EMERGENCY RESPONSE GUIDE FOR LIGHT DUTY FUEL CELL VEHICLES

Published 12/2002
Version 1.0

California Fuel Cell Partnership
DRIVING FOR THE FUTURE

DaimlerChrysler
Ford Motor Company
GM
Honda
Hyundai
Nissan
Toyota
Volkswagen

Ballard Power Systems
UTC Fuel Cells

BP
ChevronTexaco
ExxonMobil
Shell Hydrogen

California Environmental Protection Agency, Air Resources Board
California Energy Commission
South Coast AQMD
U.S. Department of Energy
U.S. Department of Transportation
U.S. Environmental Protection Agency

California Fuel Cell Partnership
3300 Industrial Blvd.
Suite 1000
West Sacramento, CA 95691

www.fuelcellpartnership.org

Dear First Responder,

Attached is the Emergency Response Guide for Light Duty Fuel Cell Vehicles for the California Fuel Cell Partnership. It has been designed to aid the emergency responder in the event of an accident with a fuel cell vehicle. The guide is to be used as a supplement with the established passenger extrication/ vehicle securing methods.

For each vehicle at the Partnership, there is vehicle specific information diagrams which can be used to determine the location of the fuel cell system components. In addition, there is general hydrogen and vehicle safety system information for education purposes.

The guide was put together by the safety team at the CaFCP in collaboration with the West Sacramento, Richmond and the California State Fire Marshall's Office. This guide will be updated on a yearly basis and updates will be circulated.

Initially, it will be distributed to first responders in the areas in California where the vehicle manufacturers place their fuel cell fleets. There will be an associated training sessions for these areas which will be coordinated through the safety team at the CaFCP.

This online version of the guide does not contain the fuel cell vehicle specific information. To obtain a full copy, you must be a qualified member of a first responder unit in one of these designated areas. Please contact the partnership for further information.

Thank you for all those who supported this project.

Sincerely,

Jesse M. Schneider

CaFCP Chair L.D. ER Guide Team

Senior Mechanical Engineer
Fuel Cell Project
Maschinenbauingenieur Brennstoffzellenprojekt
DaimlerChrysler RTNA, West Sacramento CA
Phone: (916) 375 0377 - Ext. 103
Fax: (916) 375 0378

Table of Contents

CaFCP Light Duty Fuel Cell Vehicle Diagrams

(Not included in online version)

Shut Down Procedure/ ER Diagram

Reference Documents

(Not included in online version)

I. Preface

Since the advent of the automobile in the late 1800s, steady progress has been achieved in automotive technology. These advancements—from engine performance to power-to-weight ratio—have made the internal combustion (IC) engine a reliable source of power for this means of transportation. In addition to these advances, a great deal of safety engineering has been developed for protecting vehicle passengers. Emergency response personnel have established proven ways of safely extracting a passenger from these vehicles in the event of an accident.

Today, new and cleaner vehicle technologies are gaining attention as a means of reducing or eliminating air pollution from the automobile. These include electric, battery-powered vehicles, which produce no direct emissions. While battery-powered Electric Vehicles still face significant challenges to consumer acceptance, emergency response, and safety methods have been developed. Illustrated comparisons for emergency response between today's cars and electric vehicles were developed for a publication from the California State Fire Marshall: "Emergency Response to Electric Vehicles" (see bibliography).

The new technology also includes the fuel cell, an electrochemical device that generates electricity by combining hydrogen and oxygen. When using hydrogen as a fuel, its only emission is water vapor. In the 1960s, NASA further developed the fuel cell (first invented in 1839) as a source of power and water generation onboard spaceships. Since the 1990s, automobile manufacturers have been experimenting with this power source. In addition to producing zero or near-zero emissions, fuel cell vehicles could potentially provide significant public and personal benefits, including greater fuel efficiency, reduced noise due to its quiet operation, and additional onboard power for consumer use. Today, these prototype and limited production vehicles have many built-in safeguards, which make them equal to or safer than IC vehicles today (reference DOE/CE/50389-502). But, since these vehicles use a new kind of fuel (majority is compressed hydrogen), it is important to educate both ER responders and the public how these vehicles react in an accident and how to safely extract passengers.

This "Emergency Response" Guide is one source of information for the Emergency Responder. It is designed to be a safety handbook for the current light duty fuel cell vehicles (FCV) involved in the California Fuel Cell Partnership demonstration program. Since these vehicles are not yet in volume production, and changes are likely, the Partnership is planning to renew this guide on a yearly basis (or as needed) until manufacturers are building fuel cell vehicles for mass production.

Many of these FCV are currently being tested on public roads at the California Fuel Cell Partnership in West Sacramento, California. Vehicle manufacturers, energy providers, fuel cell technology companies, and the state of California have teamed up to demonstrate the technology and its fuels, and to explore commercialization challenges.

The Partnership is working towards another common and highly important goal: Fuel Cell Vehicle Safety. This document is a step towards that goal and is intended to be a supplement to established emergency response guides and educate Emergency Responder personnel on the important safety characteristics of this new and promising technology.

The Safety Team at the CaFCP created this document. Collaborators also include the Office of the California State Fire Marshall as well as the West Sacramento and Richmond Fire departments. Many thanks go out to all those who were involved.

Jesse M. Schneider

Senior Mechanical Engineer
DaimlerChrysler RTNA
CaFCP Safety Team Co-Chair (lead)
CaFCP ER Guide Team Chair

Catherine Dunwoody

CaFCP Executive Director

Justin Ward

Mechanical Engineer
Toyota Technical Center
CaFCP Safety Team Co-Chair

Reste Bevilacqua

CaFCP Safety Advisor
Bevilacqua-Knight, Inc.

II. The California Fuel Cell Partnership

The California Fuel Cell Partnership is a collaboration of automotive companies, fuel providers, fuel cell technology companies, and government agencies that are placing fuel cell electric vehicles on the road in California. Governor Gray Davis formally announced this path-breaking venture in April 1999.

The partners include twenty companies and organizations from around the world: DaimlerChrysler; Ford; General Motors; Honda; Hyundai; Nissan; Toyota; Volkswagen; Ballard Power Systems; UTC Fuel Cells; BP; ExxonMobil; Shell Hydrogen; ChevronTexaco; the California Air Resources Board; the California Energy Commission; the South Coast Air Quality Management District; the U.S. Department of Energy; the U.S. Department of Transportation and the U.S. Environmental Protection Agency.

Additionally, there are nine Associate Partners who assist with specific areas of expertise to help meet the Partnership's goals: Hydrogen gas suppliers (Air Products and Chemicals, Inc. and Praxair); "satellite" hydrogen fueling providers (Pacific Gas & Electric, Proton Energy Systems, Inc., and Stuart Energy Systems); a methanol fuel supplier (Methanex); and bus transit companies (AC Transit, Santa Clara Valley Transportation Authority, and SunLine Transit Agency).

These members are voluntarily working together to achieve a common vision—preparing to commercialize the fuel cell vehicle technology of the 21st Century. Together, the Partnership expects to place up to 60 fuel cell passenger cars and fuel cell buses on the road by 2003.

The Partnership is demonstrating fuel cell electric vehicles in California through 2003 under day-to-day driving conditions. The facility headquarters in West Sacramento, California, houses vehicle maintenance bays, a hydrogen fueling station and a methanol fueling station. Additional satellite fueling stations will be installed and operated in various locations in the state.

The Partnership is exploring the path to commercializing fuel cell electric vehicles by examining such issues as: fuel infrastructure requirements; hydrogen station; vehicle and fuel safety; market incentives; and consumer acceptance.

The Partnership will increase public awareness of fuel cell vehicle technology and the benefits it can offer through a number of outreach tools, including hands-on exhibits, vehicle demonstrations and school presentations.

Currently, the CaFCP is implementing its on-road operations program with 15 light duty FCV on site, including deployment of a fueling infrastructure. A jointly supported, comprehensive study was completed last year, “Bringing Fuel Cell Vehicles to Market: Scenarios and Challenges with Fuel Alternatives”. Recently, the partnership added a methanol fueling station at its headquarters facility.

Further information can be found on the CaFCP website: www.cafcp.org.

The Partnership’s Goals

Through 2003, the Partnership seeks to:

- Demonstrate fuel cell technology by operating and testing vehicles on California’s roads
- Demonstrate alternative fuel infrastructure technology
- Explore the path to commercialization
- Increase public awareness through a coordinated outreach plan

By the end of 2002, the CaFCP will announce specific plans to continue these programs through 2007.

CaFCP ER Guide Disclaimer:

Vehicle specific information within this guide is property of the individual vehicle manufacturer(s) and should not be used without prior consent. In order to contact a specific vehicle manufacturer, to obtain permission to copy or reference this information, contact the California Fuel Cell Partnership at the website listed above.

III. Fuel Cell Definition

What Is a Fuel Cell?

A fuel cell is an electrochemical device in which the energy of a chemical reaction is converted directly into electricity. Unlike an electric cell or battery, a fuel cell does not run down or require recharging; it operates as long as the fuel and an oxidizer are supplied continuously from outside the cell.

Fuel cells have captured worldwide attention as a clean power source for electric vehicles (EVs). EVs powered by fuel cells are being developed by numerous auto manufacturers, and have generated interest and enthusiasm among industry, environmentalists, and consumers.

The invention of the fuel cell is credited to Sir William R. Grove in 1839. His fuel cell used a dilute sulfuric acid as the electrolyte, oxygen as the oxidizing agent, and hydrogen as the fuel. Until recently, their use has been confined to the laboratory and to exotic applications such as space travel. Phosphoric Acid fuel cells were used for the Apollo program and are being used on the space shuttle.

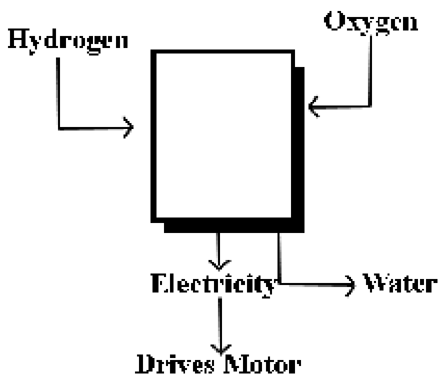
Today, over half of all U.S. air pollution is generated by "mobile sources," principally cars. Because of increasing auto use, attempts to further clean up the internal combustion engine have not successfully reduced the automobile's impact on air quality. This problem could be solved through the commercialization of zero-emission fuel cell-powered electric vehicles.

Since the hydrogen fuel (combined with oxygen from air) is converted directly into electricity instead of combustion, a fuel cell can operate at much higher efficiencies than internal combustion engines, extracting more energy from the same amount of equivalent fuel. The fuel cell itself has no moving parts—although there are sometimes external moving parts in the system—making it a quiet and reliable source of power.

How Does a Fuel Cell Work?

An individual fuel cell consists of two electrodes, one positively charged (cathode) and one negatively charged (anode), with a substance that conducts electricity (electrolyte) sandwiched between them. Oxygen from the air passes over the cathode and hydrogen over the anode, generating electricity and water. Using a catalyst on the membrane, usually platinum, optimizes this electrical process. The type of fuel cell mostly used in passenger vehicles is a Proton Exchange Membrane (PEM), due to its relatively low operating temperature and efficiency.

A Fuel Cell at Work



The hydrogen fuel for a fuel cell EV can be supplied in several ways. Some vehicles carry a pressurized tank of pure gaseous hydrogen, and some vehicles carry liquefied hydrogen. Others could be equipped with a "fuel reformer" that converts hydrocarbon fuels—such as methanol, natural gas, or gasoline into a hydrogen-rich gas.

Individual fuel cells must be combined into groups called fuel cell stacks in order to achieve the necessary power required for motor vehicle applications. These stacks are combined with control and safety systems to make a reliable and safe vehicle.

Benefits of Fuel Cell EV

A fuel cell EV, powered by an electric motor, promises the air quality benefits of a battery-powered EV, combined with the driving range and convenience of a conventional gasoline engine. Compared to conventional vehicles, fuel cell EVs can offer:

- Zero or near-zero smog-forming emissions
- Reduced water pollution from oil leaks
- Lower greenhouse gas emissions (CO_2)
- Higher fuel economy
- Greater engine efficiency
- Much quieter and smoother operation

If renewable forms of energy are used as a source for hydrogen, fuel cell EVs will have truly zero emissions from “well to wheel.”

There are also many FCV “hybrids” with electrical storage onboard. Similar to IC “hybrids,” these vehicles optimize the power range of the fuel cell system and recover energy during braking, when the electric motor is converted into a generator, thereby charging the onboard battery/ ultra capacitor. This increases overall efficiency of the vehicle.

In a FCV, there are two major systems that an emergency responder should be aware of: (1) hydrogen high (and low) pressure systems and (2) high (and low) voltage systems. The following sections explain how these systems operate under normal conditions and under impact/ fire situations.

IV. Hydrogen Information for Fuel Cell Vehicles

General Hydrogen Information

The molecular symbol for hydrogen is H_2. Hydrogen is a colorless, odorless, tasteless, non-corrosive, and flammable gas. It is also the lightest-weight gas. Since hydrogen is lighter than air, it rises and does not "pool" on the ground like gasoline, diesel, or propane fuel vapors. Gaseous hydrogen (GH_2) and liquid hydrogen (LH_2) diffuse rapidly in air.

Hydrogen gas is nontoxic but may induce suffocation (asphyxiation) if the oxygen is displaced in a confined space (similar to nitrogen or helium). Additional health hazard data are given in the hydrogen Material Safety Data Sheets (MSDS). Another reference is the Sourcebook for Hydrogen applications by the DOE/ NREL.

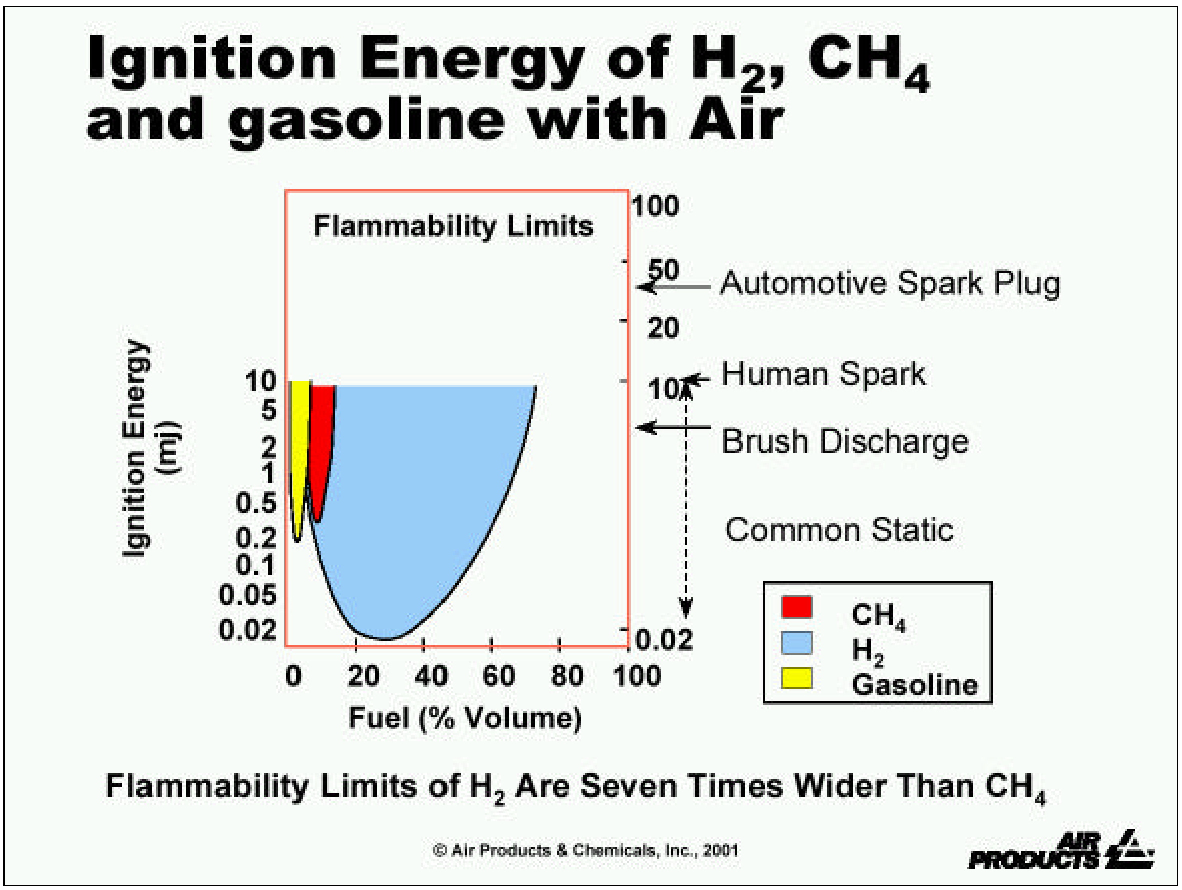


Figure 1: Flammability Limits vs. Ignition Energy of H_2, CH_4, and Gasoline in Air

Figure 1 relates the ignition energy required to ignite a fuel mixture to the upper and lower flammability limits (UFL and LFL, respectively) of hydrogen, gasoline, and methane (CH4). For hydrogen to ignite, the percentage of fuel in the air needs to be both within the UFL and LFL. Additionally, an ignition source with enough energy must be present (i.e., the energy level should be on or above the curve for each gas). In a confined space, a hydrogen-air concentration within this flammable range can be explosive. It should also be noted that H_2 burns with an invisible or near invisible flame.

As depicted in Figure 1, the LFL for Hydrogen (4%) is actually higher than Gasoline (1%). This means, it requires a greater percentage of H_2 in the air than gasoline to ignite. However, hydrogen has a wider flammability range (% in air) than Methane (CH_4) or Gasoline. One can also see from the figure that a variety of ignition sources can ignite a hydrogen-air mixture, sometimes as low as common static if it occurs in the proper mixture percentage. Note that the LFL for methanol (not shown) is 6%, which is higher than hydrogen.

For further information, reference the website www.airproducts.com/productstewardship.

Ignition Sources

In the case of a release, care should be taken to eliminate sources of ignition. Ignition sources can include open flames, mechanical sparks, electrostatic discharges, sparks from electrical equipment, and welding and cutting operations. Care should also be taken not to have any of these sources of ignition near the hydrogen vent stack (see ER Diagram for individual vent stack/PRD location). However, if Hydrogen is released in a PRD event, all of the fuel will be evacuated in a short amount of time (see section VIII).

Stored Hydrogen Systems

Compressed Hydrogen

Compressed Hydrogen (CH_2) is generally stored in Type 3 or Type 4 pressure vessels or tanks, which are stronger than conventional gasoline tanks. A Type 3 Tank is an aluminum-lined tank with carbon fiber wrapped on the outside. The Type 4 tank has a polymer lining (typically polyethylene) with a carbon fiber wrap. The carbon fiber provides additional strength for these type of vessels.

The pressure level depends on the tank system/ vehicle type and is currently at 3600 or 5000 psi (250 or 350 bar) and in the near future may be up to 10,000 psi (700 Bar). These tanks have been extensively tested for structural integrity in order to not leak hydrogen in the event of an impact.

In the unlikely event of a tank system failure, the hydrogen will be released, usually within a few minutes, by a pressure release device (PRD/TRD) or Temperature Release device through the vent stack (see ER Diagram for individual vent stack/PRD location). In this case a loud hissing sound usually indicates the pressure release (reference H_2 release indicators). Remain clear of the release area if there are indicators present. This is especially important if the vehicle is in or near a fire.

WARNING!

A controlled pressure release through a PRD can ignite into a concentrated flame for a short period (reference text).

Emergency response personnel should keep a designated distance away from the immediate area [refer to DOT emergency response guide regarding this distance], and protect surrounding exposures with hose streams until the gas completely vents to the atmosphere.

Liquid (Cryogenic) Hydrogen

Liquid Hydrogen (LH_2) is stored at –423°F (-253°C). The fuel storage cylinders are typically made of stainless steel and stronger than gasoline tanks. Cryogenic LH_2 cylinders have a tank within a tank to form a thermos-like insulating protection to reduce the rate of the boil-off of the LH_2. The space between the inner and outer tank is vacuum-sealed.

Ice frost or ice crystals on the outside of the cylinder could indicate an unlikely inner cylinder failure. In this case the LH_2 would begin to boil off into a vapor and the pressure relief valve would expel excess hydrogen gas through a vent stack to the atmosphere (see ER Diagram for individual vent stack location). Emergency response personnel should evacuate the immediate area [refer to DOT emergency response guide regarding the distance for evacuation area], and protect surrounding exposures with hose streams until the gas completely vents to the atmosphere.

Venting liquid hydrogen may be indicated by a white cloud, formed by condensed water vapor in the ambient air. These clouds may—because of the higher density of cold gases—move horizontally or even downwards and contain some cold hydrogen gas. The extent of the H_2 cloud may reach beyond the visible portion of the cloud. However this hydrogen will warm up within seconds and quickly disperse upwards. It is recommended to stay "upwind" of such clouds and remove ignition sources. Although ignition sources may not be present at the leak or spill location, fire could occur if the flammable mixture comes into contact with an ignition source.

WARNING for LH_2 Vehicles!

Never spray water on the **LH_2** vent stack. It may freeze and hinder the pressure relief. Excessive pressure may then rupture the tank and release hydrogen (See ER Diagram for each individual vehicle).

Health Concerns—LH_2

LH_2 poses a frostbite hazard (cryogenic burns) if it comes in contact with skin [refer to DOT emergency response guide]. Additionally, in case of emergency release super-cooled components, such as PRDs, pipes, valves, can 'burn' the skin with contact. The cryogenic temperature of released liquid hydrogen can liquefy ambient air, which can cause the same frostbite hazard as the liquid hydrogen. It is more likely to get in contact with condensed (liquid) air than it is with liquid hydrogen. Always wear eye protection and gloves made of appropriate protective material to protect your skin against frostbite hazard caused by LH_2 or spilling liquefied air. Please refer to the MSDS Sheets and the DOT Emergency Response manual when dealing with liquid hydrogen.

WARNING!

Liquefied air must not be allowed to drip on combustible materials such as tar and asphalt. In this case an explosive mixture can be created because of the high oxygen content of condensed air (up to 50%). Even a very small energy amount may ignite such a mixture.

Hydrogen Delivery Systems

Low Pressure Hydrogen System

A fuel cell system operates at a much lower pressure than the hydrogen storage tanks. High pressure hydrogen is generally reduced with a pressure regulator to below 70 Psi (5 Bar). This lower pressure hydrogen is fed into the fuel cell through hydrogen fuel lines. The hydrogen fuel lines (tubes) are generally made of stainless steel and are routed between the hydrogen tanks and fuel cell "stack." Depending on the specific FCV, there may be both high and low pressure lines located in the vehicle. Reference each manufacturer's Diagram for locations of the hydrogen tank and lines.

When the vehicle is turned off, the high-pressure hydrogen system is isolated (illustrated as Pink with cross-hatch in ER diagram) and cannot flow. There may be a small amount of low-pressure hydrogen left in the fuel lines.

Note—Some vehicles have an external (outside of tank) pressure regulator—see individual ER diagram for location.

V. Methanol Information for Fuel Cell Vehicles

General Methanol Information

The molecular symbol for methanol is CH_3OH. Methanol is a colorless, alcohol that has a faint odor. Methanol is used directly in solvents, paints, inks, resins, and windshield washer fluid. It is also used as fuel for both racecars and Fuel Cell Vehicles. Most vehicles at the CaFCP are either compressed or liquid hydrogen, but there is are some partners working on Methanol FCVs (reference note in lower left hand corner of ER Diagram for fuel type).

Methanol Reforming

For FCV's, methanol is converted to hydrogen with an onboard "reformer." This reformer "Cracks" the methanol and converts into hydrogen by steam reforming process. The hydrogen is fed into the fuel cell stack in the same way as compressed hydrogen FCV. For further information in regards to hydrogen low pressure systems, refer to hydrogen information.

Flammability Characteristics

Methanol is a flammable liquid and is rated as a Class 1B flammable liquid by the National Fire Protection Association—the same rating as gasoline. (See flammability limits for in section IV.)

One important characteristic of methanol is that, under daylight conditions, an uncontaminated methanol fire may burn with a low visibility or light blue flame. In general, methanol fires are visually detected by observing rising heat waves or when other materials ignite in the presence of a methanol fire producing flames and smoke that are more visible.

Potential ignition sources should be kept away from methanol. Reference ignition sources in section IV.

WARNING!

When responding to a methanol spill, avoid walking through the spill in case it is burning, as the flames may not be visible. If a methanol fire is suspected, look for the presence of heat waves/ above the methanol spill and deal with the fire hazard accordingly

Health Concerns

There are key health risks associated with methanol exposure and how to respond to an exposure. The three pathways of methanol exposure are inhalation, ingestion and skin and eye contact. For further information, reference the Methanol MSDS form.

VI. Low and High Voltage System Information for FCV

12V/ High Voltage Delivery and Storage Systems

In a FCV there is a standard 12V battery as well as a secondary high voltage system. The conventional 12V battery is used primarily in startup and running accessories.

The high voltage delivery system, which originates from the fuel cell, is between 200–400V. This system powers the electric motor, cooling system, etc. and can be identified by orange cables. In some vehicles there is an additional high voltage storage device in the form of batteries or ultra capacitors that is used to store electrical energy (improve the efficiency of the vehicle). Reference the ER FCV Diagram for each vehicle manufacturer for locations of the high voltage delivery systems.

When a vehicle is turned off, the High Voltage delivery system is deactivated, although it may take up to a few minutes for the electric motor to completely discharge (see individual ER diagram). During this time, only the high voltage storage system (shown as Orange WITH cross-hatch) retains an electric charge.

VII. Vehicle Safety Systems

In the event of an accident/hydrogen detection:

There are many safety systems in the prototype hydrogen FCVs. These systems work independently and in conjunction to ensure the safety of the occupant and their surroundings. The sensors disable (isolate) both the high voltage and hydrogen storage systems in the event of an impact, or hydrogen detection. A summary of these systems are:

- **Hydrogen Sensor(s)—**These sensors detect hydrogen leakage. If a hydrogen leak is detected, the hydrogen storage system and electrical systems will be isolated.

- **Impact Sensors—**These inertia-based sensors detect a vehicle impact. In the event of an impact the hydrogen storage and electrical system will be isolated.

- **Pressure (or Thermal) Release Device—**If there is a fire near the vehicle's hydrogen storage system, this device is designed to release the hydrogen (in a controlled manner) in the tank to the atmosphere through a special vent (see individual ER diagrams for vent locations). The purpose of this device is to prevent a hydrogen tank explosion due to extreme pressure build-up. This device will activate (open) if there is a significant pressure or temperature build-up near the tank, which can occur when the tank is exposed to significant heat (i.e., a fire). This device in effect functions as a fusible plug, which opens a valve at a rated temperature/ pressure. This event is characterized by a “hissing” sound, which is the sound of the hydrogen rapidly venting from the PRD vent orifice. At this time, stay well away from the vent area. This jet stream of hydrogen gas could ignite. Refer to the Indicators Section.

  Note: a PRD and TRD have the same function and achieve the same goal, however the PRD detects a pressure rise, while the TRD detects temperature rise.

- **Emergency Shutoff Button—**Some prototype FCVs have a manual shutoff switch in vehicle which gives the passenger/driver an additional way to shut down the vehicle and isolate the hydrogen storage and electrical storage systems. Reference the individual shut-down procedure.

VIII. Passenger Rescue/ Extrication

Before attempting to rescue occupants from a disabled or damaged Fuel Cell Vehicle or trying to move a damaged vehicle, it is important to make sure that the system is no longer running and that there are no indicators of a PRD/TRD release. Refer also to the Section below: PRD/TRD Indicators. In addition, refer to the "Manual Shut-down" procedure in the following pages for directions on how to manually "turn off" each L.D. FCV at the CaFCP.

If extrication of a passenger is necessary, standard procedure is to be followed, but additional care is to be taken into consideration for the hydrogen and electrical systems. If there is a need to cut into the vehicle to remove an occupant, make sure of the following:

- Manual shut-down procedure is followed
- If any cutting into a FCV is required, (with a Hurst Tool, etc.) caution should be taken to avoid critical components of the fuel cell system. Critical Components are defined as the hydrogen storage system and high voltage electrical storage. Any "Cross-hatched area" in the diagram should not be cut under any circumstances (i.e., vent stack, etc.). Details of each vehicle are to be found in the ER Vehicle Diagrams.
- In the case of an impact and/or a vehicle fire, approach a FCV **away** from the location of the PRD/TRD vent as indicated in the FCV diagrams. Do not stand near or in the stream of a PRD/TRD event. This is especially important if the vehicle is on fire.

⚠ WARNING:

The high voltage storage (Orange with crosshatch) should **not** be cut for any reason. After following the manual shutdown procedure, if necessary, the high voltage delivery system (Orange WITHOUT crosshatch) can be cut only if necessary. Please refer to the individual ER Diagram before making such decision, as it may be necessary to wait a few minutes for the system to discharge. If this procedure is not followed, electric shock can result.

WARNING:

The hydrogen storage tanks (Pink with crosshatch) should never be cut into in the event of an emergency. After following the manual shutdown procedure, if necessary, some of the low pressure Hydrogen lines (PINK without crosshatch) can be cut with caution. Please reference the individual Fuel Cell Vehicle diagrams. If this procedure is not followed, a hydrogen release is possible.

Location/Environment

As in all vehicle emergencies, position responding apparatus uphill, upwind, and away from the H_2 vent direction of a fuel cell vehicle accident whenever possible. Staying uphill from the accident is recommended for hybrid or Methanol FCV in order to keep emergency response personnel and equipment away in the case of from spilled electrolyte and/or methanol. With vehicle fires, staying upwind and away from H_2 vent will keep personnel from operating in toxic smoke and fumes and to avoid being in the path of PRD release. Follow the standard vehicle approach method (45 degree approach angle) taking into account the direction of the vehicle's PRD or TRD. Reference individual ER Diagram for location of vent.

Responding to Accidents

Non-Injury Accidents

For these emergencies protective clothing is recommended (i.e., out pants, jacket, boots, gloves, and helmet with face shield). Reference Equipment Recommendations for FCV Hazards. This provides the firefighting personnel with the essential protection necessary when responding to all vehicle accidents. Do not wear jewelry, rings, necklaces, or watches, as all of these items are highly conductive. Hydrogen leak detectors, if available, should be used to check for system leaks.

Catastrophic Accidents and Vehicle Fires

For these emergencies full protective clothing is recommended (IE turnout pants, jacket, boots, helmet, and SCBA). Personnel working directly with the vehicle should also be equipped with high voltage rubber gloves and use static dissipative equipment. These recommendations provide firefighting personnel with the essential protection necessary from the potential of electric shock, flammable/explosive gas, and hazardous fumes encountered during rescue. UV detectors, if available, should be used to scan for invisible hydrogen flames. If no flames are present the vehicle should be scanned with a hydrogen leak detector, if available.

IX. Hydrogen Release Indicators

As mentioned previously, a FCV is designed to be as safe or safer than conventional vehicles. In the event of an impact, the high voltage and high pressure hydrogen systems are deactivated through an impact sensor similar to those used in an airbag. But, as an added measure it is recommended that the "manual shut-down" procedure be carried out.

Extra care should be taken if there is a vehicle fire or an audible hissing sound coming from the vehicle, as there exists the possibility that the hydrogen will be released through a controlled PRD/ TRD event (for a short amount of time).

Below is a list of hydrogen release indicators:

Compressed Hydrogen PRD/TRD Release

- A loud hissing sound usually indicates a PRD/TRD release.
- An invisible pressurized gas jet will emanate from the vent stack in the event of a PRD release.
- This release can ignite into a concentrated flame stream. Hydrogen burns with a flame that may be invisible depending on the environmental conditions.

Liquid Hydrogen Leak

- Fog or cloud formed around the (cryogenic) hydrogen storage tank. Please note that the actual Hydrogen vapors may extend outside the visible cloud area.
- Ice Crystals formed around the storage Tank.

Note—sometimes frost can be apparent around the fuel lines with no leak being present.

X. Equipment Recommendations for FCV Accident

Standard Equipment Recommendations

- Turnout Pants
- Turnout Jacket
- High Voltage Boots
- High Voltage Gloves
- Helmet and Face Shield
- Self-Contained Breathing Apparatus (SCBA)
- Insulated Hand Tools

Special Equipment Recommendations

The following equipment can be helpful in fuel cell vehicle emergencies but are not required:

Static dissipative clothing and equipment are recommended.

Garments should meet or exceed the following standards:

- NFPA 70E
- NFPA 1975
- ASTM F1506-98
- OSHA Final Rule 1910.269
- Typically constructed of Nomex IIIA

To detect hydrogen/methanol fires:

UV Optical Sensor
(IR sensors typically are better suited for hydrocarbon fires)

If the above is not available:

Long Handle Broom
(The bristles should be made of a material that is easily ignited but does not release toxic fumes when burning, for example corn straw brooms.)

Hold the broom in front of you as you slowly approach the vehicle. It will ignite when passed through a hydrogen fire.

To detect hydrogen leaks (prioritized starting with the most effective sensor):

Thermal Conductivity Sensor
(Functions well in stable air environments with minimal temperature variations)

Or

Catalytic Combustion Sensor
(typically used by HAZMAT teams)
(Functions well for detecting 0 to 4 % H_2 in air, but not hydrogen specific)

Or

Electrochemical Sensor
(Exposure to cryogenic or time varying temperatures can make sensor unreliable)

For additional Information:

Reference the aforementioned documents/ DOT Emergency Response Guidebook and Emergency Response to Electric Vehicles.

XI. Common Format for ER Diagram:

Color Key

High Voltage Wires/Components—**Orange**

- Cross-hatch (vertical) high voltage storage system (i.e., high voltage battery, super capacitor)

Low and High Pressure Hydrogen storage, lines, components—**Pink**

- Cross-hatch (45 degrees) hydrogen high pressure system (i.e., hydrogen tanks, external regulators)

Emergency Electrical/ H2 Shutoff/ 12V Battery—**Red**

Items Included in Diagram

- Vent locations and flow direction
- Hydrogen Tanks
- Hydrogen lines (low and high pressure)
- Hydrogen Regulators (if external)
- H_2 Shutoff Valve (if applicable)
- All high voltage lines
- Electric Motor
- DC-DC Converter
- Fuel Cell Stack Location
- 12V Battery (location of a safe place to cut 12V Lines)
- Super capacitor/ High Voltage Battery locations

- H_2 Filling neck/ lines
- Key Shut off and Master Turn off Switch Location
- PRD (Pressure Release Device) Release Location
- Identify Front and Rear Vehicle Locations
- MSDS reference of High Voltage Storage
- Methanol/Gasoline/ Sodium Boro-hydride Tank & Fuel Line Location

All diagrams include a picture of vehicle's actual component diagrams or representative diagrams to scale**.** A common key format is located on upper left hand portion of each diagram. Each diagram shows ***side*** view and ***top*** view.

****Please note, the LH_2 and CH_2 MSDS Sheets are included in this document. Please reference external MSDS sheets if required.***

XII. Fuel Cell Vehicle Technical Terminology

ACTIVATION

- Chemical. Treatment of a substance by heat, radiation, or other activating reagent to produce a more complete or rapid chemical or physical change.
- Electrical. The process of treating a cathode to increase its rate of reduction.

ANODE

The negative electrode at which oxidation occurs.

AUXILIARY POWER

Power from an independent source that functions as required to augment/support various performance criteria established for the prime power source.

BIPOLAR PLATES

Conductive plate in a fuel cell stack, which acts as an anode for one cell and a cathode for the adjacent cell. The plate may be made of metal or a conductive polymer (which may be a carbon-filled composite). The plate usually incorporates flow channels for the fluid feeds and may also contain conduits for heat transfer.

BLOWDOWN

The difference between the opening and closing pressures of a relief/safety valve.

BLOWER

A fan used to force air and/or gas under pressure.

BOOST REGULATOR

Voltage conversion device used to raise the voltage in a DC system.

CH_2 or CH_2

Abbreviation for Compressed Hydrogen (**H_2**)

CATALYST

A chemical substance that increases the rate of a reaction without being consumed; after the reaction it can potentially be recovered from the reaction mixture chemically unchanged. The catalyst lowers the activation energy required, allowing the reaction to proceed with more quickly or at a lower temperature.

CATHODE

The positive electrode at which reduction occurs.

CIRCUIT, SAFETY-CONTROL

A circuit or portion thereof involving one or more safety controls in which failure due to grounding, opening or shorting of any part of the circuit can cause unsafe operation of the controlled equipment.

COMPRESSOR

A device used for increasing the pressure and density of gas.

CONTROLS

Devices designed to regulate the gas, air, water or electrical supplies to the controlled equipment. These may be manual, semi-automatic, or automatic.

- <u>Limit</u>: A control, which automatically responds to, changes in temperature, pressure, flow, or level for limiting the operation of the controlled equipment. This device is not considered an operating control.

- <u>Operating</u>: A control, other than a safety control or interlock, to start or regulate equipment operation according to load demand and to stop or regulate equipment operation on satisfaction of demand or upon reaching normal temperature or pressure in the equipment being operated. An operating control also may actuate auxiliary equipment.

- <u>Safety</u>: Automatic controls and interlocks (including relays, switches, and other auxiliary equipment used in conjunction therewith to form a safety-control system) which are intended to prevent unsafe operation of the controlled equipment.

CRYOGENIC LIQUID

A refrigerated liquefied gas having a boiling point colder than –90°C (-130°F) at 101kPa (14.7 psia) absolute (source DOT 49 CFR 173.115). Hydrogen is liquid at –253°C (-423°F) at atmospheric pressure.

DIFFUSION

Movement of a species under the influence of a gradient of chemical potential (i.e., a concentration gradient).

DRIVETRAIN

The elements of a propulsion system, such as the motor, transmission, axle and wheels that produce and transmit mechanical power to the drive wheels of a vehicle.

ELECTRODE

An electric conductor through which an electric current enters or leaves a medium, whether it be an electrolytic solution, solid, molten mass, gas, or vacuum.

ELECTROLYTE

A non-metallic electrical conductor in which current is carried by the movement of ions.

EXTRICATION

The act of releasing or removing by untangling or unsnarling someone from an accident vehicle.

FCV

The acronym for "Fuel Cell Vehicle".

FLAMMIBLE (EXPLOSIVE) LIMITS

For gases or vapors, which form flammable mixtures with air or oxygen, there is a minimum concentration of vapor in air or oxygen below which propagation of flame does not occur on contact with a source of ignition. There is also a maximum concentration of vapor or gas in air above which propagation of flame does not occur. These boundary-line mixtures of vapor or gas with air, which if ignited will just propagate flame, are known as the "lower and upper flammable limits" (LFL and UFL) or the "lower and upper explosive limits" (LEL and UEL), and are usually expressed in terms of percentage by volume of gas or vapor in air. LEL and LFL are different terms for the same concept and can be used interchangeably. A mixture below the lower flammable limit is too "lean" to burn or explode and a mixture above the upper flammable limit too "rich" to burn or explode.

FUEL CELL

An electrochemical device, which can continuously convert the chemical energy of a fuel and an oxidant to electrical energy. The fuel and oxidant are typically stored outside of the cell and transferred into the cell as the reactants are consumed.

FUSIBLE PLUG

A device which opens and keeps open a relief vent by the melting or softening of a fusible plug or cartridge at a predetermined temperature.

GH_2 or GH_2 or GHY

Abbreviation for gaseous Hydrogen.

GROSS POWER

The fundamental power output of an energy source prior to any conditioning and losses associated with the production of power suitable for the connected load.

GROSS VEHICLE WEIGHT(GVW)

A manufacturer's rating for maximum vehicle operating weight.

HEAT EXCHANGER

A vessel in which heat is transferred from one medium to another.

IDLE POWER

The system rate of doing work when only the minimum work rate is employed by the system.

IDLE TIME

The time when a system is capable of but not producing power; startup time

INTERLOCK

A control to prove the physical state of a required condition and to furnish that proof to the safety shutoff device circuit.

LH_2 or LHY or LH_2

Abbreviation for Liquid or Cryogenic Hydrogen (**H_2**).

LOAD-FOLLOWING

A mode of operation where fuel cell power plant is generating variable power depending on the ac load demand.

LOCATION, HAZARDOUS (CLASSIFIED)

Any area or space where combustible dust, ignitable fibers, or flammable, volatile liquids, gases, vapors or mixtures are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures.

LOWER EXPLOSIVE LIMIT (LEL)

The lowest concentration of a flammable gas/vapor in air in which flame is propagated if ignited.

MEMBRANE

The separating layer in a fuel cell, which acts as electrolyte (a cation-exchanger) as well as a barrier film separating the gases in the anode and cathode compartments of the fuel cell.

MEMBRANE ELECTRODE ASSEMBLY (MEA)

Structure consisting of a proton-exchange membrane with surfaces coated with catalyst/carbon/binder layers and sandwiched by two microporous conductive layers (which function as the gas diffusion layers and current collectors).

OPEN CIRCUIT VOLTAGE

The voltage at device terminals when no appreciable current is flowing. Also known as no load voltage.

OPERATING PRESSURE

The variable pressure at which a system operates in response to changes in various operating conditions.

OPERATING PRESSURE, MAXIMUM

The steady-state gauge pressure at which a part or system normally operates. It shall not exceed the allowable working pressure, and it is usually kept at a suitable level below the setting of pressure-limiting/relieving devices to prevent their frequent functioning.

ORIFICE

The opening in an orifice cap, orifice spud or other device whereby the flow of gas is limited and through which the gas is discharged.

PASSIVE STATE

A state for the fuel cell internal components normally entered when the power plant is purged with steam, air or nitrogen, or per the manufacturer's instructions when the power plant is turned off or prior to when the power plant is turned on (initialization).

PRD

The acronym for “Pressure Relief Device”. (Also see VALVE, RELIEF)

PRESSURE

The force exerted against an opposing body or the thrust distributed over a surface, expressed in weight per unit of area.

- Absolute: The pressure above zero pressure, the sum of the atmospheric and gauge pressures.

- Atmospheric (Standard): The pressure of the weight of air and water vapor on the surface of the earth at sea level, namely 29.92 inches (760 mm) mercury column or 14.69 pounds per square inch (101.3 kPa).

- Barometric: The atmospheric pressure as determined by a barometer, usually expressed in inches (mm) of mercury.

- Gauge: The pressure above atmospheric pressure.

- Vacuum: Any pressure less than that exerted by the atmosphere.

PROTON EXCHANGE MEMBRANE (PEM)

A membrane with the ability to transport protons (H^+) from the anode to the cathode in a fuel cell.

PURGE

To free a gas conduit of air, gas or a mixture of air and gas.

RATED POWER

The value stated on the generator nameplate. It is the power available at the output terminals of a component or piece of equipment that is operated in compliance with the manufacturer’s performance specifications.

REFORMER

A vessel within which fuel gas and other gaseous recycle stream(s) (if present) are reacted with water vapor and heat, usually in the presence of a catalyst, to produce hydrogen rich gas for use within the fuel cell power plant.

REFORMATE GAS

The fluid which exits the fuel reformer and acts as feed to the fuel cell stack.

REGENARATIVE BRAKING

The recovery of some fraction of the energy normally dissipated in braking into energy that can be used or stored.

REGULATOR, PRESSURE

A device placed in a gas line for reducing, controlling and maintaining the pressure in that portion of the piping system downstream of the device.

SHUTDOWN, SAFETY

The action of shutting off all fuel and ignition energy to the gas utilization equipment by means of a safety control or controls such that restart cannot be accomplished without manual reset.

SPECIFIC GRAVITY

The ratio of the weight or mass of a given volume of a substance to that of an equal volume of another substance (air for gases, water for liquids and solids) used as a standard, both measured under the same conditions**.**

STANDARD ATMOSPHERE

A standard unit of atmospheric pressure, defined as that pressure exerted by a 760-millimeter column of mercury at standard gravity (980.665 centimeters per second per second) at temperature 0 degrees C.

THERMAL EFFICIENCY

Efficiency with which a power source transforms the potential heat of its fuel into work or output, expressed as the ratio of the useful work done by the power source in a given time interval to the total heat energy contained in the fuel burned during the same time interval, both work and heat being expressed in the same units.

TRD

The acronym which stands for “Temperature Relief Device”. (Also see FUSIBLE PLUG)

VALVE, RELIEF

A safety valve designed to forestall the development of a dangerous condition by relieving either pressure, temperature or vacuum.

- <u>Pressure</u>: A valve which automatically opens and closes a relief vent, depending on whether the pressure is above or below a predetermined value.
- <u>Temperature</u>: A valve which automatically opens and closes a relief vent, depending on hether the temperature is above or below a predetermined value.

VENTILATION

The natural or mechanical process of supplying conditioned or unconditioned air to, or emoving such air from any space.

VENTILATION, PROPER

In general, the dilution of a flammable gas/vapor with air to a point safely below its lower explosive limit (LEL). As applied to this standard, a sufficient or adequate supply of fresh air and proper exhaust to outdoors or to a safe location with a sufficiently-vigorous and properly distributed air circulation to ensure that the flammable gas/vapor concentration in all parts of the enclosure will be below 25 percent of the LEL at all times.

XIII. Appendix

This section displays vehicle shut down instructions and diagrams for common FCV types.

XIV. Bibliography

Chang, E., M. Rawson, and R. Slaughter. *Emergency Response to Electric Vehicles*. California Department of Forestry and Fire Protection, Office of the State Fire Marshal. September 1997

Ordin, P. et al. Safety Standards for Hydrogen and Hydrogen Systems, Guidelines for Hydrogen System Design, Materials Selection, Operations, Storage, and Transportation. National Aeronautics and Space Administration. NSS 1740.16. February 1997

2000 Emergency Response Guidebook, developed jointly by Transport Canada, the U.S. Department of Transportation, and the Secretariat of Transport and Communications of Mexico, 2000

Rodney Slaughter, *Emergency Response to Natural Gas Vehicles*, California Office of Traffic Safety, California Energy Commission, California Natural Gas Vehicle Coalition, January 2003

XV. Reference Documents