Methods of hydrogen and fuel cells operations and related hazards.

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Today’s agenda

- Introduction
- Safety Issues (high Level)
- Hydrogen Related Safety practical issues
- Q+A
FUEL CELLS’ INTRO

• Definition: electrochemical cell that converts a source fuel into an electrical current.

• The fuel cell generates electricity through reactions between a fuel and an oxidant.

Source: “HYDROGEN FUEL CELLS & ENERGY EFFICIENCY”, by Claudio Bolzoni, David Carlos Echeverria, Andres Segura, Dari Seo
Hydrogen Fuel Cells

• A hydrogen fuel cell uses hydrogen as its fuel and oxygen as its oxidant.

• It's very similar to a battery but it has its differences.

• Discovered by Christian Friedrich Schönbien in 1838
• https://www.youtube.com/watch?v=tajigZ2e6tQ
Benefits

• Reduction in burning of fuel cells
• Improvement of air quality especially in urban areas
• Reduction of greenhouse gases (global warming)
• Low noise and high power
• Reduction in energy consumption (saving energy)
Problems

- Cost
- Durability
- Hydration
- Delivery
- Infrastructure
- Storage
- Safety
Examples

• Vehicles
• Bicycles
• Rockets
• Airplanes
• Buses
• Motorcycles
• Scooters
Stationary fuel cells

- Fuel cells generate water from a fuel (such as hydrogen or natural gas) and from oxygen in the air, while producing electricity and heat.
- This reaction is carried out in each of the basic cells of the fuel cell.
- Each fuel cell consists of an **anode, a cathode, and an electrolyte** allowing the charges to move from one side to the other side of the fuel cell.
- Electrons move from the anode to the cathode through an external circuit, producing an electrical current - and thus powering the load.
- Such cells are placed in series, to reach an adequate voltage output. When assembled together, the cells constitute an energy module of the required power known as the stack.
Fuel cells types (I/II)

1. Proton Exchange Membrane Fuel Cells (PEMFC),
2. Solid Oxide Fuel Cells (SOFC) and

These fuel cells are classified according to the type of electrolyte they use.

- In **Proton Exchange Membrane Fuel Cells**, a proton-conducting membrane is used as an electrolyte. In pure hydrogen PEMFC, hydrogen is dissociated into protons H+ and electrons on the anode. Protons are conducted through the proton-conducting membrane to the cathode. As the membrane is electrically insulated, electrons move from the anode to the cathode through an external circuit, producing an electrical current. On the cathode, oxygen reacts with the electrons and protons to form water. Such fuel cells operate at **temperatures between 50 and 220°C, typically 80°C**. Other types of PEMFC also exist: some are fed with a mixture of CO₂ and H₂.

Proton Exchange Membrane Fuel Cells are preferred for mobile applications.
Fuel cells types (II/II)

- In **Solid Oxide Fuel Cells**, a ceramic material called yttria-stabilized zirconia (YSZ) is most commonly used as an electrolyte. In SOFC, oxygen gas reacts on the cathode with electrons, to form negatively charged oxygen ions. These oxygen ions move through the electrolyte from the cathode to the anode, where they react with hydrogen gas, producing electricity and water. SOFC operates at **high temperatures** (between 800 and 1000°C). They can be fed with fuels other than hydrogen gas, such as natural gas for instance. **Natural gas is then reformed (i.e. converted to hydrogen) internally.**

- In **Molten Carbonate Fuel Cells**, lithium potassium carbonate salt is used as an electrolyte. At **high temperatures** (about 650°C), this salt melts and allows for the movement of the negative carbonate ions from the electrolyte. On the anode, hydrogen reacts with carbonate ions to produce mainly water, carbon dioxide and electrons. The electrons move from the anode to the cathode, producing an electrical current. On the cathode, carbon dioxide (from the anode) and oxygen react with the electrons to form carbonate ions.

MCFC can be fed with fuels other than hydrogen gas, such as natural gas for instance. **As in SOFC, natural gas is reformed (i.e. converted to hydrogen) internally.**

Because of their high operating temperatures, Molten Carbonate Fuel Cells and Solid Oxide Fuel Cells have slow start-up times. Therefore, **they are not suitable for mobile applications and are limited to stationary applications.**
Hazards and safety measures

- **Fuel cells are low-pressure systems**: upstream the fuel cell, the hydrogen feed pressure is reduced down to low pressures (e.g. 250 mbar at the cells’ inlet of Axane’s fuel cell Comm Pac™). Therefore, stationary fuel cell systems are free from hazards related with the handling of pressurized hydrogen.
- But, since fuel cells consist of a stack of basic cells in which chemical reactions involving hydrogen are carried out, there is a risk of leaks.
- In order to avoid the formation of flammable mixtures, sensors able to detect hydrogen leaks are used. Once sensors have detected the presence of hydrogen at a concentration higher than a threshold value, isolation measures are taken.
Stationary applications: standards


Provides the minimum requirements for safety and performance of fuel cell modules.
Applies to fuel cell modules with the following electrolyte chemistry: alkaline; proton exchange membrane (including direct methanol fuel cells); phosphoric acid; molten carbonate; solid oxide fuel cell modules.
Stationary applications: standards

IEC 62282-3-100 Fuel cell technologies
Part 3-100: Stationary fuel cell power systems – Safety
Edition 1 (Revision of IEC 62282-3-1)
Applies to stationary packaged, self-contained fuel cell power systems or fuel cell power systems comprised of factory matched packages of integrated systems which generate electricity through electrochemical reactions. Is a product safety standard suitable for conformity assessment.

IEC 62282-4 Fuel cell technologies – Part 4-100: Fuel cell systems for forklift applications
Safety requirements, environmental aspects and test procedures, Edition 1 will cover safety, performance, construction, marking and test requirements and interchangeability of fuel cell systems onboard specialty vehicles other than road vehicles and auxiliary power units (APUs). However, the first edition of this document will include items applicable to forklifts. The future editions of this document will include items applicable to onboard vehicles other than road vehicles and APUs

Ad hoc group no.2 Safety aspects with respect to explosion
Stationary applications: standards

**IEC 62282-3-150** Fuel cell technologies
Part 3-150: Stationary fuel cell power systems - Small stationary fuel cell power system serving as a heating appliance providing both electrical power and useful heat with or without a peak load heating device. This standard applies to fuel cell power systems that are intended to be permanently connected to the electrical system of the customer (end user). Connection to the mains directly (parallel operation) is also within the scope of this standard

**IEC 62282-3-3** Fuel cell technologies
Part 3-3: Stationary fuel cell power systems – Installation, Edition 2
Provides minimum safety requirements for the installation of indoor and outdoor stationary fuel cell power systems in compliance with IEC 62282-3-1; applies to the installation of systems intended for electrical connection to mains directly or with a transfer switch, or intended for a stand-alone power distribution system, or intended to provide AC or DC power.
Stationary applications: standards

**IEC 62282-4** will cover safety, performance, construction, marking and test requirements and interchangeability of fuel cell systems onboard specialty vehicles other than road vehicles and auxiliary power units (APUs). However, the first edition of this document will include items applicable to forklifts. The future editions of this document will include items applicable to onboard vehicles other than road vehicles and APUs.

**Ad hoc group no.2**

Safety aspects with respect to explosion

**IEC 62282-3-1:2007** Fuel cell technologies Part 3-1: Stationary fuel cell power systems – Safety Edition 1
Indoor use of hydrogen: standards

Partially covered by ISO 62282-3-3 (Fuel Cell Technologies: Installation)

ISO/TR 15916:2004 (Basic considerations for the safety of hydrogen systems) provides guidelines for the use of hydrogen in its gaseous and liquid forms. It identifies the basic safety concerns and risks, and describes the properties of hydrogen that are relevant to safety. Detailed safety requirements associated with specific hydrogen applications are treated in separate International Standards.

ISO 26142 (for hydrogen detectors)
Indoor use of hydrogen: standards

**IEC 60079-1**, Explosive atmospheres
- Part 1: Equipment protection by flameproof enclosures “d”
- Part 2: Equipment protection by pressurized enclosures “p”
- Part 7: Equipment protection by increased safety “e”
- Part 11: Equipment protection by intrinsic safety “i”
- Part 15: Equipment protection by type of protection “n”
- Part 18: Equipment protection by encapsulation “m”

**IEC/TR 60079-20-1**, Explosive atmospheres
- Part 20-1: Material characteristics for gas and vapour classification — Test methods and data

**IEC 60079-29-1**, Explosive atmospheres
- Part 29-1: Gas detectors — Performance requirements of detectors for flammable gases
Case Study: USA DoD

Project sites

Refueling station at DDJC

Fuel dispensers at DDSP

Hydrogen tank at DDSP

Mobile refueler at DDWG
Approach

• Gather detailed cost data at each site from participating manufacturers, onsite staff, open source literature
• Compare costs of fuel cells going forward with pertinent alternatives
• Include capital and operating costs
• Analysis to cover about 10 years, real costs, no discounting
Cost Categories – Hydrogen Production

• Infrastructure depreciation
• Infrastructure O&M
• Infrastructure space
• Fuel source
  • Natural gas
  • Water
• Power (in)

In each case, comparison made to cost of delivered H2
Cost Categories - Fuel Cells

- Forklift depreciation
- Forklift O&M
- Fuel cell O&M (including spares)
- Fuel cell refueling labor time
- Hydrogen infrastructure O&M
- Infrastructure space cost
- Hydrogen (either produced or delivered)
Cost categories – Batteries & Propane

• Batteries
  • Forklift depreciation
  • Forklift O&M
  • Battery depreciation
  • Battery O&M
  • Charger depreciation
  • Charger O&M
  • Power to recharge batteries
  • Battery change labor
  • Infrastructure O&M
  • Infrastructure space

• Propane
  • Forklift depreciation
  • Forklift O&M
  • Fuel
  • Infrastructure depreciation
  • Infrastructure O&M
  • Infrastructure space
  • Refueling labor
Non-economic Factors

• Reduction in hydrocarbon emissions
• Reduction in greenhouse gas emissions
• Enhanced work productivity with fuel cells
• DoD leadership in national energy effort by creating a market opportunity for fuel cell technology
• Development of a transport option that might have value to DoD & others in the future
## Results - Comparative Costs of Hydrogen

<table>
<thead>
<tr>
<th></th>
<th>Cost of Produced H2</th>
<th>Cost of delivered H2*</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDSP</td>
<td>N/A</td>
<td>$6/kg (liquid)</td>
</tr>
<tr>
<td>DDWG (steam methane reformer)</td>
<td>$22.41/kg</td>
<td>$22.50/kg (gaseous)</td>
</tr>
<tr>
<td>JBLM (waste gas digester)</td>
<td>**</td>
<td>$8/kg (liquid)</td>
</tr>
<tr>
<td>DDJC (electrolyzer)</td>
<td>$22.20/kg</td>
<td>$35/kg (gaseous)</td>
</tr>
</tbody>
</table>

*Not counting system losses.

**Insufficient information with which to estimate H2 production cost

Conclusions from Hydrogen Production Analysis

• Going in, production of H2 from natural gas thought to be the least expensive option, but ongoing technical problems with reformer reduced the attractiveness of this option
• Producing hydrogen from waste gas is a great concept but proved difficult to implement in practice
• Production via electrolysis turned out to be economic vis a vis the cost of importing gaseous H2
  • The electrolyzer ran a high percentage of the time
  • Expensive to import gaseous H2 because of the high cost of transport
  • Experiment associated with solar voltaic production of electricity, but that was treated as a separate investment
Results – Comparative Cost of Fuel Cell & Battery Forklift sample site

<table>
<thead>
<tr>
<th></th>
<th>Fuel Cell Forklift</th>
<th>Fuel Cell Forklift with Cost Reduction Program</th>
<th>Battery forklift</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 forklifts</td>
<td>$155,104</td>
<td>$119,825</td>
<td>$68,643</td>
</tr>
</tbody>
</table>

Conclusions:

- Cost of hydrogen infrastructure plus fuel cell upkeep too high for fuel cells to be economically competitive
- Cost reductions feasible but still leave fuel cells higher cost than battery option
- Expansion of the fuel cell powered fleet would render this option more competitive with batteries
Results – Comparative Cost of Fuel Cell and Propane Forklift at JBLM

<table>
<thead>
<tr>
<th></th>
<th>Fuel Cell Forklift</th>
<th>Propane Forklift</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 Forklifts</td>
<td>$129,470</td>
<td>$76,166</td>
</tr>
</tbody>
</table>

Conclusions:

- Fuel cells are not competitive with propane at JBLM
- Propane is relatively inexpensive because it requires little onsite infrastructure
- Forklifts used too little at JBLM to justify investment in hydrogen infrastructure
- Adding the bus improves forklift economics but does not make the overall project cost effective
Overall Conclusions

• Fuel cells were not economically competitive in any of DoD’s 4 experimental projects

• However, their relative attractiveness could be increased by:
  • Raising the intensity of their use
  • Increasing the number of forklifts utilizing fuel cells at each given site
  • Downsizing H2 infrastructures to more closely accord with demand
  • Accepting more of the risk of infrastructure failure
  • Longer term contracts
  • Taking advantage of tax breaks accorded fuel cells via appropriate leasing arrangements

Hydrogen Related Safety practical issues

• Source: Millennium Reign University first respondents handbook, www.mreh2.com
Safety Introduction

• Sizing up the scene
• Identifying hydrogen
• Taking initial protective actions
• Detecting gaseous or a liquid hydrogen release
• Detecting a hydrogen flame
• Fire and combustion response
Hy – Safety

- Securing the equipment
- Rescuing passengers
- Personal protective equipment
- The importance of emergency response diagrams
- Recognize probable causes to hydrogen-related incidents
Personal Protective Equipment (PPE)

• Personal protection equipment is needed for non-injury accidents, catastrophic accidents including vehicle fires, and accidents involving fuel cell vehicles.

• Thermal imaging equipment to detect a hydrogen flame is recommended, as are insulated hand tools to avoid igniting any hydrogen gas.

• Standard firefighter turn-outs and respiratory protection are necessary when working an incident where a hydrogen leak or fire may occur.

• If the incident involves liquid hydrogen, wear thermal protective clothing.
Personal Protective Equipment (PPE)

• Non-static equipment and tools are required, as are fire extinguishers, a fire blanket, and broom

• Wearing jewelry, rings, necklaces, or watches is strongly discouraged

• Equipment also provides firefighters with the essential protection necessary from the potential of electric shock, flammable/explosive gas, and hazardous fumes
Personal Protective Equipment (PPE)

- Self-contained breathing apparatus
- Coveralls, turnout pants, turnout coat
- Fire resistant gloves
- High-voltage rubber gloves
- Boots, steel toe and shank
- Helmet
- Face shield
- In case of hazmat:
  - Hooded chemical-resistant clothing (two-piece chemical splash suit, disposable chemical resistant overalls, disposable chemical resistant boot-covers)
# Hydrogen Safety Facts

<table>
<thead>
<tr>
<th>Safe Handling</th>
<th>Emergency – Eye/Skin</th>
<th>Inhalation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Safety Glasses – Well ventilated area</td>
<td>• Not a factor</td>
<td>• Hydrogen is not poisonous, but is an asphyxiate. Accidental inhalation of sufficient hydrogen to cause breathing problems is unlikely. Move to a well ventilated area. Use CPR if breathing has stopped.</td>
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- **Emergency – Eye/Skin**
  - Not a factor

- **Inhalation**
  - Hydrogen is not poisonous, but is an asphyxiate. Accidental inhalation of sufficient hydrogen to cause breathing problems is unlikely. Move to a well ventilated area. Use CPR if breathing has stopped.
General Hazards and Risks Hydrogen Storage

- Hydrogen is capable of migrating through small openings
- The main concerns for emergency responders are electrical shocks and flammability of fuel
- Other concerns include cryogenic burns and asphyxiation
- Venting of stored hydrogen may be the best means of mitigating a situation as long as the area is free from ignition sources
- Hydrogen will dissipate very quickly
- Hydrogen will combine with oxygen to form water.
How tos:

• Eliminate ignition sources
• No smoking or open flames
• Keep tools and equipment in good condition and use only non-sparking tools; use the correct size tool for loosening and tightening hardware.
• No synthetic clothing (nylon, etc.), silk, or wool. Ordinary cotton, flame retardant cotton, or Nomex® clothing is preferred
• Electrical equipment must be explosion proof and intrinsically safe or purged
General Hazards and Risks for Tanks / Cylinders

- Liquid hydrogen tanks always emit small quantities of hydrogen if the hydrogen is not oxidized or burned off in a controlled manner.
- All hydrogen-containing fuel systems have great propensity for at least small leaks due to the pressure of the gaseous hydrogen and the small size of the molecules.
- Because of the high dispersion rate of hydrogen, small leaks would likely pose a problem in rare instances such as unvented, very tight, small individual garages.
- Safety concerns in larger unvented private or public parking garages will be more of an issue.
General Hazards and Risks Cylinders

• Never crack open a hydrogen cylinder to clear the valve of dust as the escape hydrogen may ignite
• Never drop, drag, roll, or slide cylinders
• Wrenches - never be used to open or close a valve equipped cylinder.
• Use only a strap-wrench to remove over-tightened or rusted caps
• Group of cylinders is burning - fire fighters keep their distance. Aware of fragments or shrapnel if an explosion occurs
General Hazards and Risks: Valves, Leaks, and PRDs

- Hydrogen systems include high- and low-pressure fuel lines.
- They are equipped with pressure relief devices for safety; the location of the pressure relief device depends on the type of system; there is no standard location.
- Hydrogen leaks generally originate from valves, flanges, diaphragms, gaskets, and various types of seals and fittings.
- For leaks that are relatively small and controllable, use the shut-off valve; for leaks that are uncontrollable, shut off the supply source and evacuate the area.
General Hazards and Risks Valves, Leaks, and PRDs

- Indicators:
  - For compressed hydrogen – a loud hissing or high-pitched shrill sound with PRD release and/or concentrated flame stream
  - For liquid hydrogen – a fog or cloud formed around the cryogenic hydrogen storage tank; ice crystals formed around the storage tank

- Liquid hydrogen poses greater risks than compressed hydrogen due to its cryogenic capabilities

- Hydrogen is stored as a liquid at \(-423\)°F \((-253\)°C), can cause cryogenic burns or lung damage

- Detection sensors and personal protective equipment are critical when handling liquid hydrogen

- Properly-working ventilation equipment can minimize potential hazards.
General Hazards and Risks Valves, Leaks, and PRDs

• Precautions:
  • Eliminate source of ignition, and if possible, remove cylinder to remote outdoor location away from possible sources of ignition
  • Ventilate area
  • Avoid skin contact, with liquid or cold boil-off gas
  • Do not enter area containing flammable mixtures
  • Avoid spraying water on pressure relief devices or gas vents
General Hazards and Risks Venting and Asphyxiation

• Hydrogen is an asphyxiate. In rare instance and in closed spaces it can displace oxygen, causing an oxygen deficient atmosphere.

• Precautions:
  • Always open a compressed gas cylinder valve slowly to avoid rapid system pressurization.
  • Indicators:
  • Some signs and symptoms of overexposure include headache, drowsiness, dizziness, excitation, excess salvation, vomiting, and unconsciousness.
General Hazards and Risks for Hydrogen Vehicles

- The two prime dangers from fuel cell and hydrogen-powered vehicles are the danger of:
  1. Electrical shock
  2. Flammability of the fuel
General Hazards and Risks Hydrogen Vehicles

- Precaution: The danger of electrical shock is present.
- The voltage needed to power the electric motors is much higher in the new vehicles than can be accommodated by the current standard voltage of a 14V system; the automobile industry is in the process of moving to a new standard of a 42V system.
- The 42 volt system was chosen as an industry standard in part for safety reasons; anything greater than 50V can stop a human heart.
- Some fuel cell vehicle motors run on voltages between 200-400V.
General Hazards and Risks Hydrogen Vehicles

- Precaution: Hydrogen’s flammability range is very wide compared to other fuels
- Other fuels used to power fuel cells include methanol, ethanol, and methane
- Fuel used to power a vehicle does not necessarily have to be stored on the equipment as hydrogen
- Reforming different hydrogen sources, such as alcohols, methane, propane, and even regular gasoline, can create gaseous hydrogen in the vehicle itself
Emergency Procedures

• Sizing up the scene
• Identifying hydrogen in commercial transport or stationary facilities
• Identifying hydrogen vehicles (in the case of a hydrogen vehicle accident)
• Taking initial protective actions
• Detecting gaseous or a liquid hydrogen release
• Detecting a hydrogen flame
• Securing the vehicle (in the case of a hydrogen vehicle accident)
• Fire and combustion response
• Extrication of passengers from vehicles (in the case of a hydrogen vehicle accident)
Sizing Up the Scene

- Do not rush in
- Position responding units (fire trucks, police cruisers, and ambulances) upwind and away from leaking hydrogen or PRD vents
- Regarding hydrogen fuel cell vehicles, in case of spill from the high-voltage battery pack, contact hazmat immediately
Identifying Hydrogen in Commercial Transport

- Placards and/or other markings are required on bulk shipments
- Markings help emergency responders recognize the material and respond appropriately in the event of an emergency.
Identifying Hydrogen Fueling Stations (USA)

• The National Fire Protection Association also has a standard for hazard placards to identify hydrogen used at stationary facilities.

• The NFPA 704 hazard placards used for gaseous and liquid hydrogen are shown here – the “4” shown in both the gaseous and liquid hydrogen placards indicates flammability, and the “3” on the liquid placard denotes the health issue related to a cryogenic substance.
Initial Protective Actions

• When approaching an incident:
  • Keep unauthorized personnel away
  • Isolate the area,
  • Stay upwind
• Listen for venting gas and watch for thermal waves that could signal hydrogen flames
• Follow standard operating procedure
• Eliminate all potential ignition sources
• Hydrogen fire is detected, allow it to burn if safe to do so, and protect adjacent structures
Detecting a Gaseous Hydrogen Release

- Hydrogen gas is colorless and odorless - human senses cannot detect it.

- Recommended that the responder listen for the sound of high-pressure gas escaping from the vent or a breech in the container.

- Use commercially available thermal conductivity sensors, catalytic combustion sensors, or electrochemical sensors.

- Gas and flame detectors may be permanently installed in storage facilities and fueling stations - where leaks may occur. Listen and watch for alarms.

- Regarding vehicles, when it is safe to do so, listen for the sound of hydrogen escaping, look for frost around the PRD vent.
Detecting a Liquid Hydrogen Release

- A leaking liquid hydrogen container may have frost or ice crystals on the outside.
- Small spills of hydrogen disperse quickly - any spill should be considered a potential fire hazard.
- Large spills cause ground freezing; hydrogen will not vaporize quickly.
- Evacuate area until spill has dissipated.
- Use water spray to reduce fog and diffuse vapors.
- Clouds of gas can quickly become huge fire balls with tragic results.
Detecting a Liquid Hydrogen Release

- Even in dry climates, a liquid hydrogen spill will create a white cloud of condensed water vapor.
- As the hydrogen warms, it will dissipate and quickly rise.

Source: Millennium Reign University first respondents handbook, www.mreh2.com
Detecting Hydrogen Flame

- Hydrogen burns with a pale blue flame that is nearly invisible in daylight.
- The flame may appear yellow if there are impurities in the air like dust, sodium from the ocean spray, etc.
- A pure hydrogen flame will not produce smoke.
- Hydrogen flames have low radiant heat – unlike a hydrocarbon fire, you may not feel heat until you are very close to the flame.
Securing Hydrogen Vehicles

• When approaching a hydrogen vehicle that has been involved in an incident, immobilize, stabilize, and disable.

• Approach hydrogen vehicle at a 45° angle when possible to help avoid direct exposure to a pressure relief device release.
Securing Hydrogen Vehicles

• It is essential that the location of the PRD vent be identified before beginning any operation on a hydrogen vehicle.

• Listen for venting hydrogen, and watch for thermal waves that could signal a hydrogen flame.

Source: Millennium Reign University first respondents handbook, www.mreh2.com
Securing Hydrogen Vehicles

• If safe to do so, isolate the high-pressure hydrogen and high-voltage systems by turning the ignition key off or by cutting the negative cable of the 12-volt auxiliary battery.

• It may take a couple of minutes for the electrical system to completely discharge.
Securing Hydrogen Vehicles

• Once the vehicle is turned off, the high-pressure systems are isolated.
• Simply turning off the key closes the high-pressure hydrogen gas tank.
• However, the hydrogen fuel lines from the tank to the engine will still contain a small amount of hydrogen (approximately 2 teaspoons of gasoline equivalent).
Securing Hydrogen Vehicles

• Regarding hydrogen fuel cell vehicles, it is essential to identify both the 12-volt auxiliary electrical system and the 200-500 volt, 200-300 amp electrical system.

• Refer to vehicle emergency response guides to identify high- and low-voltage systems.
Securing Hydrogen Vehicles

• The high-voltage Ni-MH battery pack must be disconnected from the electrical system.

• To do this, simply remove the high-voltage service disconnect switch. To remove this switch, turn it counterclockwise and lift it out.

• Refer to vehicle emergency response guides to determine the specific location of this switch.
Fire and Combustion Response

• The best way to handle a hydrogen fire is to let it burn under control until the hydrogen flow can be stopped or the fire is burned off.

• Small fires can be extinguished with carbon dioxide or water spray; larger fires may be controlled with steam and/or nitrogen.

• if fire is extinguished before all the gas burns off, watch for pockets which may suddenly re-ignite.
Fire and Combustion Response

- A hydrogen flame is invisible under many conditions; therefore, burns may result from unknowingly walking into a hydrogen fire.
- Hydrogen flames cause little damage from radiation.
- Hydrogen flames can burn in a strong wind and be stretched out away from their source by a number a feet.
- Tanks containing hydrogen should be cooled with water if near a fire.
Fire and Combustion Response

• Pipeline fires, where shutoff is possible and with flame characteristics of a jet or torch, can be effectively controlled as follows:
  • Slowly reduce the flow of hydrogen feeding the fire.
  • When the jet is small enough to be approached, put out the flame with carbon dioxide or dry powder extinguisher.
  • Close off the supply of hydrogen completely.
  • Ventilate the area thoroughly.
• Unusual fire or explosion hazard: Potential explosion hazard from re-ignition if fire is extinguished without shutting off hydrogen.
Fire and Combustion Response

• For hydrogen vehicles, if the hydrogen system can be isolated, put out the fire with traditional means.
• However, if the hydrogen system cannot be isolated, let the fire burn.
• Concentrate on keeping the fire from spreading into other areas or neighboring objects.
Extrication

• Never cut into the hydrogen fuel lines, the hydrogen storage tank, or the PRD vent line.

• For hydrogen fuel cell vehicles, do not cut the orange electric cables, the high-voltage Ni-MH battery pack, or the fuel cell stack.
How a Hy-system looks like?
End of Session

Thank you for your attention!

Q&A
More info?
igk@unipi.gr