International Symposium on Fire Investigation Science and Technology
June 2006

FIRE INVESTIGATION FOR HYBRID AND HYDROGEN-FUELED VEHICLES

R. Rhoads Stephenson, CFEI, CVFI
Motor Vehicle Fire Research Institute, USA

and

Orrin West, P.E.
Ford Motor Company, USA

ABSTRACT

In recent years there have been several different types of alternative vehicles introduced. They include: pure electrics, gasoline Internal Combustion Engine (ICE) hybrids, natural gas (NG) fueled ICEs, and hydrogen-fueled vehicles which could utilize either an ICE or a fuel cell. The hydrogen fuel cell vehicles will likely also be hybrids. These innovative vehicles introduce new hazards to the fire investigator, and also new energy sources and possible fire scenarios. There are on the order of 140,000 NG and 200,000 hybrid vehicles on the road in the US, and it has been estimated that there are about 500 hydrogen vehicles worldwide at the current time. It is especially important that these new vehicles have thorough and in-depth fire investigations so that the designs and safety performance can be improved as these technologies are introduced into the fleet.

The 2004 edition of NFPA 921 "Guide for Fire and Explosion Investigation[1]" is in the process of being updated. Chapter 25 of this document applies to motor vehicle fires. An NFPA/SAE Task Group has been formed to propose updates to Chapter 25. The authors have suggested adding several new paragraphs to cover high voltage electrical systems, electric motors, hybrids, and hydrogen-fueled vehicles. Some of our ideas are presented in this paper. No changes will be finalized until NFPA publishes their draft for review and comment, the entire final document is balloted, and then published in 2008.

NFPA 921 espouses the "scientific method" for fire investigation. This method requires a physical understanding of the involved components and systems. A high voltage DC system is common to virtually all of the new alternative vehicles and will be initially unfamiliar to most investigators. As a primer, a general description, based on physical and engineering principles, of how such systems might be expected to behave under a number of fault conditions is presented.

INTRODUCTION

There are special precautions and techniques required to properly investigate a fire in a hybrid or hydrogen-fueled car. An example of a hybrid currently being sold is shown in Figure 1. Hybrid vehicles were first introduced by Honda (the Insight) in 1997. Their popularity has been growing in recent years and Toyota is planning on selling 150,000 Prius vehicles in CY 2006. The U.S. automakers now have hybrid offerings and will be adding many additional models over the next few years. Some experts predict a 10-15% market share for hybrids by 2010. Ford has introduced the Hybrid Escape, the first hybrid SUV, starting with the 2005 model year. Production volume of hybrid vehicles has to some extent been limited by availability of key components, such as the high voltage battery. It is expected that such bottlenecks will loosen as suppliers climb the learning curve.

Figure 1. Ford Escape Hybrid Vehicle

Hydrogen-fueled vehicles can be powered by either an internal combustion engine or a fuel cell which produces electricity. Most fuel cell vehicles will have a battery (or ultra-capacitor) to store electrical energy and will thus also be hybrids. An example of a prototype hydrogen fuel cell vehicle is shown in Figure 2.

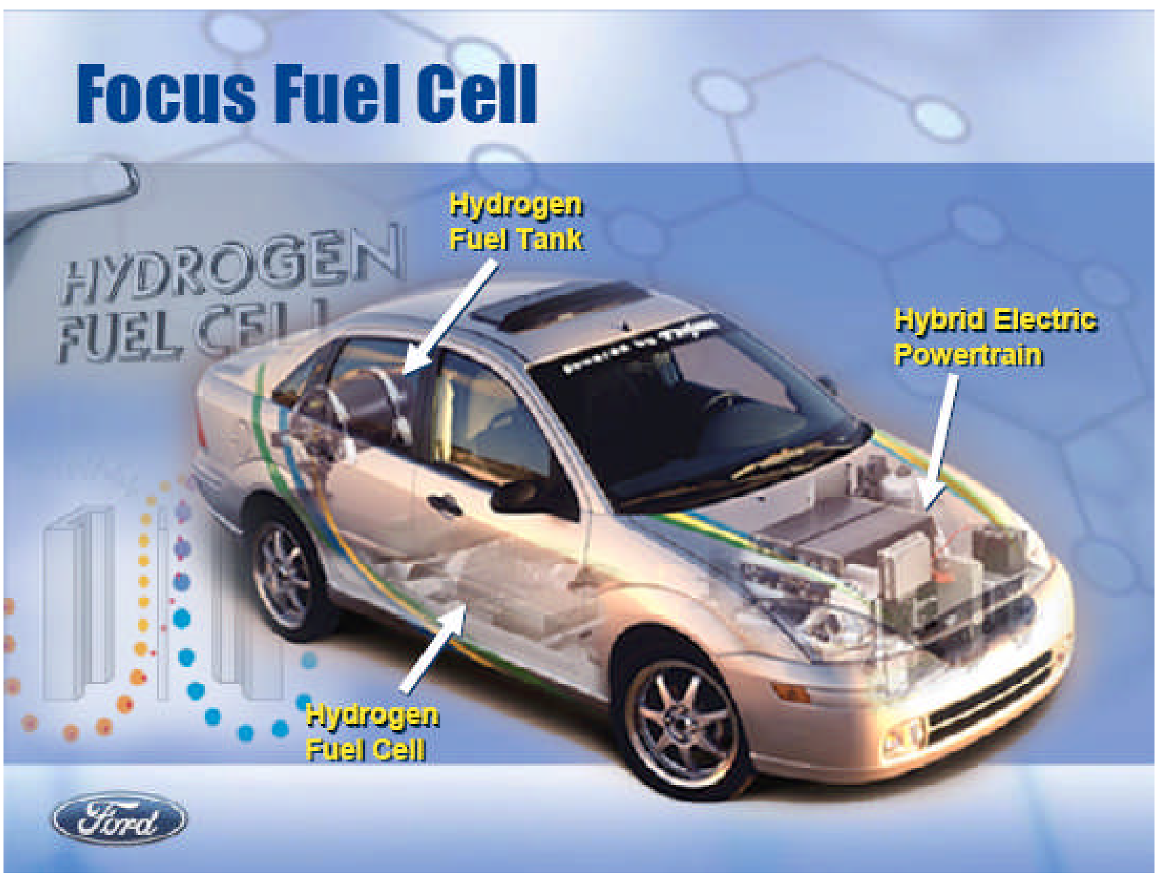

Figure 2. Ford Focus Fuel Cell Vehicle

Fuel cell vehicles are under intensive development by all the major auto manufacturers. There is a large government/industry program called the FreedomCAR and Fuels Partnership which includes the Department of Energy, the USCAR consortium of US Original Equipment Manufacturers (OEMs), and 5 major energy companies (previously known as "oil" companies). It is estimated that there are ca 500 hydrogen vehicles on the road (including buses) and that number is increasing as several DOE/industry demonstration fleets are rolled out. The number of fueling stations in the US is currently several dozen and also will increase over the next few years.

At present, the cost and durability of automotive fuel cells and hydrogen storage capacity will limit their use to special demonstration fleets and prototype vehicles. It is not expected that large scale fueling infrastructure will be added until a satisfactory, mass producible fuel cell has been developed.

The NFPA 921 "Guide for Fire and Explosion Investigations: 2004 Edition[1]" is currently being updated and the next version is scheduled to be released in 2008. Chapter 25 covers Motor Vehicle Fires.

This paper proposes language for adding appropriate paragraphs to this Chapter to handle the special requirements for investigating hybrid and hydrogen vehicles. The suggestions are those of the authors only, and nothing has been accepted by NFPA at this time. It is expected that the exact wording will change substantially as this material is reviewed and commented upon during the NFPA process.

VEHICLE INVESTIGATION SAFETY

Section 25.2 covers precautions to avoid injuries to the investigator. There are special procedures for hybrid and hydrogen vehicles because of the high-voltage and gaseous, flammable fuel. Two new paragraphs are suggested below.

Hybrid Vehicle Investigation Safety

"As a safety precaution, the investigator should approach the hybrid vehicle as though the high voltage system was energized. Before inspecting a hybrid vehicle the inspector should familiarize himself/herself with the high voltage system. Most hybrid vehicles will have a manual disconnect means to isolate high voltage to the battery pack. Inspectors should ensure that the disconnect is in the isolation position before beginning any hands-on inspection procedures. As an additional precaution, inspectors should have, understand, and use an appropriate voltmeter to check whether high voltage is present on any suspect wiring or component. The high voltage battery potential could range from a low of 42 volts for "mild" hybrids to 300 - 600 volts for "full" hybrids. Opening the battery pack could be extremely hazardous and should not be attempted by untrained personnel."

Hydrogen-Fueled Vehicle Investigation Safety

"Immediately after a fire or crash, the hydrogen tank or downstream fuel system may be venting its contents. This venting may produce a very loud noise. This escaping hydrogen may or may not be ignited, but it could ignite at any time. Any investigation should wait until all venting is completed. Another hazardous situation is if the tank or fuel system is damaged due to a crash and/or fire. The tank could burst some considerable time after the crash or fire. Each vehicle model may have electronic or mechanical means for safely venting the hydrogen before doing a vehicle fire investigation. Many hydrogen vehicles will also be battery hybrids – so all the precautions for high voltage electrical safety also apply. Hydrogen has very low ignition energy (ca 0.02 mJ) and burns with an invisible flame. It diffuses rapidly and is lighter than air so it can quickly become diluted below the lower flammability limit (ca 4% by volume) unless it is trapped somewhere. It can also explode under some conditions, and leaks in confined spaces are the most dangerous."

SYSTEMS DESCRIPTION

Chapter 25 of NFPA 921 has a several sections which describe the fuel, electrical, and mechanical systems on a typical vehicle.

Electric Motors

Hybrids and hydrogen fuel cell vehicles both use one or more electric motors to provide torque to the wheels. It is therefore desirable to add a paragraph on electric motors to the Mechanical Power Distribution Section 25.5.5. Here is suggested wording.

"Vehicles such as pure electrics, Internal Combustion Engine-hybrids, and hydrogen fuel cell vehicles will have one or more high power electric motors to provide or augment the torque to drive the vehicle. Some will have a single electric motor and a transmission and differential system to power the wheels. Others will have two motors and some may have a motor for each wheel. These motors will be connected to power electronics which in turn will be powered by a battery (or ultra-capacitor) and/or fuel cell. The voltages feeding the motor may be in the range of 300-600 volts. Some electric motors may be DC, but most modern electric motors will be driven by variable frequency AC."

Hybrid Vehicle Description

Here is the suggested wording.

"Hybrid vehicles contain as means of propulsion both an internal combustion engine and an electric drive system. The electrical system of a hybrid vehicle will consist of a high voltage system used for traction and a regular automotive 14-volt system used for all other electrical loads. The high voltage system will consist of a high voltage battery (or ultra-capacitor) , a high voltage traction motor, a generator for charging the battery from the Internal Combustion Engine, an electronic controller, and a converter for stepping voltage between the high and low voltage systems. Most hybrid vehicles also contain a standard 14-volt automotive battery for non-traction loads. Most hybrid vehicles do not have a separate alternator or starter motor. As hybrid technology evolves other automotive loads, such as power steering and air conditioning, may become powered from the high voltage bus. The high voltage system is not grounded to chassis and so there will be two conductors to every high voltage load. It is standard to reserve the color orange for all high voltage wiring. The high voltage system will most likely be protected by an automatic disconnecting means that may be activated by any number of events including KEY OFF, detection of a ground path, detection of an open high voltage connector, sensing of a crash (such as an inertial disconnect switch if so equipped), etc. Most high voltage systems will also contain a fuse or other circuit protection device as part of the battery pack to protect against a direct short."

"There is no standardized marking required on hybrid vehicles. Some say "hybrid" on the rear of the vehicle. Others may have stickers which allow them onto the carpool lanes in certain states. The Lexus is the most subtle – they just put a lower case "h" after the model number."

Hydrogen-Fueled Vehicle Description

Here is the suggested wording.

"Vehicles fueled with hydrogen may store that fuel as high-pressure compressed gas (5,000 – 10,000 psi), in the form of a cryogenic liquid, or in a moderate pressure tank (up to 1500 psi) as a hydride. These storage devices and the downstream fuel system will be protected by one or more Pressure Relief Devices (PRDs) and/or rupture disks. The devices may be actuated by either high pressure or high temperature (from a vehicle fire). There will also be one or more pressure regulators to reduce the pressure to that required by the fuel cell or internal combustion engine. There will also be a fill line, one or more electrically actuated shut-off valves, and vent lines for the PRDs and the fuel cell exhaust. The manufacturer's manuals should be consulted to get the exact configuration of the fuel system. Hydrogen vehicles, parking garages, and fueling stations may have hydrogen sensors which could set off an alarm when leaking hydrogen is detected. Some prototype hydrogen vehicles have hydrogen sensors in the wheel wells."

"Some vehicle manufacturers have proposed using reformers to supply the source of hydrogen. A reformer uses chemical processes to free hydrogen from a standard fuel such as gasoline. Vehicles of this type will most likely have a gasoline system as well."

"Hydrogen vehicles have standardized markings as specified by SAE J2578. The vehicle will have a blue diamond sticker which says "Compressed Hydrogen" or "Liquid Hydrogen" in white letters."

VEHICLE INVESTIGATION

Section 25.8 of NFPA 921 covers Motor Vehicle Examinations. Since hybrid and hydrogen vehicles have new systems and subsystems, it is important to examine additional portions of the vehicle.

Hybrid Vehicle Investigations

Here is the suggested wording.

"Investigation proceeds as usual for vehicles except that the high voltage system must be considered as a potential cause. To this end, investigators must obtain vehicle-specific information regarding not only the type and location of all high voltage components but also the protective strategies implemented by the manufacturers to reduce the risk of unintended energy release from the high voltage system. One step should be to determine if the disconnect means is open and whether the high-voltage circuit protection device (or fuse) is open."

Hydrogen Vehicle Investigations

Here is the suggested wording.

"It is important to determine whether the hydrogen was involved in the vehicle fire or not. Was the hydrogen the first fuel burned, or did the vehicle fire from other causes subsequently attack the hydrogen storage tank or other components containing hydrogen? After ensuring the investigator's safety (Section 25.2), it is important to examine the entire fuel system and determine: (1) Were any of the tanks mechanically damaged from a crash? (2) Were any of the tanks damaged by fire? (3) Did the tanks leak or burst and release their contents? (4) Was any of the high-pressure or intermediate pressure plumbing damaged? (5) Did any of the pressure relief devices open and vent hydrogen? (6) Did any hydrogen sensors detect a leak, and were any alarms sounded? (7) Is there any evidence that any tanks, plumbing or fittings had been repaired, modified or damaged prior to the fire? Many hydrogen vehicles will also be hybrids with high voltage present, so the investigation should also include the high-voltage electrical system as discussed in the section on how to investigate hybrid vehicles"

DISCUSSION

Hybrid and hydrogen vehicles are being fielded – with much larger numbers of hybrids at the current time. It is important that any crashes and/or fires in such vehicles be safely and thoroughly investigated and the results fed back to the manufacturers and standards organizations.

The text above may be useful to investigators if they encounter one of these new technology vehicles. Any additions, corrections, or comments on these suggested paragraphs should be directed to both authors by email.

ABOUT THE AUTHORS

R. Rhoads Stephenson

R. Rhoads Stephenson has a PhD in Mechanical Engineering from Carnegie Mellon University. He spent 36 years at Caltech's JPL and worked in both the energy and space areas. He is now retired and a consultant to the Motor Vehicle Fire Research Institute (MVFRI). He was head of R&D for the National Highway Traffic Safety Administration (NHTSA) from 1978 to 1981. For the last four years he has been a consultant to MVFRI. This institute is sponsoring ca $ 4M of crash-induced auto fire safety research. Our program and results can be found at: www.mvfri.org

Dr. Stephenson is a member of DOE's Hydrogen Safety Review Panel (HSRP) and the National Research Council's review of the FreedomCAR program. He has also organized 6 sessions on auto fire safety for the April 2006 SAE World Congress.

The author can be reached at: rodys@earthlink.net

Orrin West

Orrin West, P.E. has a Masters degree from Wayne State University and BSEE from Kansas State. For the last 12 years he has been a product development and design analysis engineer for Ford Motor Company. Nine of those years have been exclusively with electric vehicles. His primary focus has been with the design and development of the high voltage electric drive subsystems of these vehicles. He holds three patents related to electric drive technology.

For the past three years he has investigated the causes of vehicle fires including electrical, chemical and mechanical means.

Mr. West can be reached at: owest@ford.com

REFERENCES

[1] NFPA 921, Guide for Fire and Explosion Investigations: 2004 Edition. Chapter 25. “Motor Vehicle Fires.”