline spent fuel waste, and on-board reformulation systems that produce the hydrogen from hydrocarbon fuels. High-pressure storage carries the risk of fuel tank rupture and missile damage. Liquid hydrogen is cryogenic (-253 degrees Celsius) and requires special tanks, insulation, and venting systems, to maintain liquid conditions. The hazard from a leak or spill is the potential for cryogenic burns and fires.

Third, fuel cells are electrical devices, but they operate differently than batteries, which are power storage devices. Fuel cell vehicles operate at high voltage, and in some cases are equipped with auxiliary propulsion batteries, so that the issues of electrical shock, isolation, and ignition of surrounding materials such as plastics must be studied as well.

Finally, passenger compartment integrity and crush zone design in hydrogen and fuel cell vehicles may be tied to a significantly different mass distribution and stiffness than that of current conventional vehicles. An analysis and forecast prepared by the Massachusetts Institute of Technology compares a 1996 baseline vehicle to 11 advanced vehicle designs with varying drivetrain options projected for MY 2020 and concludes that overall vehicle weight will not be reduced, but propulsion systems will be heavier and structural and body components will be lighter [2]. The volumetric envelope of the propulsion system components will differ as well, and 4 different packaging options have been identified that alter the mass distribution when compared to vehicles today [3].

OBJECTIVES

The objective of this research program is to ultimately ensure that hydrogen and fuel cell vehicles attain a level of safety equivalent to that of conventionally fueled vehicles. Current Federal motor vehicle safety standards (FMVSS) for fuel system integrity do not address the unique characteristics of hydrogen and fuel cells discussed in the previous section. Industry and government codes, standards, and regulations are still in the very early stages of development and would benefit greatly from real world risk assessment. Similarly, development of test procedures and suitable performance criteria are critical in order to quantify potential failures and resulting unsafe conditions as these vehicles are operated in the real world.

CURRENT BASELINE STATUS OF HYDROGEN-POWERED VEHICLES

A report published in February 2004 by the Department of Energy identifies over sixty passenger vehicle models (1994 – 2003) fueled by hydrogen [4]. Although many of these vehicles can be classified as experimental or concept vehicles, some are production prototypes, in use in demonstration fleets and available for public ride-and-drive events. These vehicles range from compacts to minivans to SUV's. Fuel storage options are onboard reformulation of gasoline or hydrocarbon fuels, high-pressure compressed hydrogen, cryogenic liquid hydrogen, sodium borohydride, and metal hydrides. Vehicles may have additional batteries or ultracapacitors to buffer power delivery.

Honda has a production prototype vehicle, the FCX, on the road in California that is self-certified as meeting all existing FMVSS and has been crash tested in front, offset, side and rear crash modes without failure of the fuel system or occupant protection requirements. The vehicle incorporates several safety features not required by current FMVSS. If any front, side or rear impact is severe enough, the control unit automatically shuts off the flow of electricity from the fuel cell module and the capacitor module. In less than a second, there is no current in the high voltage cables. Each hydrogen tank contains three internal safety valves. One prevents backflow of hydrogen during refill, another shuts off flow of hydrogen when signaled by the power control unit, and the third is a temperature activated relief device designed to release all hydrogen through a line and out the back of the vehicle until the tanks are empty, which could take up to five minutes if the tanks are full. In addition to the in-tank safety valves, several sensors are located along hydrogen lines to detect any possible leak. If a leak is detected, the power control unit stops the flow of hydrogen from the tanks. The vehicle is also equipped with a manual shut-off valve inside the right wheel well. NHTSA will need to test these safety systems and determine whether regulations specifying performance criteria are required. The Japanese government intends to have regulations in place in 2005 addressing the safety of these vehicles, with a commercialization goal of 2010.

NHTSA'S RESEARCH PLAN AND RELATED ACTIVITIES

Subject to the availability of research funds through the Department, NHTSA will continue to develop research plans and begin program implementation in FY 2005. This program will have several elements:

Outside Activities

Review and or participate in development of applicable industry codes and standards, public outreach, and safety information collection.

National/International Voluntary Standards Organizations, Codes and Standards

- NHTSA reviewing Society of Automotive Engineers (SAE) Recommended Practices J2572, J2578, J2579, J2600, J2601.
- NHTSA reviewing Canadian Standards Association (CSA) America HGV standards.
- NHTSA participating in International Organization for Standardization (ISO) activities.

Expand Outreach to the Public Safety Community

Obtain input and feedback from first responder experts from the fire service, emergency medical service, traffic law enforcement and involve public safety professionals in formulation, development, and post-implementation evaluations of codes and standards.

Information Collection

Collect real world safety performance and vehicle specification data from:

Demonstration vehicles -

- DOE demonstration program
- DOT/Federal Transit Administration bus demonstration program – Three 30-foot fuel cell test-bed buses were developed in conjunction with DOE, and work on two 40-foot transit buses has begun.
- California Fuel Cell Partnership program – Collaboration between vehicle and equipment manufacturers, fuel suppliers, and government to prepare the market for commercialization of fuel cell vehicles.
- EPA/DaimlerChrylser/UPS Fuel Cell Delivery Vehicle Initiative, announced May 2003. Collaborative project in which UPS will operate package delivery vehicles powered by hydrogen fuel cells supplied by DaimlerChrysler, beginning late 2003 and continuing in 2004. The EPA will supply a hydrogen refueling station at its Ann Arbor facility. This is the first use of fuel cell technology in a commercial delivery fleet in North America.
- California South Coast Air Quality Management District - Development and demonstration of vehicles with ICE using hydrogen fuel and development of 5 hydrogen refueling stations.

- General Motors' Washington DC fuel cell preview program launched in May 2003, is a Washington-based fleet of hydrogen-powered vehicles providing up to 10,000 test-drives of GM's HydroGen3 fuel cell prototype, fueled by the nation's first hydrogen station. The two-year program will provide test drives for legislators, regulators, environmentalists, and other policy makers.
- General Motors' HydroGen3 vehicles will operate in FedExpress service in Tokyo, Japan.
- Toronto City and Hydrogenics Corporation three-year project demonstrating hydrogen and fuel cell technology for mobile and stationary power.

Manufacturer data -
- Follow manufacturer development of hydrogen and fuel cell vehicles (BMW, DaimlerChrysler, Ford, General Motors, Honda, Hyundai, Mazda, Nissan, Toyota, Volkswagen)

Vehicle Safety Research

<u>Powertrain, vehicle fuel container, and delivery system performance testing (vehicle or fuel system mockup)</u>

Effectiveness of safety systems:
- Evaluate performance of pressure relief devices, thermal and electrical management systems for tanks, fuel cells and batteries, purging of fuel cell and lines, and discharge of residual voltage in fuel cell stack.

Leak Detection:
- Measure hydrogen leakage and concentrations in and around fuel system over time. Test passive vs. active ventilation systems.
- Determine suitable surrogate for hydrogen that is safe for leak detection and vehicle crash testing program.

Fire Exposure:
- Conduct vehicle buck ignition and flammability tests through controlled releases of hydrogen and electrical arcs at various severed locations in tubing between onboard storage tanks and fuel cell stack. Using a vehicle underbody buck, conduct pool fire testing, similar to the ECE-R34 test for plastic fuel tanks for gasoline.
- Conduct material flammability tests with a hydrogen flame.
- Conduct self-ignition tests to determine if external debris or particulate matter can cause ignition of venting hydrogen.

Road hazards exposure:
- Conduct tests to determine vulnerability of components/packaging to road debris.

<u>Refueling system performance testing</u>

Leakage:
- Conduct tests to monitor hydrogen leakage from vehicle/fueling system interface.

Spark/grounding:
- Evaluate static electricity/spark suppression mechanisms on vehicle and fueling station.

<u>Full vehicle performance testing</u>

Crash:
- Run series of crash tests to determine compliance and/or obstacles to compliance with Federal Motor Vehicle Safety Standards (FMVSS) 208, 214, 302, and 305.
- Determine comparable areas of fuel system integrity not covered under existing FMVSS 301, 303, and 304.

Leakage:
- During operation and while parked, measure hydrogen leakage and concentrations inside and outside the vehicle over time. Test passive vs. active ventilation systems and performance of recovery or conversion systems to remove hydrogen.

Electrical isolation of fuel cell, cooling system and auxiliary batteries:
- Conduct tests to determine electrical isolation of the entire high voltage system and its components (fuel cell, batteries, cooling system) pre- and post crash and after several charge/discharge cycles of the propulsion system.
- Determine appropriate safety factor for electrical isolation for fuel cells, battery packs, ultra capacitors and other electrical, high-energy storage devices (current requirement under FMVSS 305 is 500 ohms/volt). (NOTE: Some manufacturers indicate that this level is not attainable in certain systems.)

Incident Management:
- Determine any special post crash handling requirements for vehicle occupants, public safety personnel, towing, storage, or disposal.
- Review California Fuel Cell Partnership emergency response guide and other available responder training materials.

Special Crash Investigations Program:
- In-depth investigations of any real world incidents.

Recycling:
- Coordinate with EPA and identify toxic/hazardous materials used in the manufacture of vehicles.

Corporate Average Fuel Economy (CAFE) analysis and evaluation:
- Determine appropriate gallon equivalent of hydrogen. NHTSA is statutorily required to set hydrogen gasoline gallon equivalency (GGE) factors by the Alternative Motor Fuels Act, as amended. In 1996, NHTSA issued a final rule entitled "Manufacturing Incentives for Alternative Fuel Vehicles" (49 CFR 538.8), establishing a GGE value for internal combustion engine (ICE) hydrogen vehicles. NHTSA is in the process of determining the applicability of the hydrogen ICE equivalency value to hydrogen fuel cell vehicles.

- Assess hydrogen vehicle fuel economy levels. Since the agency is required to set fuel economy standards at the maximum feasible level for each model year, it is necessary for the agency to investigate and analyze the potential increases in fuel economy attributable to hydrogen vehicles. To accurately project fuel economy increases, NHTSA must understand the critical path of various fuel cell designs, and the technological challenges manufacturers face with each model.
- Review work by Japan Automobile Research Institute (JARI) and others to determine appropriate methodology to utilize for hydrogen fuel economy measurement during fuel economy testing.

International Regulations/International Policy and Harmonization

Assess need for regulation based on research test results and safety performance of passenger cars, multipurpose vehicles, trucks, and buses.
- Goal- Development of performance based Global Technical Regulations (GTR) for Hydrogen/Fuel Cell Vehicles.
- Participation in the UN/Economic Commission for Europe (UNECE) World Forum for Harmonization of Vehicle Regulations (WP.29) Hydrogen/Fuel Cells Working Group.
- Cooperation with Canada, the European Union and Japan on the development of safety regulations for hydrogen fueled vehicles under bilateral cooperative agreements with those regions. Identify best safety approaches and conduct joint research and testing.
- Cost, weight and lead time impacts of alternative fuel vehicles

RESEARCH TIMELINE

Tables 1 – 5 provide the timeline that will be followed in assessing the safety performance of hydrogen, fuel cell and hybrid vehicles (i.e., those using auxiliary batteries or ultracapacitors) and subsystems. Availability of test vehicles, components and hydrogen fueling stations is critical to the success of this assessment. Current costs for hydrogen-powered vehicles exceed $1,000,000 per unit. Fuel cell stacks for vehicles range in price from $250,000 to $1,000,000. NHTSA is working closely with manufacturers and other stakeholders in the hydrogen economy to cost share resources and testing through cooperative agreements, and by “piggy-backing” safety testing onto other programs. For example, manufacturers may provide vehicles in order to share the cost of testing, or demonstration fleets may provide “retired” vehicles for testing prior to disposal.

The results of this assessment may be used as input to regulations (GTR, FMVSS) that minimize the potential for harmful events or outcomes caused by loss of fuel system integrity.

The following timelines are proposed and subject to change:

Table 1. Component level testing – Powertrain, vehicle fuel container, delivery system performance testing (tanks, or fuel system mockup)

	YEAR 1	YEAR 2	YEAR 3	YEAR 4
1.1) Determine suitable surrogate for hydrogen that is safe for leak detection and vehicle crash testing (Helium or Nitrogen?)	√			
1.2.) Destructive testing of (a) compressed and liquid H2 tanks	√	√		
(b) Other hydrogen storage Similar to FMVSS 304 testing			√	
1.3.) Evaluate methods for leak detection	√			
1.4.) Evaluate thermal and electrical management systems for fuel cells, batteries, ultracapacitors		√	√	

1.5.) Evaluate effectiveness of safety systems for shutting down hydrogen flow, strategies for controlled and rapid release of hydrogen (venting and blowdown), purging of fuel cell and lines	√	√		
1.6.) Fire Exposure – (a) Vehicle buck ignition and flammability through controlled release of hydrogen, electrical arcs (b) Pool Fire – ECE-R3 test (c) Material flammability (d) Autoignition testing		√	√	√ √
1.7) Road Hazards Exposure Vulnerability of packaging/ components road debris				√

Table 2. On board refueling system performance testing – Conduct tests on up to 35 identified vehicle platforms, fueling station architecture currently unknown – Identify and test at available fueling stations.

	YEAR 1	YEAR 2	YEAR 3	YEAR 4
2.1) Evaluate communication to prevent overpressure, leakage	√	√	√	√
2.2) Evaluate effectiveness of spark suppression/grounding	√	√	√	√

Table 3. Full vehicle performance testing – Conduct crash, static pre and post-crash hydrogen leakage, electrical isolation tests, develop post -crash handling/EMS procedures. Coordinate with EPA on recycling issues. Destructive testing on 3 vehicles per year, non-destructive testing on available demonstration vehicles. Assume cost share with manufacturer or other stakeholder.

	YEAR 1	YEAR 2	YEAR 3	YEAR 4
3.1) Crash - Procure at least one representative vehicle model per year and conduct front, side rear occupant protection and fuel system integrity crash tests (FMVSS 208, 214, 300 series - requires 3 vehicles per test series)	√	√	√	√
3.2) Leakage - Measure/monitor during operation while parked/garaged test active ventilation systems and performance of H2 recovery or conversion systems	√	√	√	√

3.3) Electrical Isolation of high voltage systems pre post crash, charge cycling, determine appropriate safety factor for isolation (currently 500 ohms/volt	√	√	√	√
3.4) Incident Management – Vehicle, occupants, public safety, towing storage, disposal	√	√	√	√
3.5) Special Crash Investigations	√	√	√	√
3.6) Recycling – Coordinate with EPA	TBD			

Table 4. Corporate Average Fuel Economy (CAFE)

	YEAR 1	YEAR 2	YEAR 3	YEAR 4
4.1) Corporate Average Fuel Economy (CAFE) – Hydrogen measurement, gallon equivalency, rulemaking requirements	√	√	√	√

Table 5. International harmonization of codes and standards, development of Global Technical Regulation for hydrogen fueled vehicles

	YEAR 1	YEAR 2	YEAR 3	YEAR 4
5.1) Representation at UNECE WP 29 (GRPE) - Comparative testing of European and Japanese requirements - Develop global technical regulation	√	√	√	√
5.2) Cost, weight, and lead time impacts of alternative fuel vehicles		√	√	√

CONCLUSIONS

Following NHTSA's discussions with vehicle manufacturers and participation with the UN/Economic Commission for Europe (UNECE) World Forum for Harmonization of Vehicle Regulations (WP.29) Hydrogen/Fuel Cells Working Group, research in support of draft and adoption of global technical regulation should be completed within the next three to four years for manufacturers to be able to initiate mass production of hydrogen vehicles around 2010. With that timeline quickly approaching, the supporting research, if pursued aggressively and collaboratively with other interested parties to a completion in 2008-2009, could result in adoption of a GTR in 2010-2012.

REFERENCES

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