Hydrogen Safety Training Materials

Below are links to online training tools targeted to different audiences:

National Hydrogen and Fuel Cell Emergency Response Training Resource

Featured Resource! The California Fuel Cell Partnership and the Pacific Northwest National Laboratory collaborated to develop a national hydrogen safety training resource for emergency responders. The resource provides a single repository of credible and reliable information related to hydrogen and fuel cells that is current and accurate and eliminates duplicative efforts among various training programs. This approach will enable government and private training organizations nationwide to develop their own training programs with consistent hydrogen and fuel cells content and standards. See more information about using this resource.

Introduction to Hydrogen Safety for First Responders

DOE's Introduction to Hydrogen Safety for First Responders is a Web-based course that provides an "awareness level" overview of hydrogen for fire, law enforcement, and emergency medical personnel. This multimedia tutorial acquaints first responders with hydrogen, its basic properties, and how it compares to other familiar fuels; hydrogen use in fuel cells for transportation and stationary power; potential hazards; initial protective actions should a responder witness an incident; and supplemental resources including videos, supporting documents, and links relevant to hydrogen safety.

Hydrogen Safety Training for Researchers

Laboratory researchers and technical personnel handling hydrogen need basic information on pressure, cryogenics, flammability, asphyxiation, and other risks and precautions for using hydrogen. The objective of the Hydrogen Safety Training for Researchers interactive online course is to provide basic hydrogen safety training.

Introduction to Hydrogen for Code Officials

The Introduction to Hydrogen for Code Officials online training course provides an overview of hydrogen and fuel cell technologies, how these technologies are used in real-world applications, and the codes and standards required for permitting them. A short quiz is offered at the end of each module. In addition, the course features a Library section with supplementary information including publications, related links, and a glossary of terms used in the course.

Vehicle Emergency Response Guides

Honda FCX Clarity

- Honda FCX Clarity

Toyota Mirai

- Mirai Documents
- Toyota Overall ERG

GM Equinox Fuel Cell

- ERG
- ER Quick Reference sheet

Hyundai

- Hyundai Emergency Response Guide

AC Transit Bus

- AC Transit Bus

ElDorado National – CA

- ElDorado Fuel Cell Bus

HYDROGEN
Emergency Response
Training Resources

National Hydrogen and Fuel Cells EMERGENCY RESPONSE TRAINING TEMPLATE

A properly trained first responder community is critical to the successful introduction of hydrogen fuel cell applications and their transformation in how we use energy. We envision that hydrogen and fuel cell-related first responder training will be delivered locally to serve missions to protect life and preserve property, utilizing this national emergency response training resource as a consistent source of accurate information and current knowledge. These training materials are adaptable to the specific needs of first responders and training organizations and are meant to complement the extensive training programs already in place to serve their missions. The note pages format of the slides provides more details for the instructor to conduct the training. Instructors should share this information when presenting the slides.

This nationally-focused training template is intended to serve as a resource and guide for the delivery of a variety of training regimens to various audiences. These materials are adaptable for different presentation styles, ranging from higher level overview formats to more comprehensive classroom training. Three example uses of the slides are provided in the included Excel file National_HFC_ER_Training_Guide_Examples.xlsx based on the discussion below.

- **L1 (Overview)** – This example refers to a course directed to a responder audience that has little knowledge about hydrogen and fuel cell technologies. The presentation is limited to background information to provide the attendee with an overview of the technologies and their applications. The instructor may very well choose to use additional slides appropriate for the audience.
- **L2 (Short Course)** – A short course would be directed to a responder audience that has an intermediate level of knowledge about alternative fuel vehicle technologies not necessarily including hydrogen. One example could be an auto extrication classroom session for which background and other detailed information are minimized and operations-related slides are highlighted.
- **L3 (Full Course) –** A day-long classroom curriculum could very well cover training materials contained in all the slides including practical exercises for which small groups would discuss incident scenarios. Some of these slides could also be used for purposes intended for an L1 and/or L2 training regimen.

Feedback from presenters and audiences to the developers of the National Hydrogen and Fuel Cells Emergency Response Training will help ensure that the development of new and updated training content and techniques serves to continually enhance the value of this resource. Feedback should be provided to nick.barilo@pnnl.gov or jjhamilton@cafcp.org.

Revision Date: December 22, 2015

Slide Number	Section Number	First Responder Training Template	L1-Overview	L2- Short Course	L3- Full Course
			Suggested Use of Training Slides		
1		The Program: What and Why	✓	✓	✓
2		National Hydrogen and Fuel Cells ER Education Program	✓	✓	✓
3	**1.0**	**Introduction and Background**			
4		*Fuel cells overview*	✓	✓	✓
5			✓	✓	✓
6		*Fuel cells- Where are we today?*	✓	✓	✓
7			✓	✓	✓
8	**2.0**	**Hydrogen and Fuel Cell Basics**			
	2.1	***Hydrogen - Where does it come from and how do we use it now?***			
9		*Why hydrogen?*	✓	✓	✓
10		*Where do we get hydrogen?*	✓	✓	✓
11		*Hydrogen uses*	✓	✓	✓
12		*Hydrogen distribution*			✓
13		*Transporting hydrogen today*			✓
	2.2	***Properties of hydrogen and its safe use***			
14		*Hydrogen properties and behavior*	✓	✓	✓
15		*Hydrogen properties: a comparison*	✓	✓	✓
16		*Relative vapor density*			✓
17		*Auto ignition temperature*			✓
18		*Comparison of flammability*	✓	✓	✓
19		*Flammability range*			✓
20		*Comparison of fuel odorants and toxicity*			✓
21					✓
22		*Designing safe systems- gaseous hydrogen*			✓
23					✓
24		*Designing safe systems- liquid hydrogen*			✓
	2.3	***How a fuel cell works***			
25		*Fuel cell basics*	✓	✓	✓
26		*How a fuel cell works*	✓	✓	✓
	2.4	***Fuel cell applications***			
27		*Fuel cell applications*			✓
	2.4.1	***Stationary/back-up power***			
28		*24 x 7 reliable large industrial-scale fuel cell power*			✓
	2.4.2	***Industrial trucks***			
29		*Fuel cells for speciality vehicles*			✓
30		*Industrial trucks*			✓
31		*Companies with fuel cell industrial trucks*			✓
	2.4.3	***Auxiliary power units (APUs)***			
		slides to be added in future version			
	2.4.4	***Medium duty applications***			

	slides to be added in future version			
	2.4.5 Off-road lighting			
32	*Stationary fuel cell lighting application*			✓
	2.4.6 Small-scale applications			
33	*Small-scale applications for fuel cells*			✓
34	**3.0 Hydrogen-fueled vehicles (light duty and transit)**			
35	*Fuel cell electric vehicles (FCEV)*	✓	✓	✓
36	*Public vehicles*		✓	✓
37	*FCEV coming soon*		✓	✓
	3.1 How the vehicles work			
38	*Standard components of all vehicles*			✓
39	*FCEV vs. gasoline hybrid-electric vehicle*			✓
40	*FCEV vs. compressed natural gas (CNG) vehicle*			✓
41	*FCEV system layout*	✓	✓	✓
42	*FCEV system and passenger layout*		✓	✓
43	*Fuel cell component location*		✓	✓
	3.2 FCEV components and systems			
	3.2.1 Voltage systems			
44	*Low and high voltage systems*	✓	✓	✓
45	*High voltage systems*		✓	✓
46	*Bus low and high voltage systems*		✓	✓
	3.2.2 Hydrogen delivery and storage			
47	*Hydrogen delivery system*	✓	✓	✓
48	*Hydrogen delivery system- bus*	✓	✓	✓
49	*Onboard hydrogen storage*			✓
50	*Compressed hydrogen storage systems*	✓	✓	✓
51	*Example of gaseous hydrogen storage system*			✓
52	*70 MPa tanks*			✓
	3.3 Vehicle systems safety			
53	*Compressed hydrogen storage tank testing*	✓	✓	✓
54				✓
55	*Compressed hydrogen storage tank testing: high strain rate impact test*			✓
56	*Compressed hydrogen storage tank testing: bonfire test*			✓
57	*Equinox fuel cell- FMVSS 208 certification (occupant protection)*			✓
58	*Hyundai ix35 FCEV- FMVSS 305 and ECE R94-25s certification*			✓
59	*Hyundai ix35 FCEV- FMVSS 305 and ECE R94-50s certification*			✓
60	*Fuel isolation in typical or normal operation*		✓	✓
61	*Hydrogen vehicle safety systems*		✓	✓
62	*Safety systems*	✓	✓	✓
63	*Hydrogen sensors example*		✓	✓
64	**4.0 Stationary Facilities**			
65	*Types of stationary facilities*	✓	✓	✓
66	*Identifying stationary facilities*		✓	✓
	4.1 Fueling stations (light duty/outdoor, fork lift/indoor			
67	*Hydrogen fueling stations*	✓	✓	✓
68	*Components for fueling a hydrogen vehicle*		✓	✓

69		*Hydrogen fueling*		✓	✓
70		*Hydrogen fueling diagram*			✓
	4.1.2 Station safety systems				
71		*General station safety systems*			✓
72					✓
	4.1.3 Hydrogen fueling station configurations and components				
73		*Typical station configuration*			✓
74		*Hydrogen fueling stations: gaseous hydrogen delivery*			✓
75		*Hydrogen fueling stations: gaseous hydrogen storage*			✓
76		*Hydrogen fueling stations: liquid hydrogen delivery*			✓
77		*Hydrogen fueling stations: liquid hydrogen storage*			✓
78		*Hydrogen fueling stations: onsite hydrogen generation by reforming*			✓
79		*Hydrogen fueling stations: onsite reforming components*			✓
80		*Hydrogen fueling stations: onsite hydrogen generation by electrolysis*			✓
81		*Hydrogen fueling stations: onsite electrolysis components*			✓
82		*Comparison between gasoline and hydrogen fueling stations*			✓
83	**5.0 Managing hydrogen-related emergencies**				
84		*Considerations for managing hydrogen-related emergencies*			✓
85					✓
86		*National fire academy (NFA) command sequence*		✓	✓
	5.1 Vehicle incidents				
	5.1.1 Size up				
87			✓	✓	✓
88		*Hydrogen vehicles- size up*			✓
89					✓
	5.1.2 Plan (Identify)				
90				✓	✓
91		*Formal identification- plan*		✓	✓
92				✓	✓
93				✓	✓
94		*Informal identification- plan*		✓	✓
95				✓	✓
96		*Plan*			✓
97					✓
98		*How do you identify other types of vehicles- plan*		✓	✓
99		*Hydrogen release indicators- plan*		✓	✓
100		*Hydrogen transport vehicles*			✓
101		*Hydrogen vehicles-plan*			✓
102					✓
103		*Hydrogen lines and high voltage systems*		✓	✓
	5.1.3 Act				
104		*Isolate-act*		✓	✓
105		*Rescue: extrication-act*		✓	✓
106		*Hydrogen vehicle-extrication considerations-act*			✓
107		*Hydrogen vehicle- extrication tactics-act*			✓
108		*Extrication- dash roll-act*		✓	✓

109		*Hydrogen vehicles- extrication training-act*	✓	✓
110			✓	✓
111		*Images-extrication-act*	✓	✓
112			✓	✓
	5.2	***Stationary systems/facilites incidents***		
113		*Stationary facilities-size up*		✓
114		*Stationary facilities-plan*		✓
	5.3	***Vehicle and stationary facility responses***		
115		*Vehicle and facility incidents-act*		✓
116		*Vehicle and facility incidents-evaluate*		✓
117	**6.0**	**Practical exercises**		
	6.1	***In-class scenarios***		
118		*Instructions*		✓
119		*Checklist-what to think about when you arrive*		✓
120				✓
121		*Single vehicle accident*		✓
122		*Single vehicle accident with fire*		✓
123		*Multiple vehicle accident*		✓
124		*Hydrogen fueling station-unintended release*		✓
125		*Unintended hydrogen release in an enclosure*		✓
126		*Hydrogen transport incident*		✓
	6.2	***Practical exercises***		
		Slides/videos to be added in future version		
	6.2.1	***Demo of hydrogen flame with thermal imaging camera***		
		Slides/videos to be added in future version		
	6.2.2	***Rescue drills***		
		Slides/videos to be added in future version		
127	**7.0**	**Wrap up**		
128		*Publications and presentations*		
129		*Acknowledgements*		
130		*Contact information*		

Revision Date: December 22, 2015

What and Why?

National Hydrogen and Fuel Cell Emergency Response Training

A properly trained first responder community is critical to the successful introduction of hydrogen fuel cell applications and their transformation in how we use energy. We envision that hydrogen and fuel cell-related first responder training will be delivered locally to serve missions to protect life and preserve property, utilizing this national emergency response training resource as a consistent source of accurate information and current knowledge. These training materials are adaptable to the specific needs of first responders and training organizations and are meant to complement the extensive training programs already in place to serve their missions. **The note pages format of these slides provides more details for the instructor to conduct the training. Instructors should share this information when presenting the slides.**

The nationally-focused training template that accompanies these materials is intended to serve as a resource and guide for the delivery of a variety of training regimens to various audiences. These materials are adaptable for different presentation styles, ranging from higher level overview formats to more comprehensive classroom training. Three example uses of the slides are provided in the companion Word file.

Feedback from presenters and audiences to the developers of the National Hydrogen and Fuel Cells Emergency Response Training will help ensure that the development of new and updated training content and techniques serves to continually enhance the value of this resource.

Revision Date: December 22, 2015

HYDROGEN
Emergency Response
Training Resources

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

California Fuel Cell Partnership
DRIVING FOR THE FUTURE

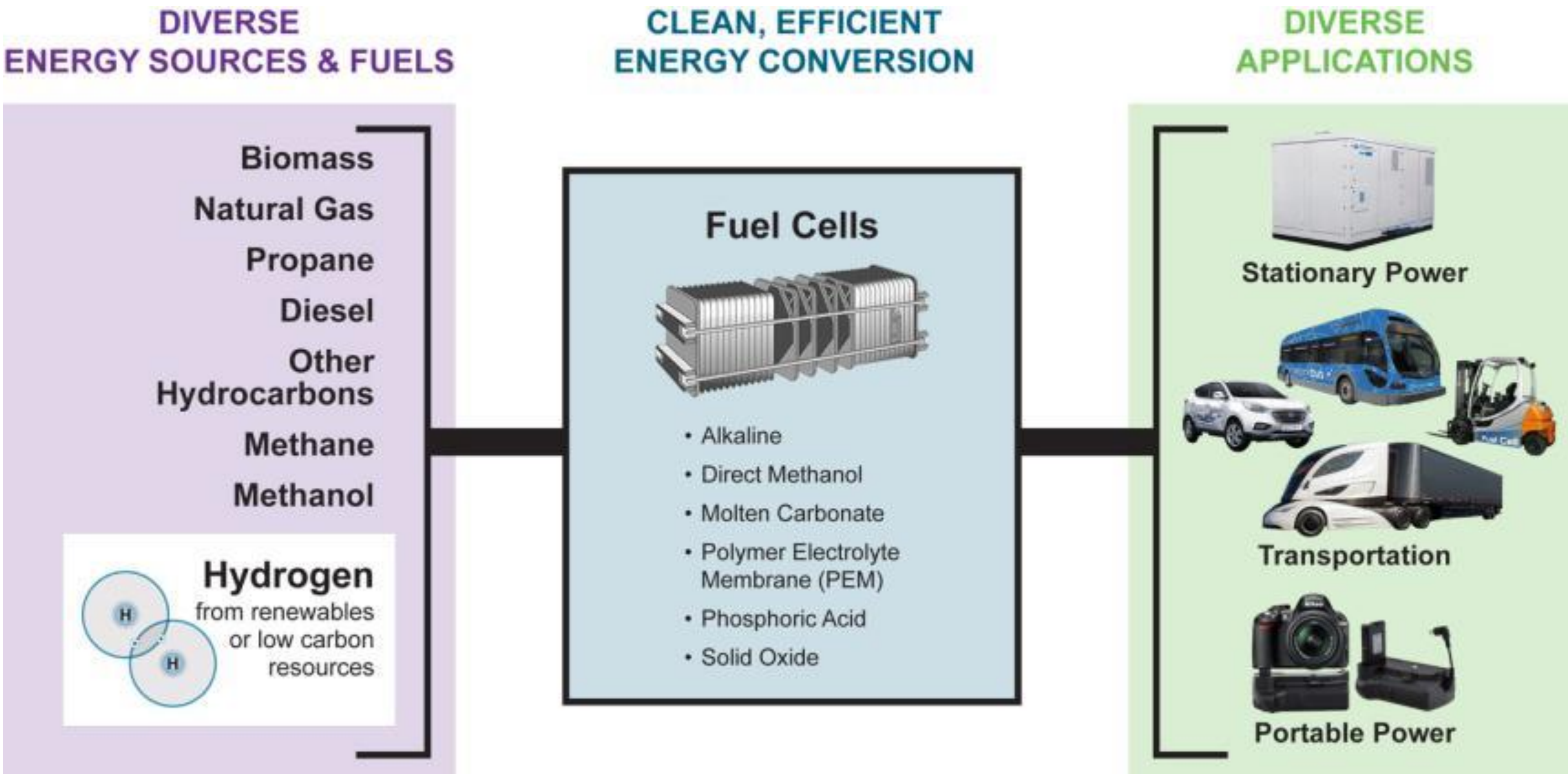
National
Hydrogen and Fuel Cells Emergency Response
TRAINING

SECTION 1:

Introduction and Background

- An overview of fuel cells
- An overview of current hydrogen production and delivery
- Current markets for fuel cells

Fuel Cells Overview



Fuel Cells
Where are We Today?

Fuel Cells for Stationary Power, Auxiliary Power, and Specialty Vehicles

The largest markets for fuel cells today are in stationary power, portable power, auxiliary power units, and material handling

More than 50,000 fuel cells shipped worldwide in 2014 (~a global increase of 37% over 2013)

More than 50,000 fuel cells, totaling over 180 MW, were shipped worldwide in 2014

Fuel cells can be a cost-competitive option for critical-load facilities, backup power, and forklifts

Source: US DOE Fuel Cell Technologies Market Report 2014

Where are We Today?

Production & Delivery of Hydrogen

In the U.S., there are currently:

- ~9 million metric tons of H_2 produced annually
- > 1,500 miles of H_2 pipelines
- Primary use in petroleum refining
- Many other industrial uses

Source: US Department of Energy 2009/2010

Fuel Cells
Where are We Today?

Fuel Cells for Transportation

The US DOE completed the world's largest FCEV and hydrogen demonstration to date for all purposes (with 50/50 DOE/Industry cost share)

- More than 180 fuel cell vehicles
- 25 fueling stations ~3.6 million miles travelled (~500,000 trips)

FCEVs are being sold now in Japan and the US, with several other automakers announcing commercial sales in the 2017-2020 timeframe

- ~100 stations in CA by 2023

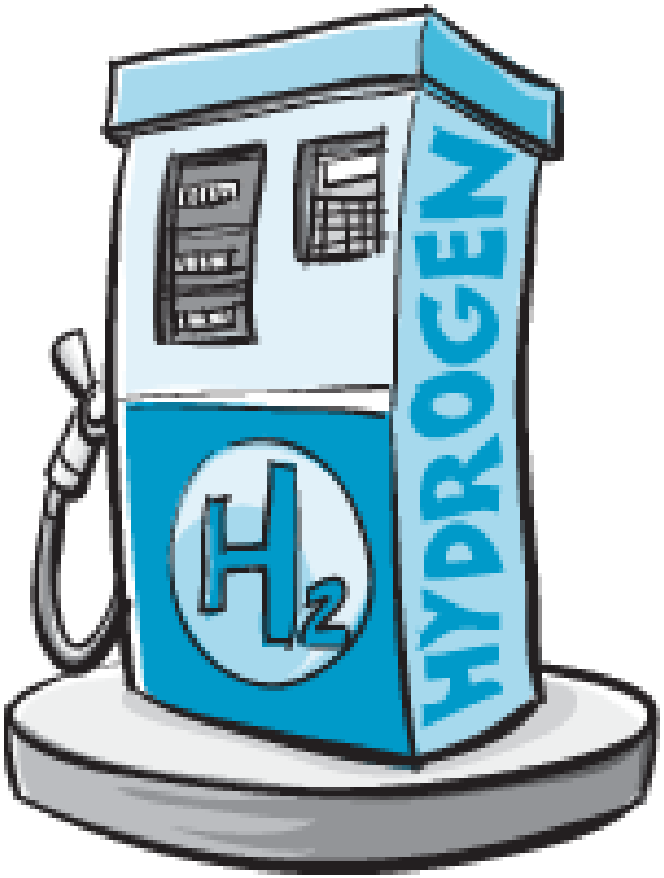
Hydrogen and Fuel Cell Basics

This section covers:

- Basic properties and behaviors of hydrogen
- How hydrogen compares to other fuels
- How a hydrogen fuel cell works
- Potential hazards with hydrogen that may differ from those of other fuels
- The controls commonly used to assure the safe use of hydrogen

Why Hydrogen?

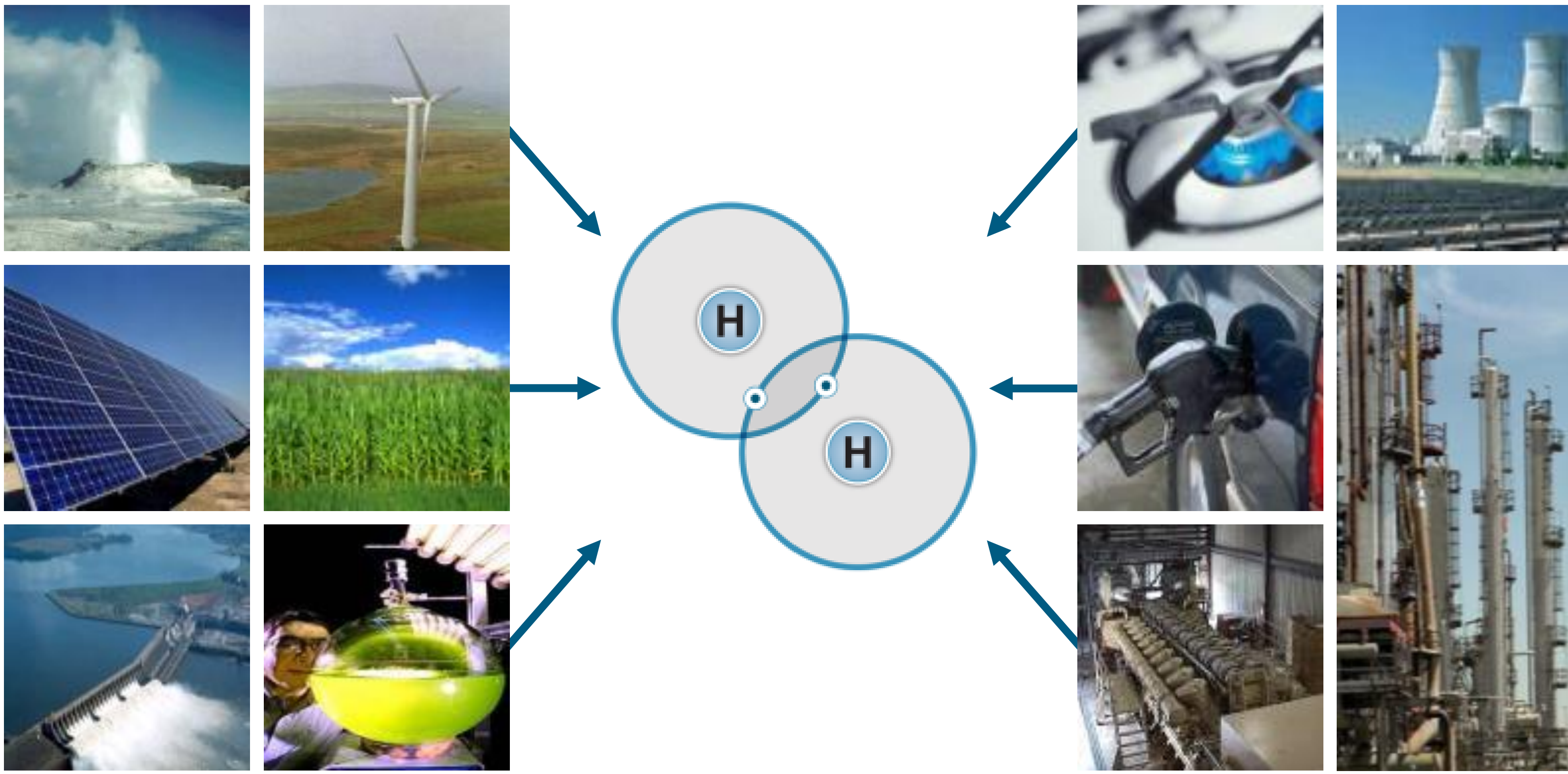
- Excellent energy carrier
- Nonpolluting
- Economically competitive
- As safe as gasoline
- Used safely for over 50 years
- Produced from a variety of sources



Where Do We Get Hydrogen?

Renewable Sources

Traditional Sources



Solar, wind, geothermal, hydro, biomass, algae

Natural gas, gasoline, nuclear, coal

Hydrogen Uses

The use of hydrogen is not new; private industry has used it safely for many decades. Nine million tons of hydrogen are safely produced and used in the United States every year. 56 billion kg/yr are produced globally. For example, H_2 is used for:

- Petroleum refining
- Glass purification
- Aerospace applications
- Fertilizers
- Annealing and heat treating metals
- Pharmaceutical products

The Air Products and Chemicals hydrogen production facilities in Port Arthur, Texas, is funded by the Energy Department through the 2009 Recovery Act. | Photo credit Air Products and Chemicals hydrogen production facilities.

- Petrochemical manufacturing
- Semiconductor industry
- Hydrogenation of unsaturated fatty acids in vegetable oil
- Welding
- Coolant in power generators

Hydrogen Distribution

- DOT regulated transportation…
- Cryogenic liquid transport
  - -423°F (-253°C)
  - Low pressure (<100 psi)
- Pressurized gas trailers
  - ~2,000-6,500 psi
- Truck, rail, barge and pipeline

Photo: Praxair, Inc.

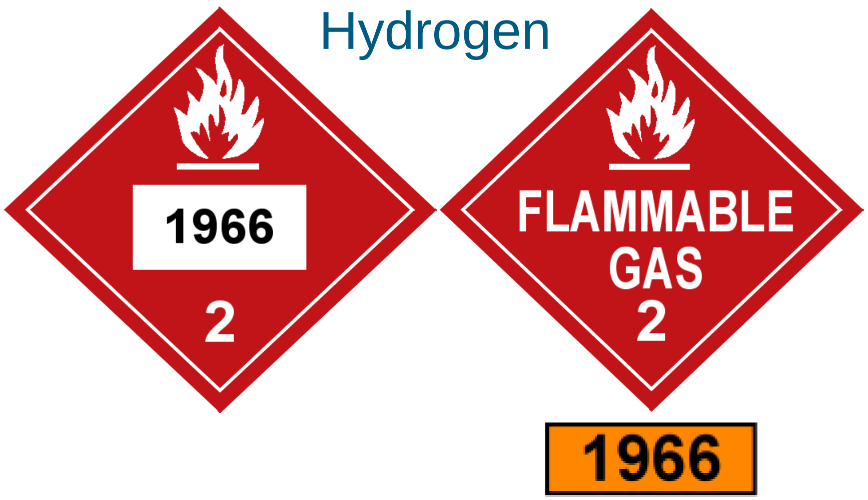
Photo: Ovonics

Photo: Air Products & Chemicals, Inc.

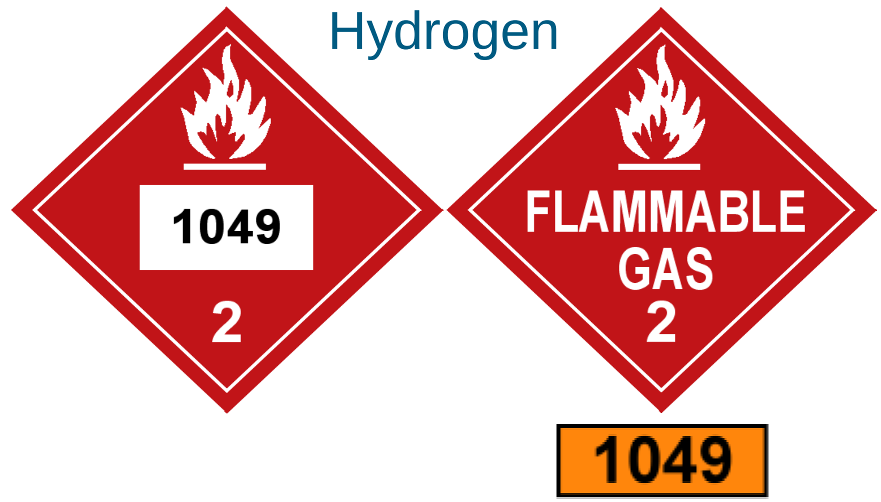
Transporting Hydrogen Today

DOT placards for commercial transport of hydrogen

Liquid
Hydrogen

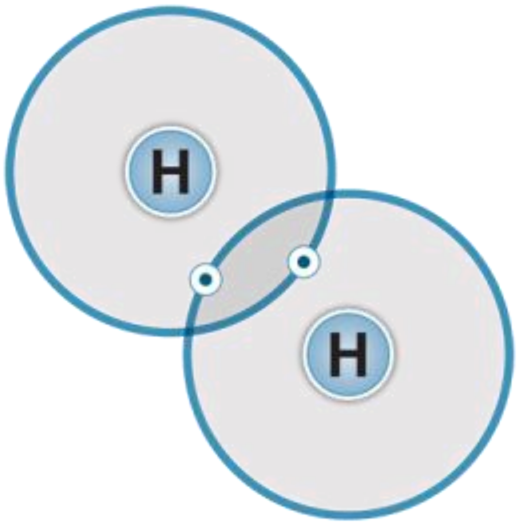


Gaseous
Hydrogen



Hydrogen Properties and Behavior

- A gas at ambient conditions
- Hydrogen is a cryogen: exists as a liquid at -423°F (-253°C).
  - Compressing the gas does not liquefy it
  - No liquid phase in a compressed gaseous hydrogen storage tanks
- LH2 storage at relatively low pressure (50 psi)
- Double walled, vacuum insulated tanks with burst disks, vents, and PRDs
- Volumetric ratio of liquid to gas is 1:848
  - Compare water to steam (1:1700)
- Energy content of 1kg of H_2 is approximately equal to 1 gal of gasoline (in BTUs)



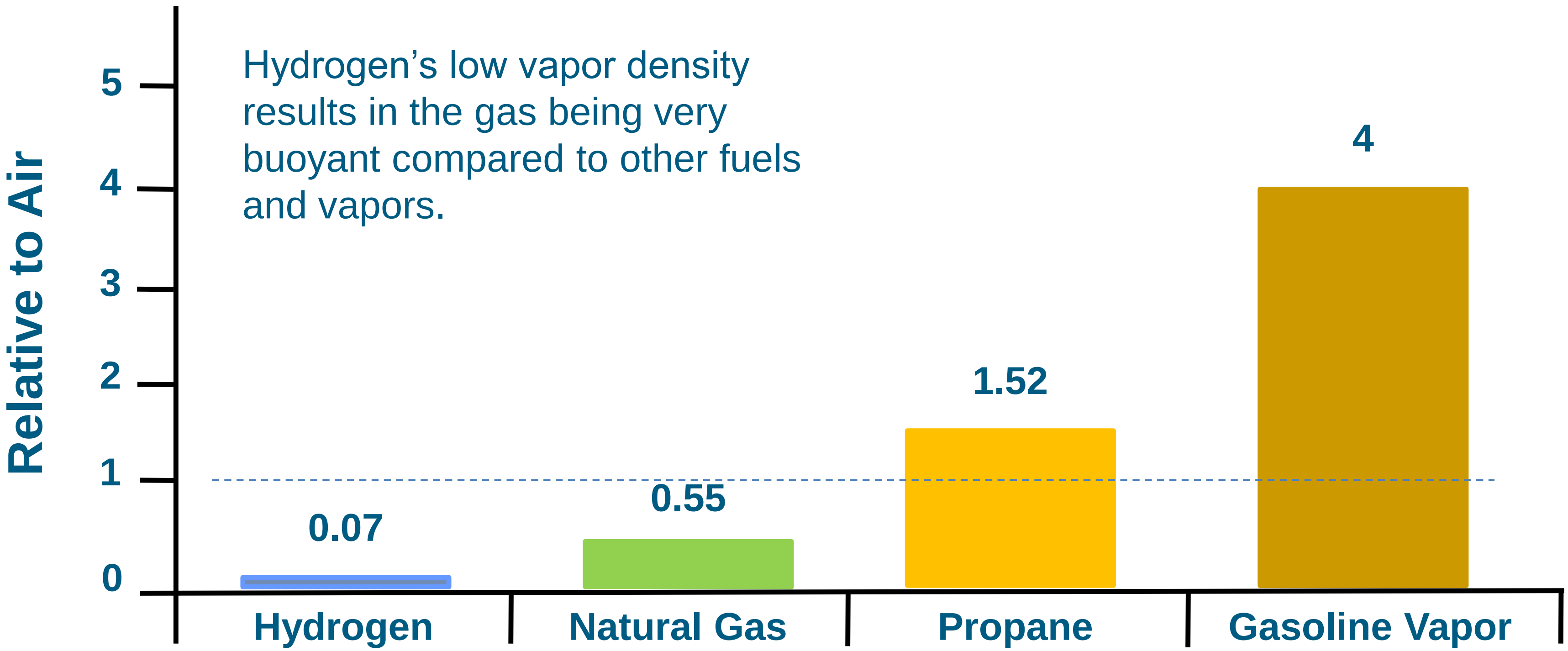
Molecular Hydrogen

Hydrogen Properties: A Comparison

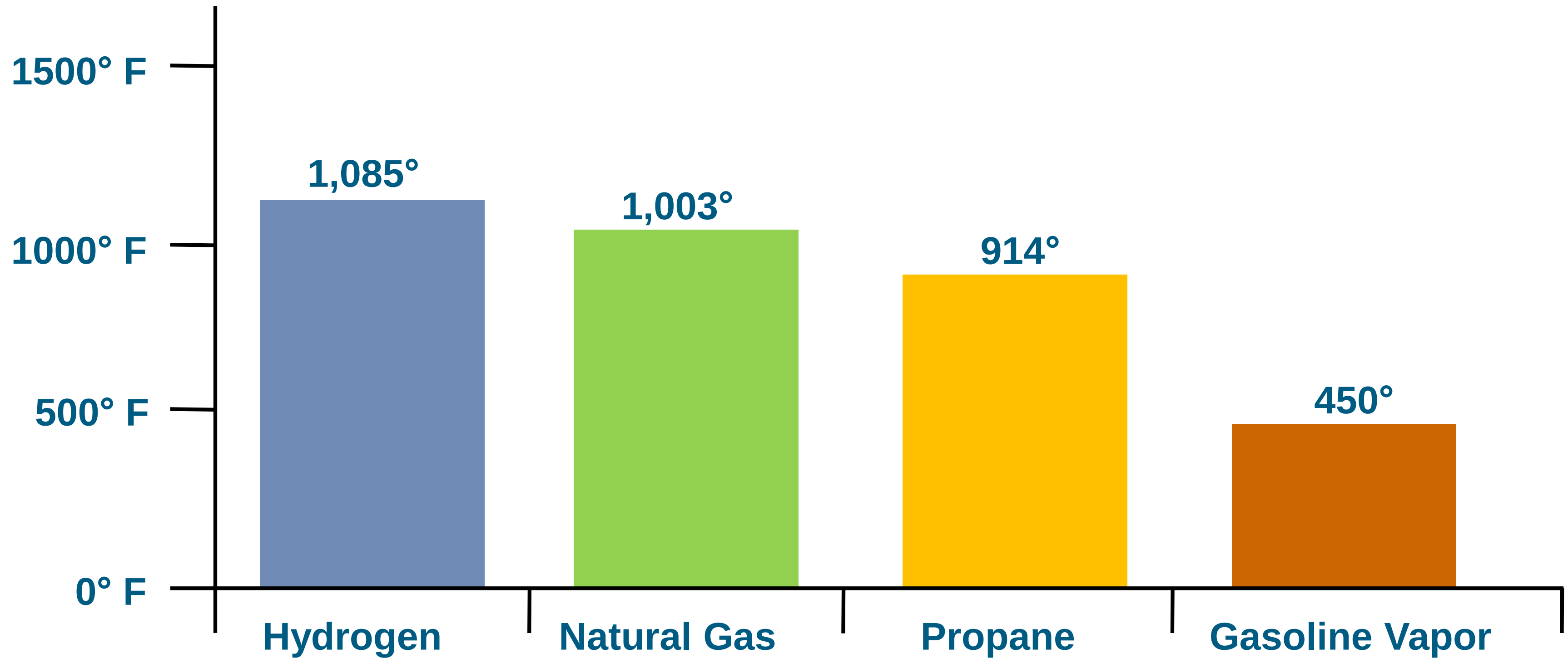
	Hydrogen	Natural Gas	Gasoline
Color	**No**	**No**	**Yes**
Toxicity	**None**	**Some**	**High**
Odor	**Odorless**	**Mercaptan**	**Yes**
Buoyancy Relative to Air	**14X** Lighter	**2X** Lighter	**3.75X** Heavier
Energy by Weight	**2.8X** > Gasoline	**~1.2X** > Gasoline	**43** MJ/kg
Energy by Volume	**4X** < Gasoline	**1.5X** < Gasoline	**120** MJ/Gallon

Source: California Fuel Cell Partnership

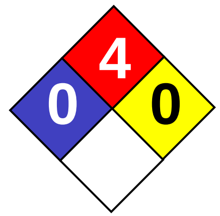
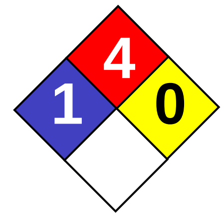
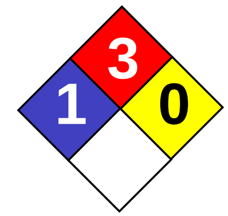
Relative Vapor Density



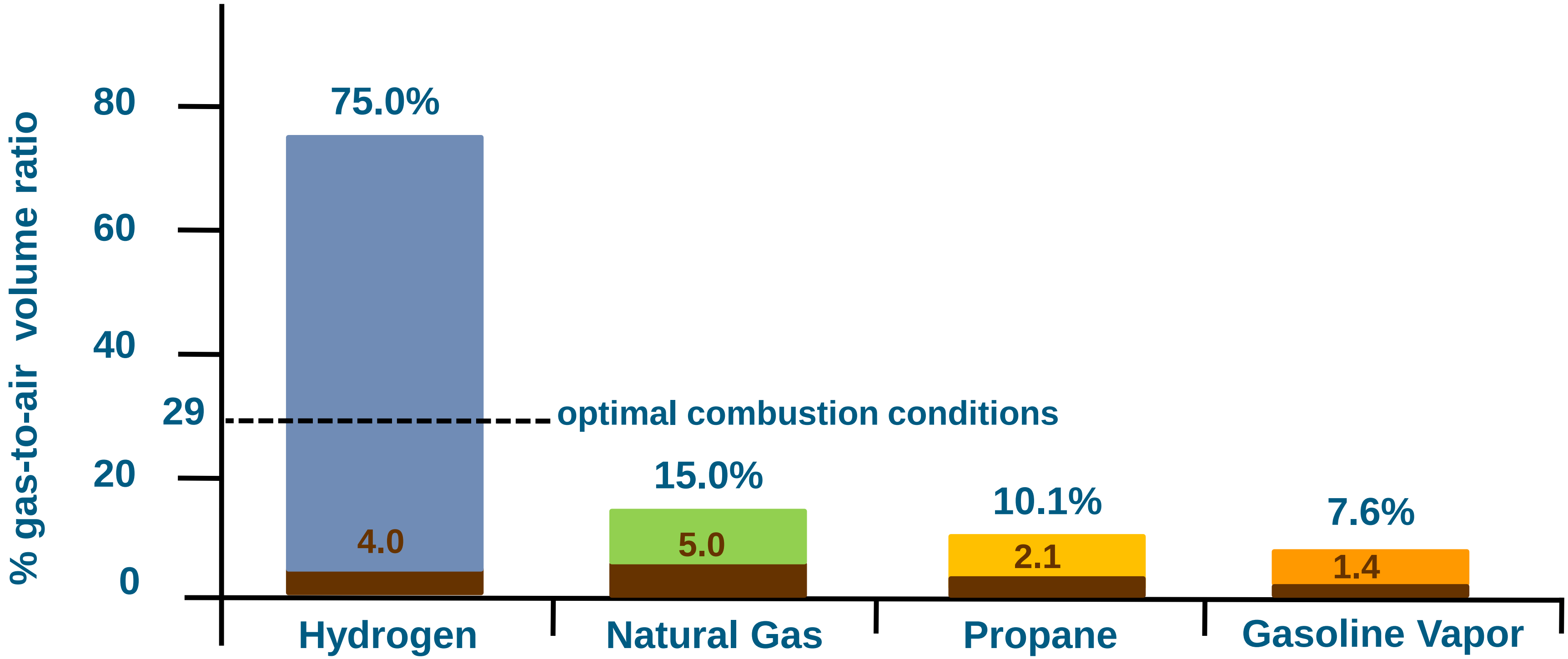
Auto-ignition Temperature



Comparison of Flammability

	Hydrogen	Natural Gas	Gasoline
			
Flammability in air (LFL – UFL)	4.1% - 74%	5.3% - 15%	1.4% - 7.6%
Most easily ignited mixture in air	29%	9%	2%
Flame temperature (°F)	4010	3562	3591

Flammability Range



Comparison of Fuel Odorants and Toxicity

Fuels	Odorant Added?	Toxic?
Hydrogen	**No**	**No**
Compressed Natural Gas (CNG)	**Yes**	**No**
Liquefied Natural Gas (LNG)	**No**	**No**
Propane	**Yes**	**No**
Gasoline Vapor	**NOT NEEDED** Naturally Strong Odor	**Yes**

Designing Safe Systems – Gaseous Hydrogen

Characteristic	Potential Hazard	Control
• Colorless • Odorless • Tasteless	• Impossible for human senses to detect	• Detection sensors
• Low Viscosity • Very small molecule (can be absorbed into materials)	• High leak rate • Embrittles certain materials; can result in structural failure	• Leak detection systems • Ventilation • Material selection
• Low Volumetric Energy Density	• Stored at high pressures	• Storage container design • Pressure-relief devices

Designing Safe Systems – Gaseous Hydrogen

Characteristic	Potential Hazard	Control
• Asphyxiant	• Potential for accumulation in confined spaces (any gas that displaces oxygen in sufficient concentrations will not support life)	• Ventilation • Leak-detection systems
• Wide flammability range (4% – 75%)	• Can ignite or explode over a wide range of concentrations; leaks of all sizes are a concern	• Ventilation • Leak-detection systems

Designing Safe Systems – Gaseous Hydrogen

Characteristic	Potential Hazard	Control
• Low ignition energy	• Minimal energy (small spark) can ignite	• Ventilation • Grounding • System design/removal of possible ignition sources
• Burns with a pale blue flame that is nearly invisible in daylight and does not produce smoke • Low heat emission	• Potential for undetected flame	• Flame detectors

Designing Safe Systems – Liquid Hydrogen

Characteristic	Potential Hazard	Control
• Low liquefying temperature (-423°F/-253°C)	• Cryogenic burns • Lung damage	• System design • Leak-detection systems • Personal protective equipment
• Rapid phase change from liquid to gas	• Over-pressurization	• System design • Pressure-relief devices • Ventilation
• Spill may cause liquid oxygen to form on asphalt surface	• Shock-sensitive surface area	• Ventilation

Fuel Cell Basics

- The type of electrolyte determines the kind of fuel cell
  - The polymer electrolyte membrane fuel cell is the most promising for light-duty transportation
  - Other fuel-cell types, such as solid oxide, molten carbonate, and phosphoric acid fuel cells, use different electrolytes
- To increase the amount of electricity generated, individual fuel cells are combined into a fuel-cell "stack," which may consist of hundreds of individual fuel cells

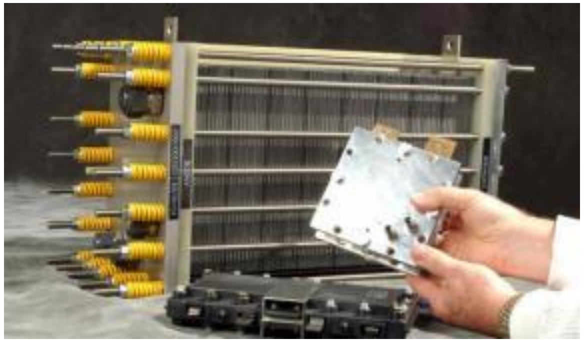
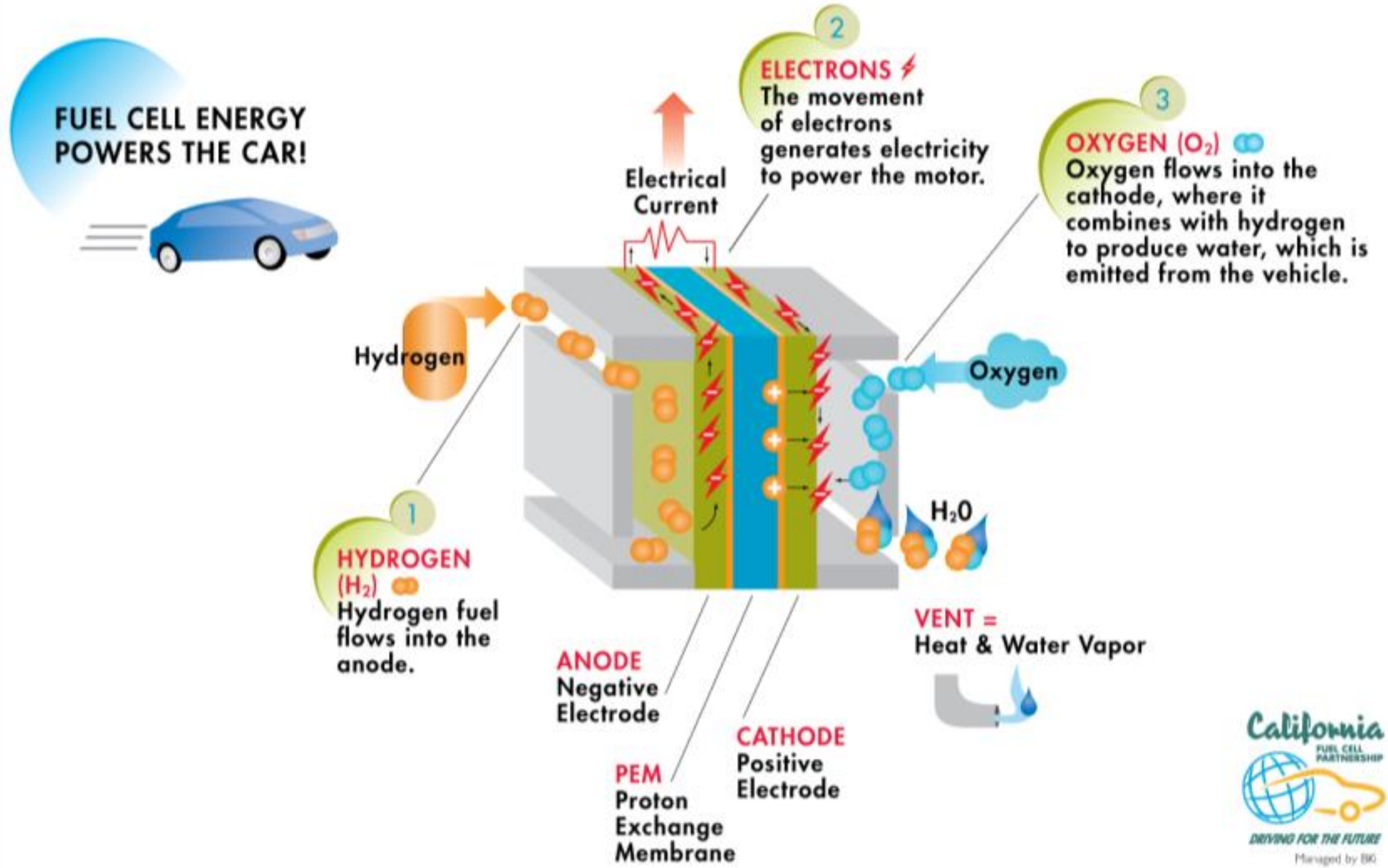


Photo: National Renewable Energy Laboratory

Photo: California Hydrogen Business Council

How a Fuel Cell Works



Fuel Cell Applications

Fuel cells have a broad range of applications:

- Transportation
  - Light and medium duty
  - Heavy duty and transit
  - Auxiliary power for refrigeration trailers and trucks
  - Forklifts
  - Maritime
- Stationary power
  - Backup power for cell tower sites
  - Combined heat and power
  - Data centers, etc.
- Portable power

Photo: Cellcom

Photo: Nuvera

24 x 7 Reliable Large Industrial-scale Fuel Cell Power

- 1MW (250kW x 4) net output
- Runs on a blend of digester gas and natural gas
- Connected in parallel with electric grid
- Provides 95% of the electrical requirements for the brewery
- Heat recovery provides about 65% of the hot water/steam requirements

Photo: FuelCell Energy

Fuel Cells for Specialty Vehicles

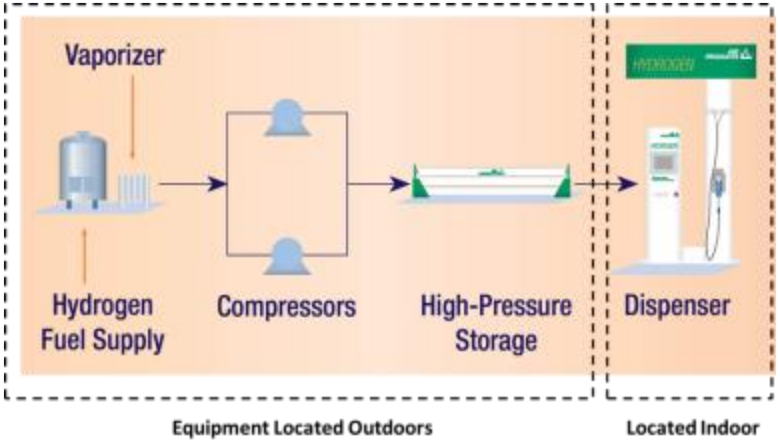
- Organizations with large warehouses or distribution centers can use fuel cells to power material handling equipment (e.g., industrial trucks)
- 3 to 8 kW fuel cells are typically paired with a battery
- Hydrogen gas is stored outside in cylinders and can be delivered or produced onsite. Hydrogen dispensers for industrial truck refueling are generally indoors

Photo: Hydrogenics

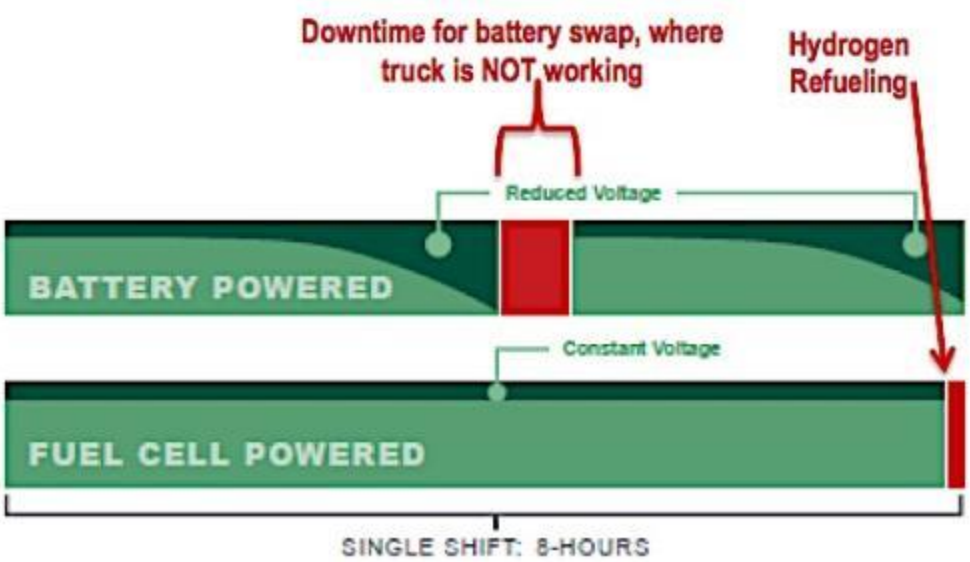
Photo: Plug Power

Industrial Trucks

Forklift Equipped with Fuel Cells



Typical Hydrogen Fueling Infrastructure (Courtesy of Air Products and Chemicals, Inc.)



- Forklifts are equipped with fuel cells as a replacement for traditional battery packs.
- A typical project consists of a refueling system (tank, compressor, piping, etc.) providing hydrogen to a dispenser located inside a warehouse.

Companies with Fuel Cell Industrial Trucks

Some of the companies that are deploying fuel cell industrial trucks in their facilities are:

- Walmart
- Sysco
- Whole Foods
- Coca-Cola
- Central Grocers
- Nestle Water
- FedEx
- Genco

Photo: Nuvera

Stationary Fuel Cell Lighting Application

- Developed by Sandia National Laboratories, Multiquip and Altergy
- Fuel cell and hydrogen tanks enclosed in mobile trailer
- 50,000-hour lighting lifetime
- High energy efficiency
- Very low noise level
- Zero emissions
- Indoor or outdoor use

Small Scale Applications for Fuel Cells

Angstrom
PowerCell Phones

Courtesy of Angstrom Power

Horizon
Fuel Cell Technologies

BRUNTON

Hydrogen-Fueled Vehicles (Light Duty and Transit)

In this section, we want to:

- Understand the basic components of a hydrogen vehicle
- Be able to recognize hydrogen vehicles from markings and labels
- Discuss the similarities and differences between hydrogen vehicles and other vehicles
- Be aware of vehicle safety features

Fuel Cell Electric Vehicles (FCEV)

- Run on hydrogen
- Use a fuel cell and electric motor, no engine
- Quiet, mostly air compressor and valves
- Emit zero pollutants

Mercedes-Benz

Nissan

General Motors

Hyundai / Kia

Honda

AC Transit

Volkswagen / Audi

Toyota

Public Vehicles

FCEV Coming soon

Standard Components of All Vehicles

- Similarities between hydrogen vehicles and other vehicles:
  - Outward appearance is the same
  - Vehicles share a number of the same components
- If an incident occurs with any vehicle, some of the following components may pose a potential hazard:
  - Bumpers
  - Shock absorbers
  - Tires
  - Hood and trunk struts
  - Airbags
  - Seat belt pre-tensioners
  - Air-conditioning system
  - Batteries

Example:

12-volt battery in an FCEV

Photo: Honda Motor Company

FCEV vs. Gasoline Hybrid-electric Vehicle

Similar components include:

- Electrical storage devices (batteries, capacitors)
- Electric motors
- High-voltage electrical cables
- Regenerative braking

Example:

High-voltage battery location in an FCV

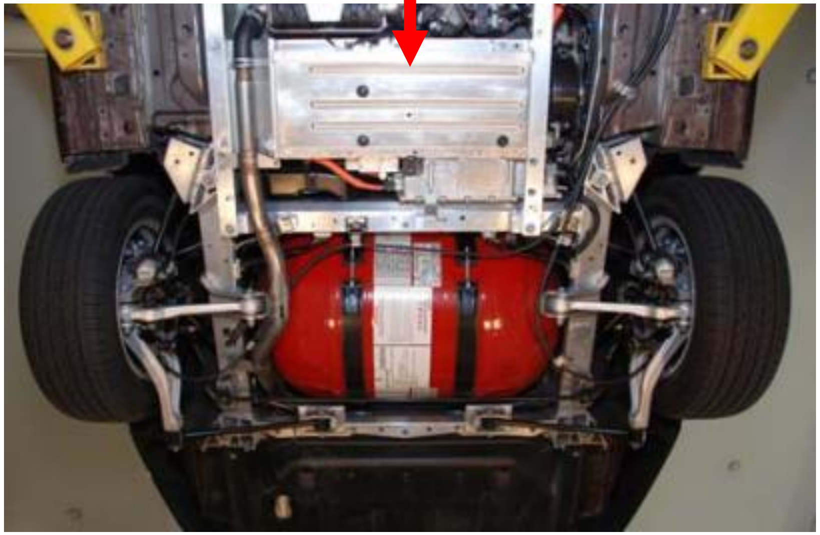


Photo: Honda Motor Company

FCEV vs. Compressed Natural Gas (CNG) Vehicle

Similar components include:

- High-pressure tanks (typically 3,600 psi for CNG and 5,000 psi or 10,000 psi for hydrogen gas)
- Low- and high-pressure fuel lines
- Pressure-relief device on tank (thermally activated)
- Pressure vent line (usually)
- Pressure in piping is reduced to typically <150 psig

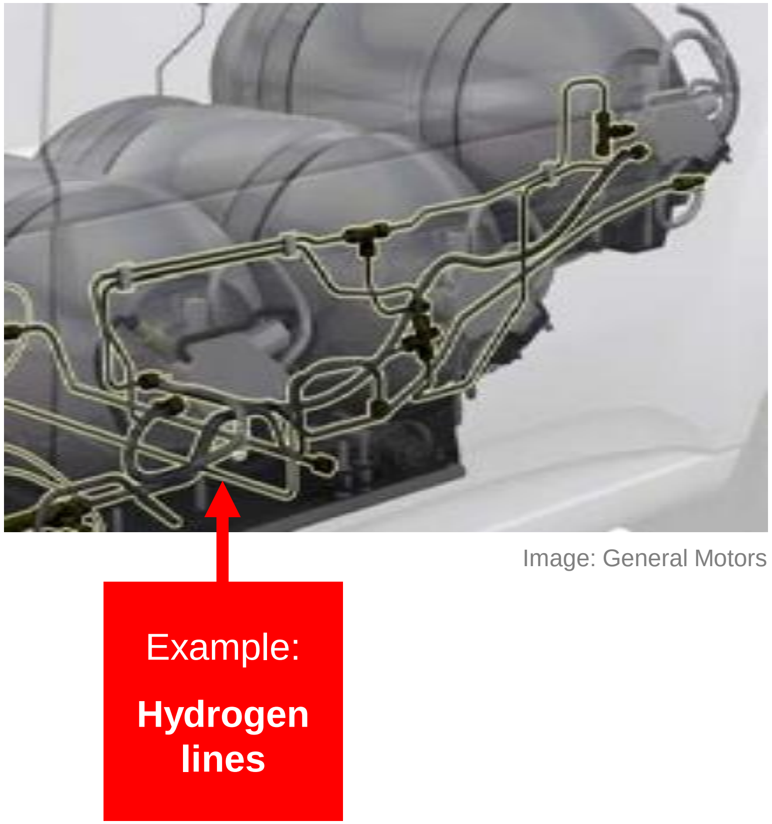
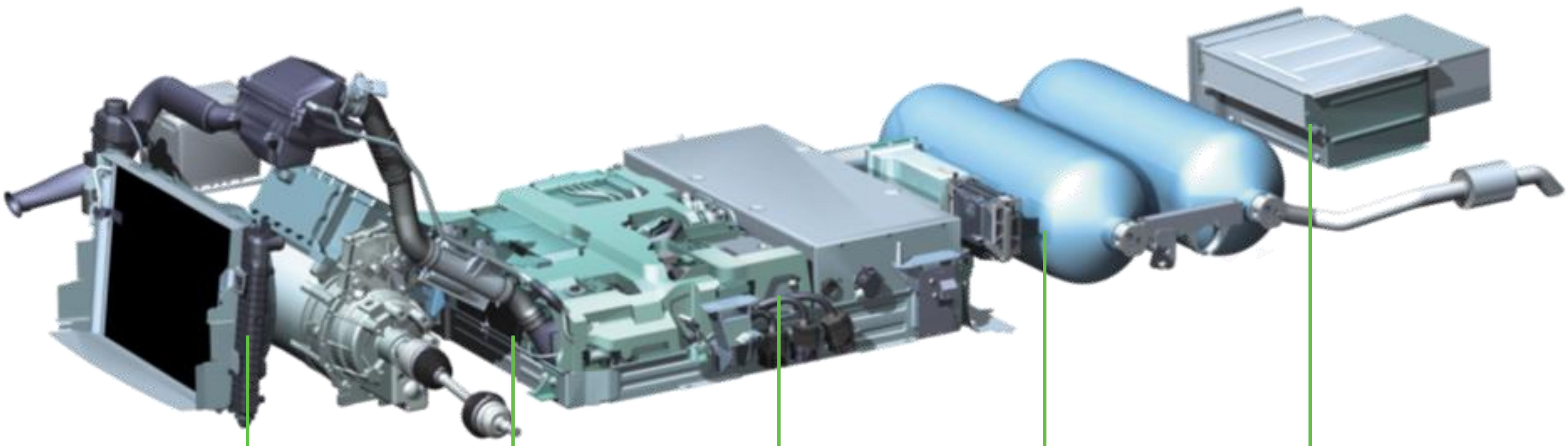


Image: General Motors

FCEV System Layout



Cooling System
Typically, slightly larger radiators than conventional

Electric Motor
Electrical component; drives vehicle by electricity

Power Electronics
Electrical component; distributes electricity

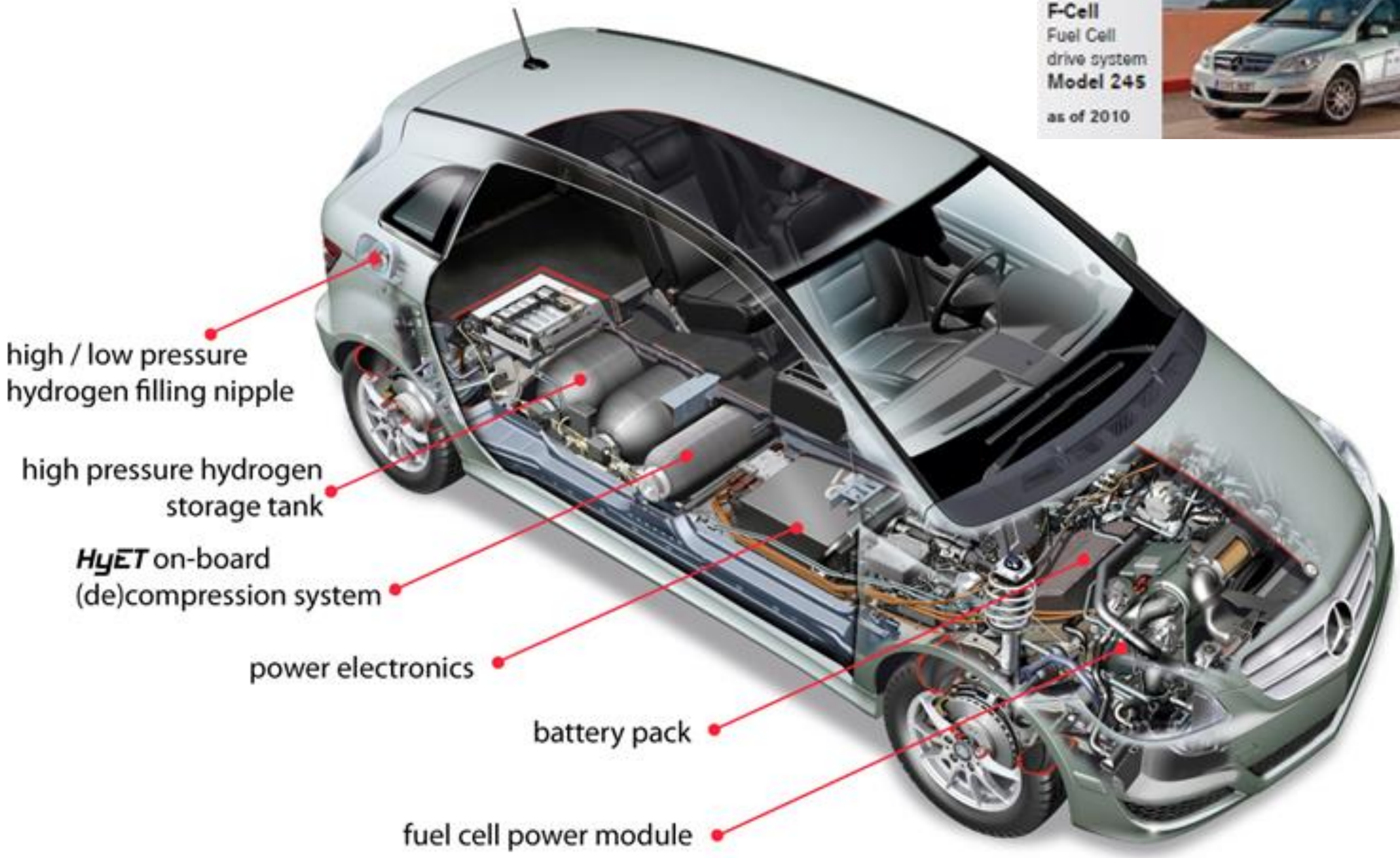
Fuel Cell
Electrical component; generates electricity from hydrogen

Hydrogen Tanks
Compressed, gaseous fuel; vehicle fueled with hydrogen

High Voltage Battery
Electrical component; captures regen braking, supports acceleration

Source: California Fuel Cell Partnership

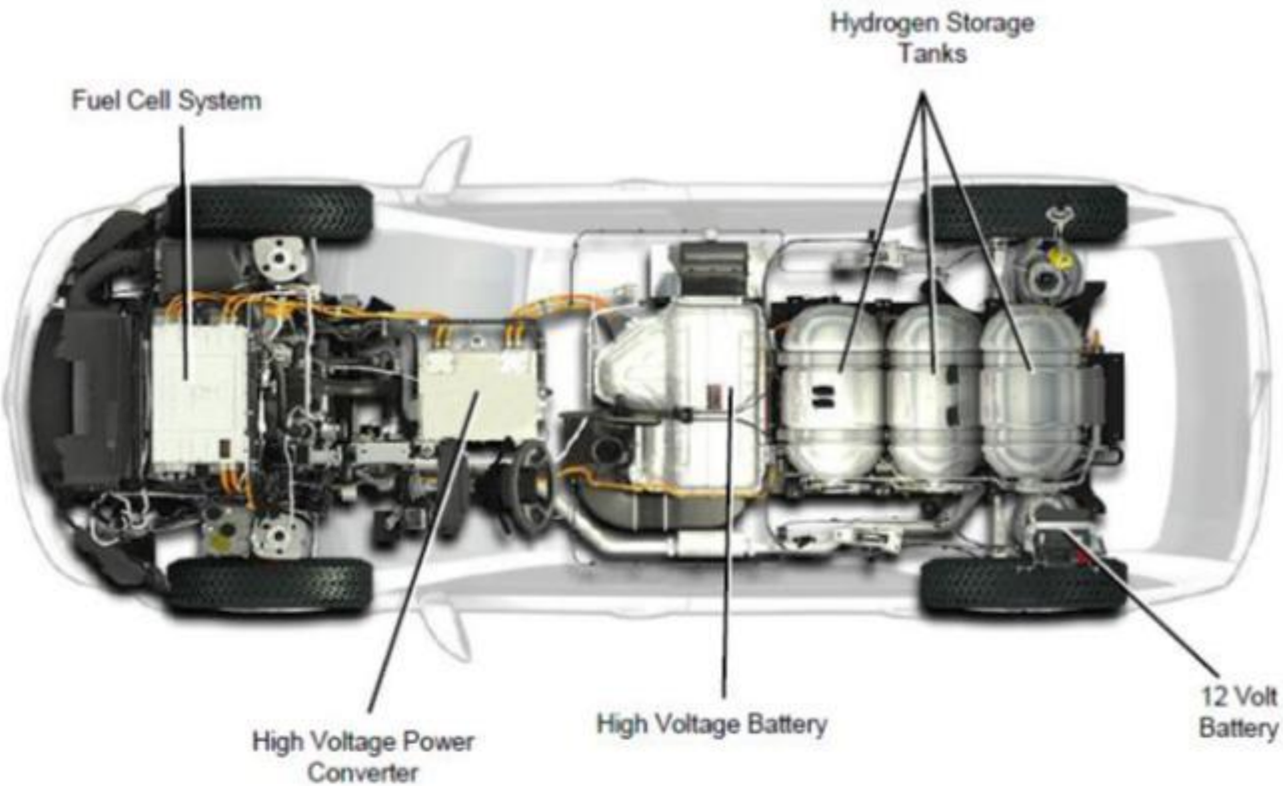
FCEV System and Passenger Layout



Fuel Cell Component Location

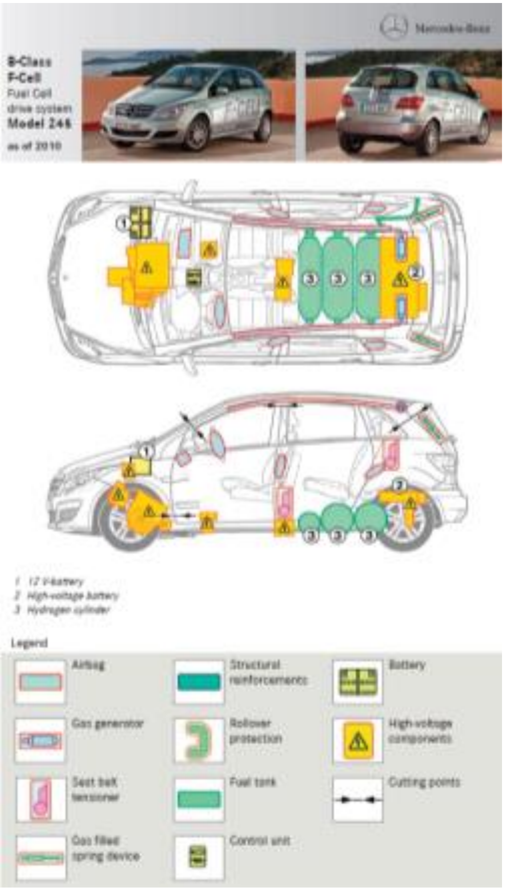
Equinox Fuel Cell Component Location

This illustration shows the location of the main Equinox Fuel Cell components from a top view of the vehicle.



Low and High Voltage Systems

- Fuel cells produce:
  - 200 – 450V (light duty)
  - 400 – 600V (buses)
- High-voltage batteries or ultra-capacitors
  - Additional power, braking regeneration
- 12V (light duty)/24V (bus) systems
  - Startup and running accessories



High Voltage System

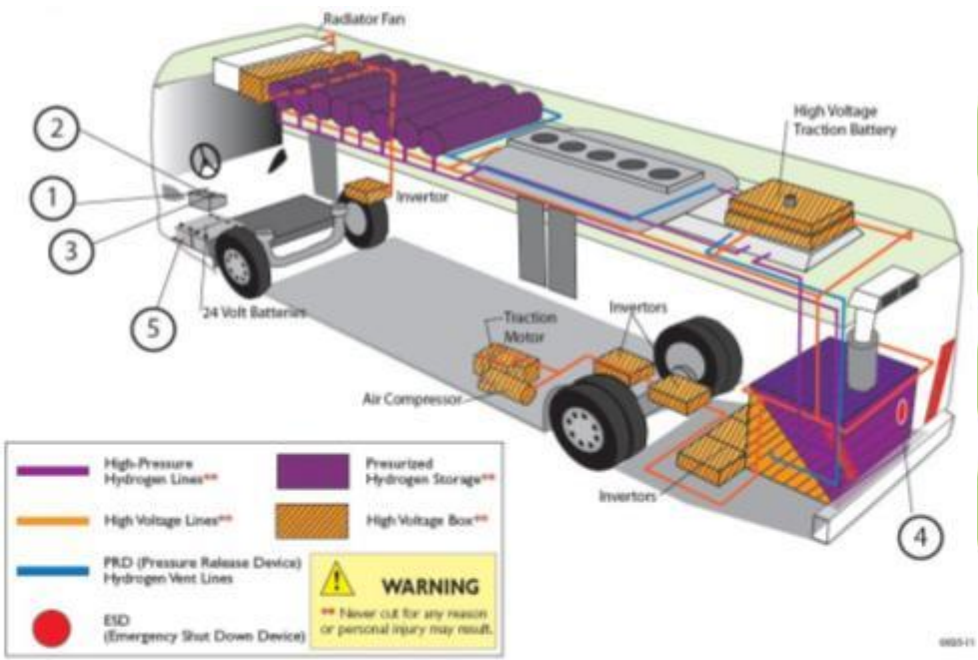
- Same technology as other alt fuel vehicles (gas/electric hybrids)
- Orange high-voltage wiring per SAE
- Isolated + and – sides (not grounded to the chassis)
- Automatic high voltage system disconnect
  - Inertia switch
  - Ground fault monitoring

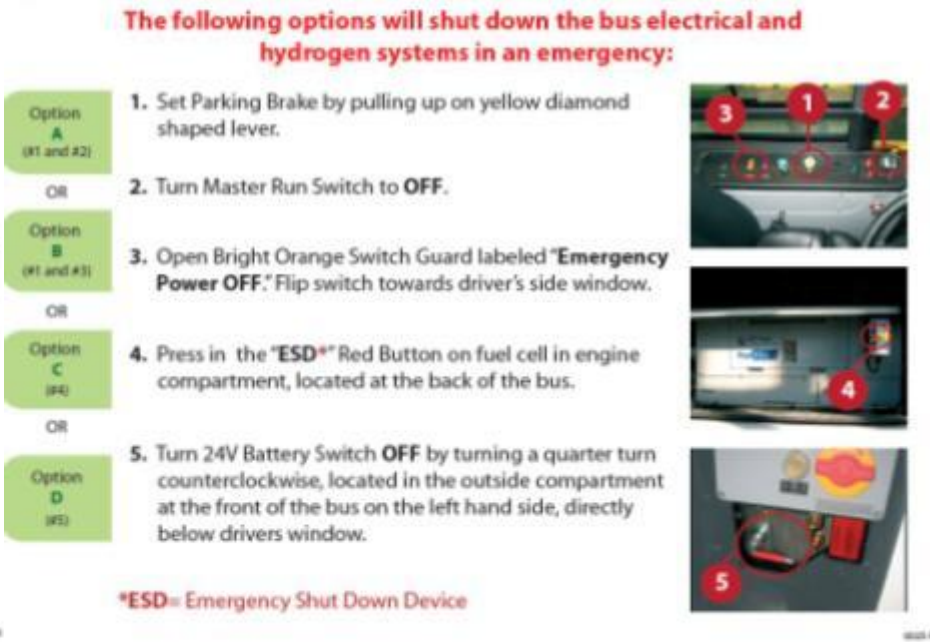
Light Duty Vehicle

Transit Bus

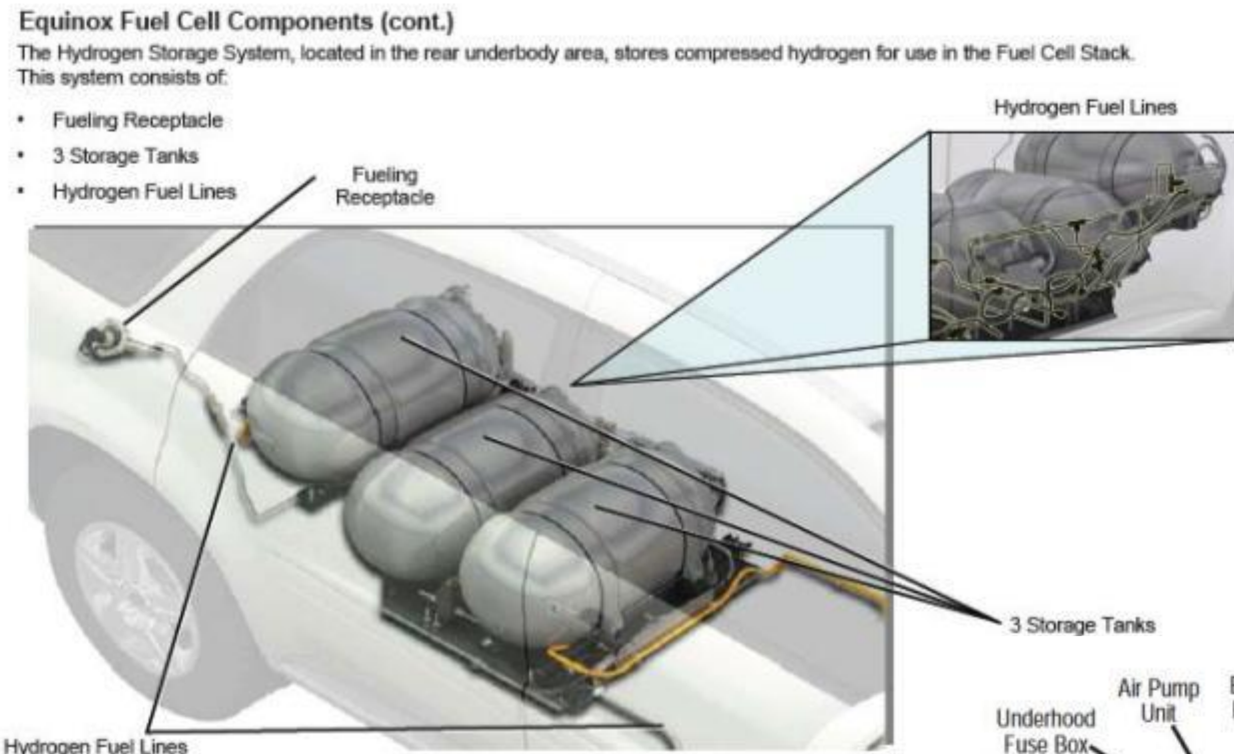
Bus Low and High-voltage Systems

- 24V (bus) systems
  - Startup and running accessories
- Fuel cells produce:
  - 400 – 600V (buses)
- High-voltage batteries or ultra-capacitors
  - Additional power, braking regeneration

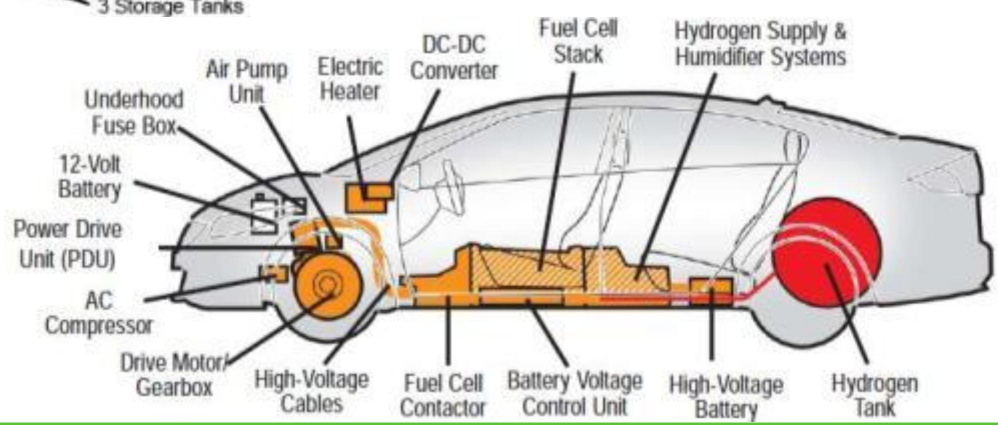




Hydrogen Delivery System



- Single tank and multi-tank set-ups
- Distribution lines contain lower pressures than tanks
- Tank PRDs/TRDs vent directly or are connected to fuel vent line(s)

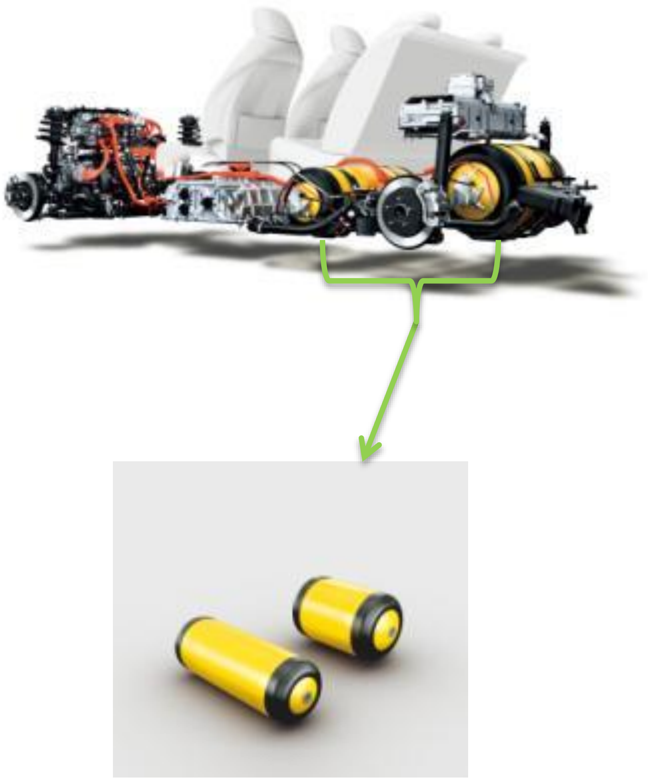


Hydrogen Delivery System – Bus

- Bus fuel tanks on roof
- All equipped with PRDs and vent lines
- Larger capacity storage

Onboard Hydrogen Storage

- Hydrogen can be stored as a gas or liquid
- To date, light duty vehicles use gaseous hydrogen
- Gaseous hydrogen: 35 or 70 MPa (approximately 5,000 or 10,000 psi, respectively)
- Passenger vehicles typically store up to 6 kg of hydrogen gas
- Buses with multiple tanks can store as much as 40 kg to 50 kg of hydrogen gas
- To date, buses carry gaseous hydrogen



Toyota Mirai fuel cell sedan power train, seats, and hydrogen tanks
Source: http://newsroom.toyota.co.jp/en/detail/4198334

Compressed Hydrogen Storage Systems

- Carbon fiber wrapped, metal or polymer lined tanks
- Equipped with temperature activated pressure relief devices (PRD/TRD)
- Stronger than conventional gasoline tanks
  - Absorb 5X crash energy of steel

Wall thickness comparison:
35 MPa vs. 70 MPa cylinders

(Photo courtesy of Powertech)

Example of Gaseous Hydrogen Storage System

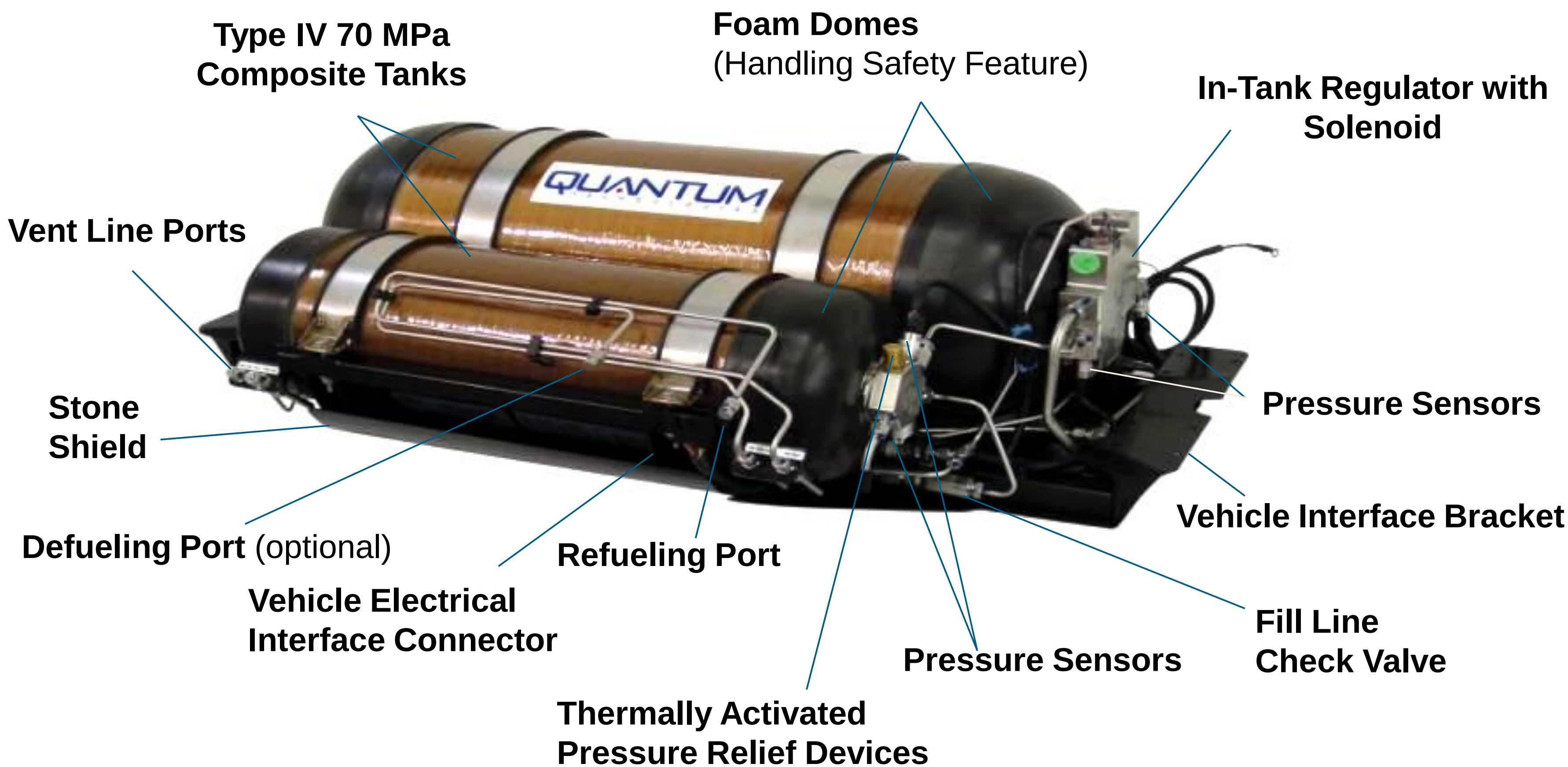
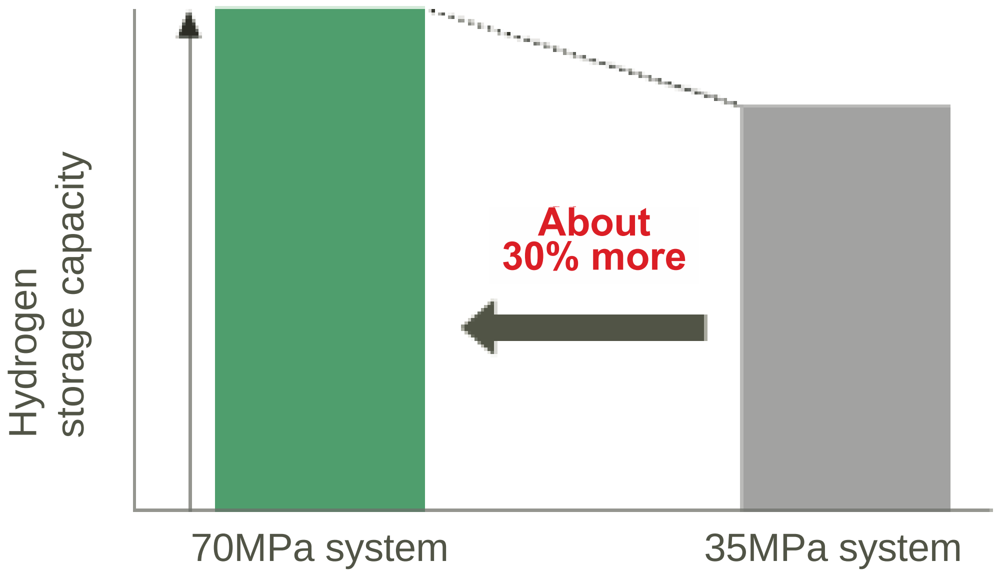
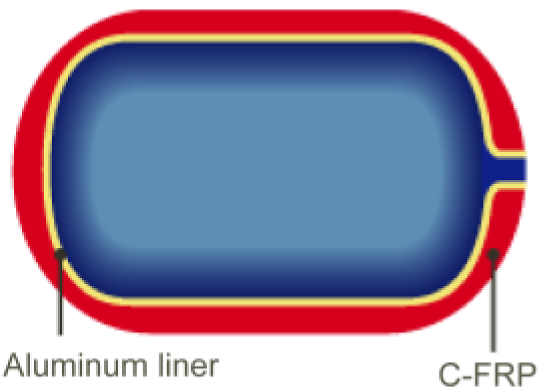


Photo: Quantum Technologies, Inc.

70 MPa Tanks

- A ~~The~~ **Type III,**10,000 psi ~~Nissan~~ tank holds ~30% more than a 5,000 psi tank. It has an inner aluminum liner and an outer layer of carbon fiber reinforced plastic with an optimally designed winding pattern for strength





Graphics: Nissan

Compressed Hydrogen Tank Testing

- Bonfire
- Drop
- Gun fire
- Pressure cycling
- Overpressure
- Temperature
- Impact
- Permeation
- “Tank life” – at least 15 years
- Rated for 2.25x service pressure

Compressed Hydrogen Tank Testing

- In accordance with latest proposed hydrogen vehicle tank standards (SAE J2579, CSA HGV2)
- Tests conducted as part of the design qualification testing for new tanks
- Vent only, no rupture

High Strain Rate Impact Test

Gunfire test of 35 MPa hydrogen tank:

- Objective: penetrate tank while pressurized
- Tank filled with hydrogen to 5,000 psi
- 30 caliber armor piercing bullet, 45° angle
- Simulate a high-strain rate penetration event due to collision

Bonfire Test

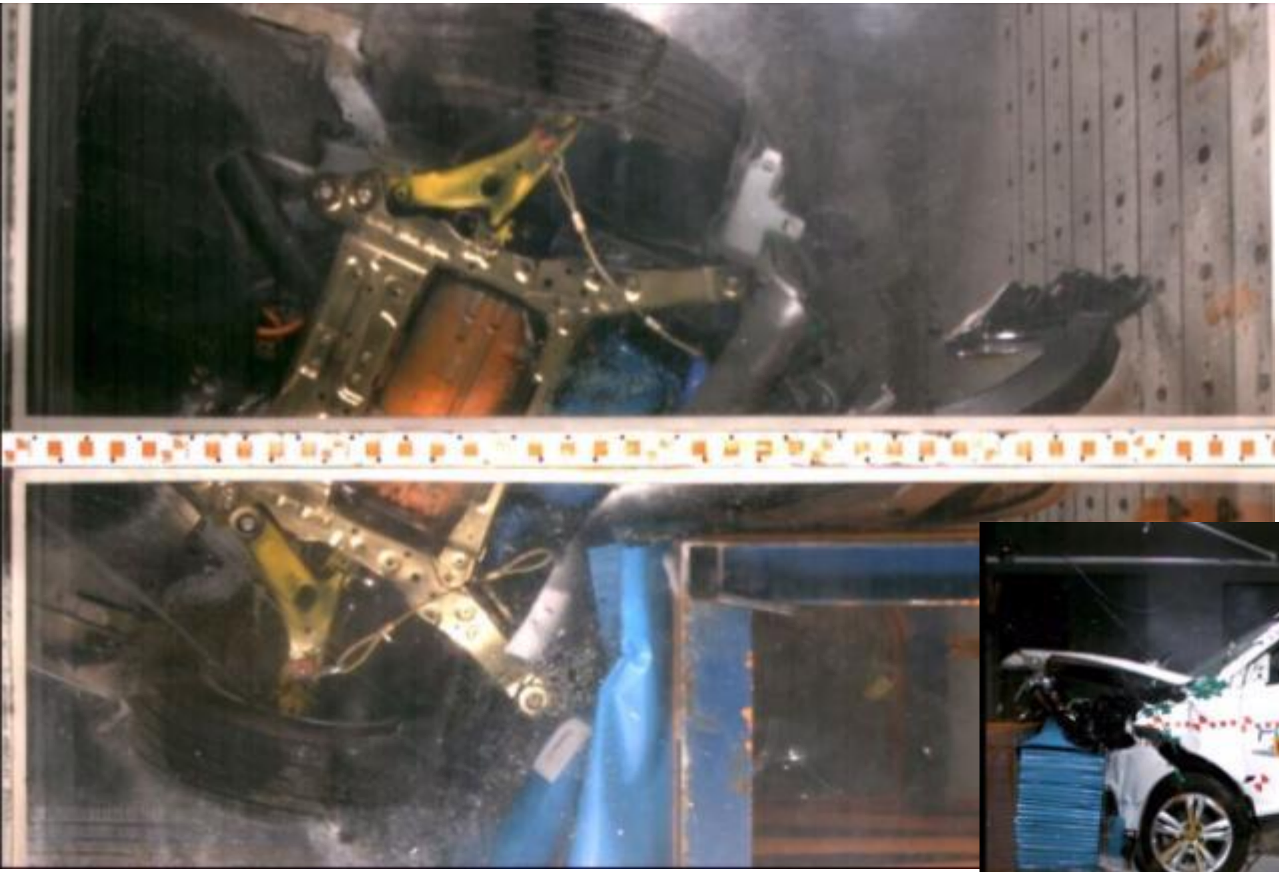
Bonfire test of 70 MPa hydrogen tank:

- Objective to simulate vehicle fire; entire tank engulfed
- Tank filled with hydrogen to 10,000 psi
- Subjected to a propane burner fire, 1.65m long
- PRD activated and hydrogen vented to atmosphere without incident

Equinox Fuel Cell – FMVSS 208 Certification (occupant protection)

Test With Operating Fuel Cell and Hydrogen Onboard Witnessed by NHTSA and Transport Canada

Hyundai ix35 FCEV- FMVSS 305 and ECE R94-25s Certification



Hyundai ix35 FCEV- FMVSS 305 and ECE R94-50s Certification

Fuel Isolation in Typical or Normal Operation

In typical operation of turning off the vehicle (key to "Off"):

- Cuts the 12 volt signal, therefore…
  - Closing the electrically activated solenoid(s) in the fuel storage system
  - Opening the electrically activated relays in the high voltage system
- This isolates the fuel to the tank and high voltage to the battery pack

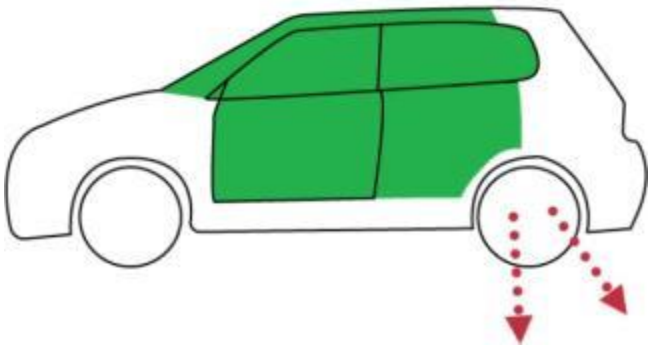
Photo: GM Equinox FCV

Ignition Switch Off (O) Position

Photo: Honda FCX Clarity

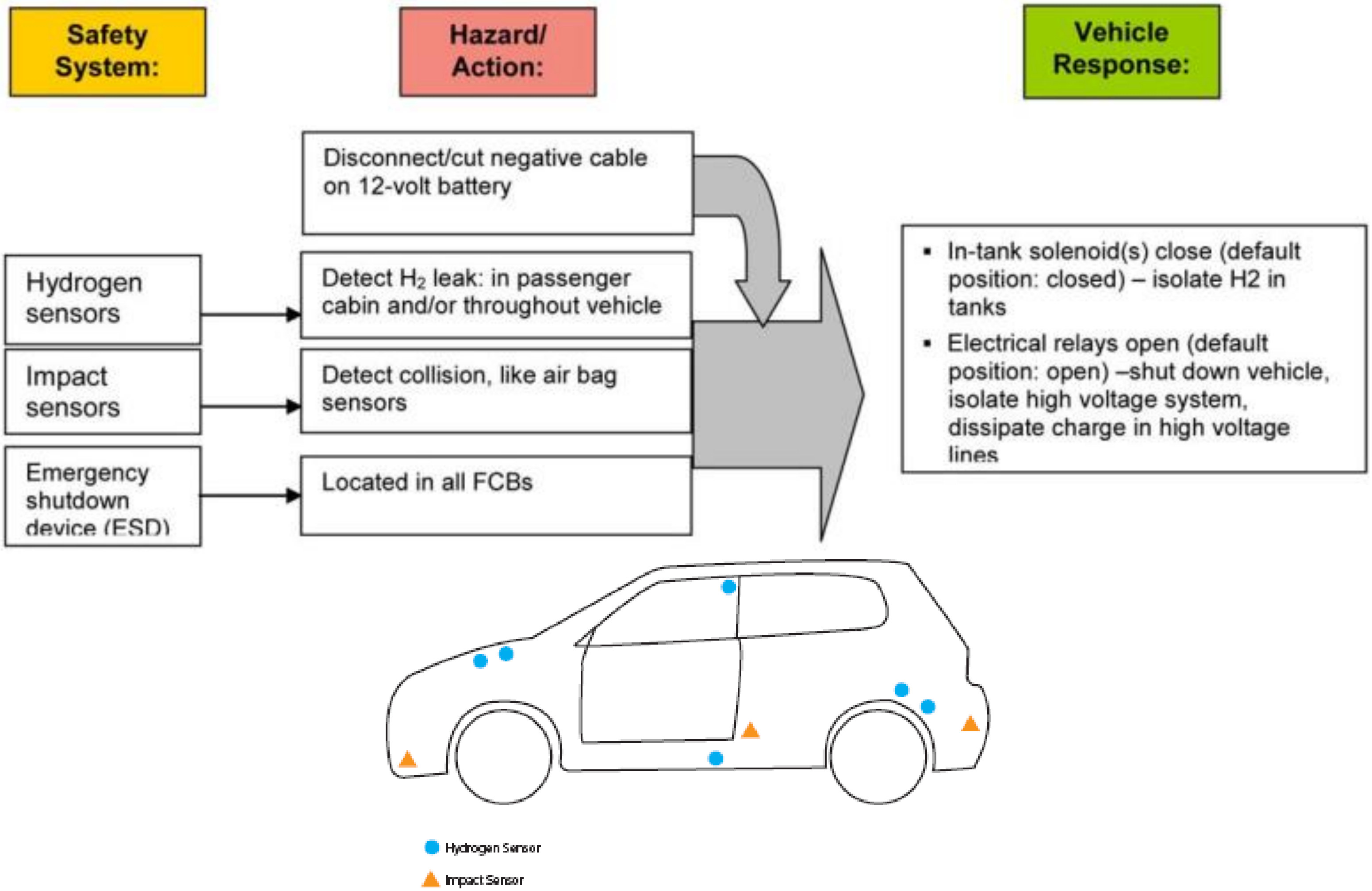
Hydrogen Vehicle Safety Systems

- When a leak is detected by hydrogen sensors, solenoid valves close, shutting off the flow of hydrogen, and the vehicle safely shuts down
- When collision sensors activate:
  - Tank solenoid valves close so that hydrogen remains locked in the tank.
  - In FCVs, high-voltage relays open so that the high-voltage battery/capacitors are isolated from the system
- Tank solenoid valves also close when the vehicle is turned off or the power is disrupted
- Tanks have thermally activated pressure relief devices (TPRDs)



TPRD vent direction

Safety Systems



Hydrogen Sensors Example

Image: General Motors

Stationary Facilities

This section describes and discusses:

- Types of stationary facilities
- Options for bulk transport and storage of hydrogen
- Stationary hydrogen fuel cell applications
- Components and configurations of a hydrogen fueling station
- Safety features of a stationary facility

Types of Stationary Facilities

Stationary facilities include:

- Stationary fuel cells
- Bulk hydrogen storage
- Hydrogen fueling stations

Photo: Air Products and Chemicals, Inc.

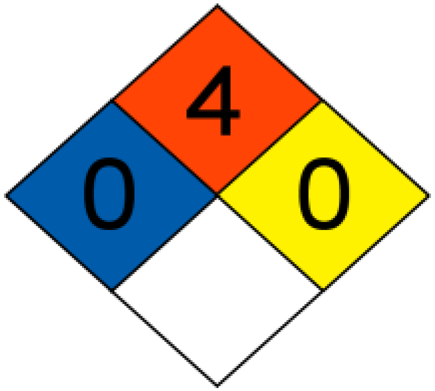
Photo: Plug Power, Inc.

Photo: California Fuel Cell Partnership

Identifying Stationary Facilities

NFPA 704 Hazard Placards

- Red = Flammability
- Blue = Health
- Yellow = Reactivity
- White = Special Precautions



Gaseous Hydrogen

Liquid Hydrogen

Hydrogen Fueling Stations




Components for Fueling a Hydrogen Vehicle

- The dispensing nozzle “locks on” to the vehicle before any hydrogen will flow
- Hydrogen dispensers are equipped with safety devices:
  - Breakaway hoses
  - Leak detection
  - Grounding platform

Photo: California Fuel Cell Partnership

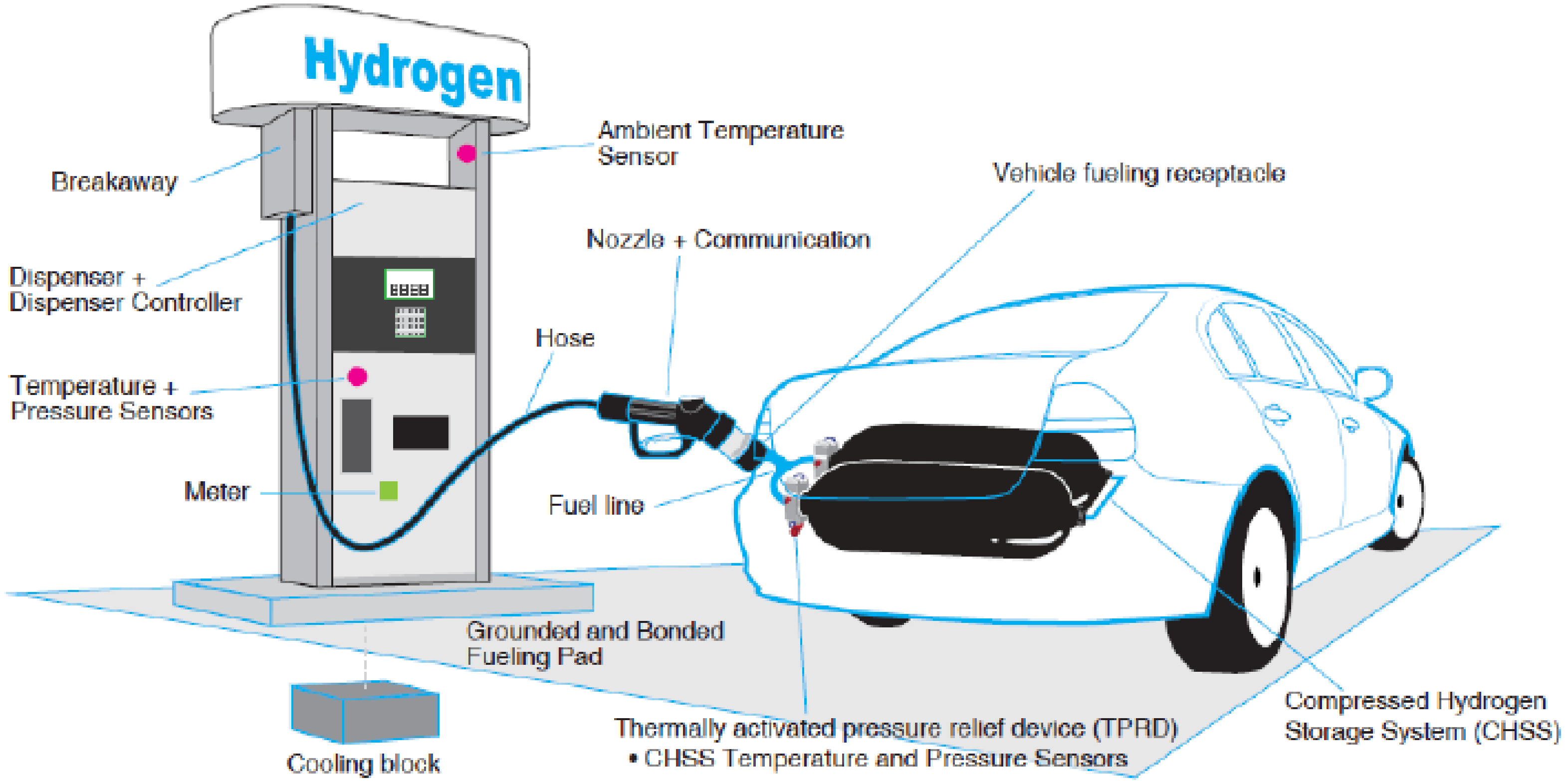
Hydrogen Fueling

- Closed-loop design, no leaks or vapors
- Experienced suppliers and providers: Linde, Shell Hydrogen, Air Products, Air Liquide, Hydrogen Frontiers, ProtonOnsite, **First Element, HTEC,** HyGen Industries and others

35 MPa Nozzle **(H35)**

70 MPa Nozzle **(H70)**

Hydrogen Fueling Diagram



General Station Safety Systems

- Pressure relief systems
  - Burst disks
  - Pressure relief valves/devices (PRV/PRD)
  - Safety vents
- Fire and leak detection systems
  - Telemetric monitoring
  - Hydrogen gas detectors
  - UV/IR cameras
  - Fueling line leak check on nozzle connect

ASME steel and composite stationary storage tubes

General Station Safety Systems

- Design elements
  - Engineering safety margins and analysis (HAZOP, etc.)
  - Hydrogen compatible materials
  - Siting to established regulations
  - Cross-hatched areas for user attention
- Other systems
  - Emergency stops
  - Dispenser hose break-away devices
  - Impact sensors at dispenser
  - Controlled access
  - Excess flow control (fueling)
  - Pre-coolers (-40^{o}F)

Typical Station Configurations

- Hydrogen can be delivered or made on site
- Liquid delivered $\rightarrow$ gaseous H_2
- Gaseous delivered or piped $\rightarrow$ booster compressed gaseous H_2
- Natural gas $\rightarrow$ gaseous H_2
- Water + electricity $\rightarrow$ gaseous H_2

Hydrogen Fueling Stations
Gaseous Hydrogen Delivery

Gaseous hydrogen can be delivered to the fueling station by tube trailer or mobile refueler

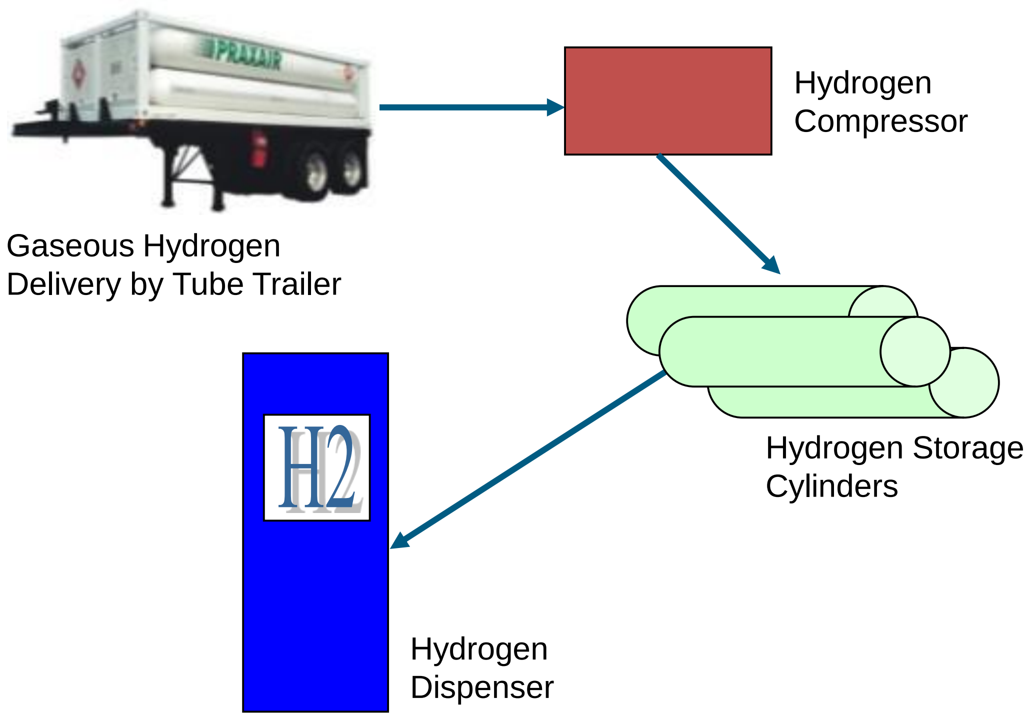
Photo: National Renewable Energy Laboratory

Photo: U.S. Department of Energy

Gaseous Hydrogen Storage

Gaseous hydrogen is:

- Delivered to fueling station by tube trailer
- Compressed and stored onsite in cylinders
- Piped to dispenser for fueling vehicles



Graphic: Pacific Northwest National Laboratory

Hydrogen Fueling Stations
Liquid Hydrogen Delivery

Liquid hydrogen can be delivered to the fueling station by tanker truck, as is shown for this hydrogen and gasoline station

Compressed gas storage

IC 90 Compressor

LH2 tank

Fueling dispenser & canopy

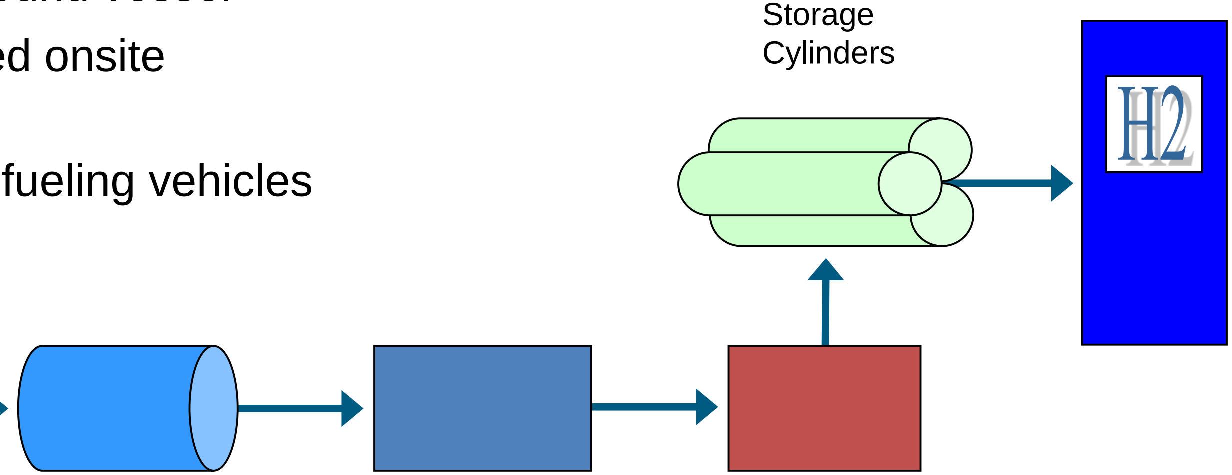
Photos: California Fuel Cell Partnership and Linde.

Liquid Hydrogen Storage

Liquid hydrogen is:

- Delivered to fueling station by tanker truck
- Stored underground as a liquid
- Vaporized in above-ground vessel
- Compressed and stored onsite in cylinders
- Piped to dispenser for fueling vehicles

Liquid Hydrogen Delivery by Tanker Truck



Onsite Hydrogen Generation by Reforming

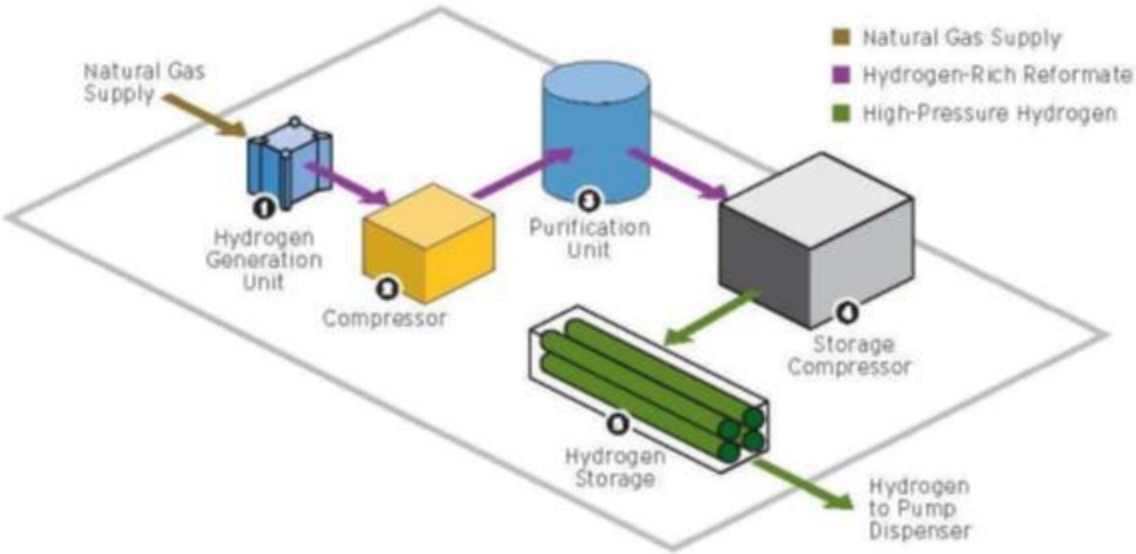
- Hydrogen can be generated onsite at the fueling station
- Photo shows a station in Newport Beach, California
- Natural gas is piped to the station and converted to hydrogen in a reformer

Photos: California Fuel Cell Partnership

Hydrogen Fueling Stations

Onsite Reforming Components

- Some hydrogen fueling stations use reforming technology to convert natural gas into hydrogen
- Hydrogen is compressed, purified, stored, and dispensed into fuel cell vehicles



Station can fuel up to 2 fuel cell vehicles in 3 to 5 minutes.

Hydrogen Fueling Stations

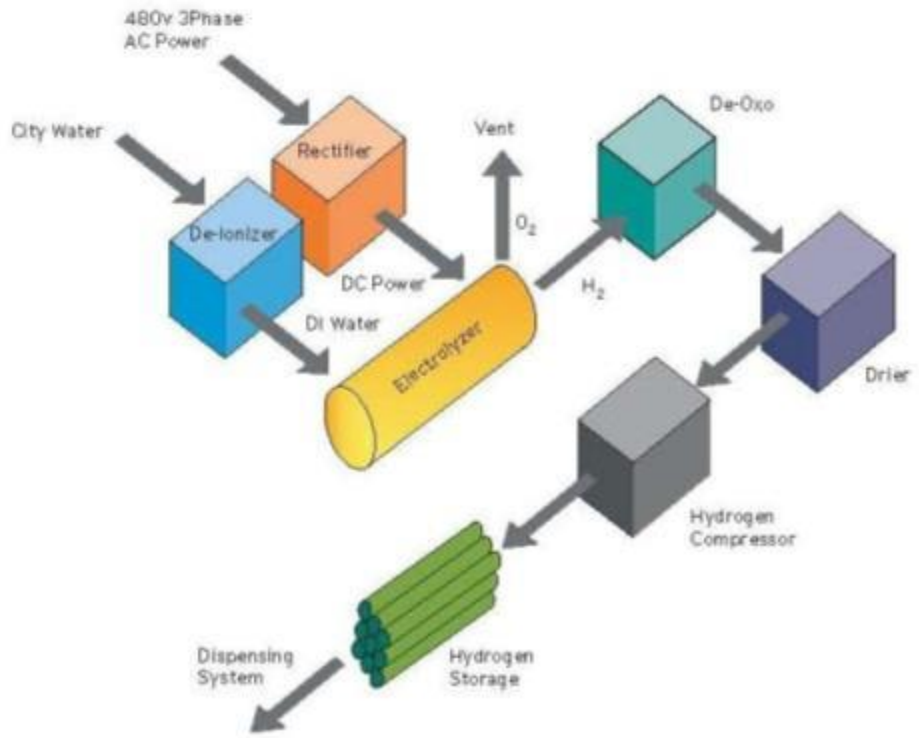
Onsite Hydrogen Generation by Electrolysis

- Hydrogen can be generated onsite by electrolysis of water as at Emeryville, CA with this Proton OnSite electrolyzer
- Using 100% renewable solar-powered electricity, it produces 65 kg/day of hydrogen for dispensing to passenger vehicles

Photos: CaFCP

Hydrogen Fueling Stations
Onsite Electrolysis Components

- City water and electricity are fed to an electrolyzer
- Electricity splits water into hydrogen and oxygen, which are separated
- Hydrogen is compressed and stored in tubes
- High-pressure hydrogen is sent to dispenser to fill FCEV hydrogen tanks up to 10,000 psi



Comparison Between Gasoline and Hydrogen Fueling Stations

Component	Gasoline	Hydrogen
Number of U.S. Fueling Stations	**Nearly 153,000**	**Less than 100**
Fuel Storage	**Tanker trucks pump gas into storage tanks** (above or below ground)**.**	**Hydrogen can be stored as a liquid or a compressed gas in cylinders, tubes, or tanks. Currently all storage is above grade.**
Fueling	**Stations are self-service, except in Oregon and New Jersey. No smoking and no cell phone use.**	**Vehicles are currently fueled by the driver/consumer. No training is required per NFPA 2. Same general safety applies: ~~n~~o smoking and no cell phone use.**
Vehicle Interface	**Nozzle *may* have vapor recovery device(s).**	**Nozzle must lock in place for hydrogen to flow.**
Fueling Station Safety Systems	• **Dispenser hose break-away devices** • **Emergency stop buttons** • **Vapor recovery systems** • **Emergency electrical disconnects on fuel dispensing systems** • **Automatic fire suppression systems** • **Warning signs** (e.g., “do not re-enter vehicle while gas is pumping”)	• **Dispenser hose break-away devices** • **Emergency stop buttons** • **Pressure-relief systems** (e.g., burst disks, PRDs, safety vents) • **Leak and flame detection systems** • **Grounding** • **Continuous monitoring**

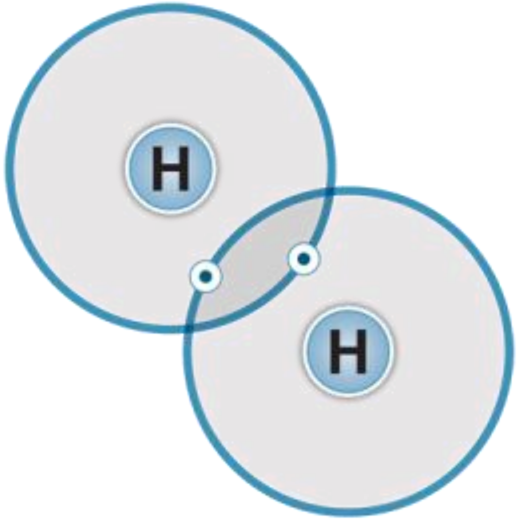
In this section, we want to:

- Discuss potential hazards associated with hydrogen vehicles and stationary facilities
- Discuss emergency response actions for both vehicle and facility incidents within the context of the National Fire Academy (NFA) Command Sequence
- Identify sources for additional emergency response information useful in dealing with a hydrogen incident

Considerations for Managing Hydrogen-related Emergencies

Buoyancy of hydrogen gas:

- It's 14 times lighter than air
- When released outside, it rises at ~45 mph
- It's a small molecule and very difficult to confine
- When released inside, it quickly finds its way through most materials
- Due to an inverse Joule-Thomson effect, hydrogen does not cool the surrounding environment (won't cause ice on the valve)



Molecular Hydrogen

Considerations for Managing Hydrogen-related Emergencies

Radiant heat:

- The hydrogen flame is ~ 4010 °F, but no radiant heat is produced. Responders may not feel heat until almost in the flame
- Gasoline releases carbon when it burns, so radiant heat can be felt from a great distance
- Due to CO_2 released when burning, E85 produces twice the radiant heat as the same volume of gasoline

National Fire Academy (NFA) Command Sequence

1. Size Up (Think) — **SIZE-UP**
2. Identify Strategy/Tactics — **PLAN**
3. Assign Tasks — **ACT**
4. Review Results of Actions/Critique — **EVALUATE**

Photo: Volpentest HAMMER Federal Training Center

Follow SOPs for vehicle response, paying particular attention to unique systems and characteristics for hydrogen-powered fuel cell vehicles

Hydrogen Vehicles

SIZE-UP

The hazards encountered with hydrogen vehicles are similar to those of other vehicles. Questions to ask during size up should consider:

- Types of vehicles involved (cars, small trucks, buses)
- Fuels and quantities (gasoline, diesel, E85, LPG, hydrogen, hybrids)
- Closed compartments (drive shafts, batteries, LPG tanks, hood or trunk struts, passenger compartments, tires, fuel tanks)
- Exposures (including other vehicles, structures, cargo)

Hydrogen Vehicles

SIZE-UP

Additional considerations during vehicle incident size up:

- Hydrogen fuel tank
  - Is there fire?
  - If so, is it impinging the hydrogen tank?
  - Is the tank currently venting?
  - Has the tank already vented?
- Hydrogen fuel
  - If the hydrogen is venting, is it burning?
  - If the hydrogen is not burning, are there potential ignition sources?
  - Can the hydrogen be dispersed to levels below the LFL?

Hydrogen Vehicles

SIZE-UP

High-Voltage System, Potential Ignition and Shock Hazard:

- Has the key been turned off and removed from the ignition? If key is unreachable, consider disconnecting or cutting the low-voltage battery cables
- Are any of the high-voltage components exposed? Avoid these until fully deactivated

  Note: Power remains in system for 5 minutes after deactivation
- Is the high-voltage battery on fire?

  Note: Nickel metal hydride batteries, common in these vehicles, may reignite if left smoldering

Formal Identification

PLAN

May have decals and graphics identifying car/bus as an FCEV

Formal Identification

PLAN

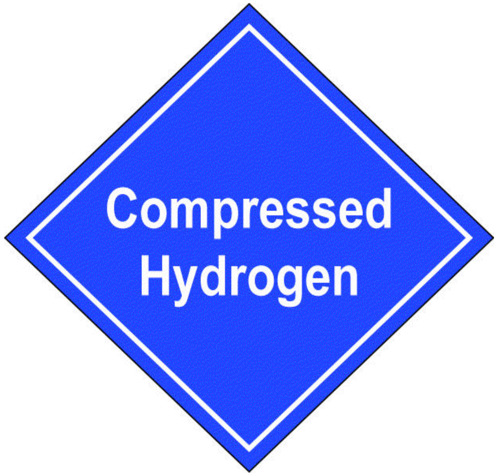
Vehicle badging, per SAE International

Formal Identification

For vehicles greater than 19,500 lbs (8845 kg) GVWR (Heavy duty)

Blue diamond sticker on rear

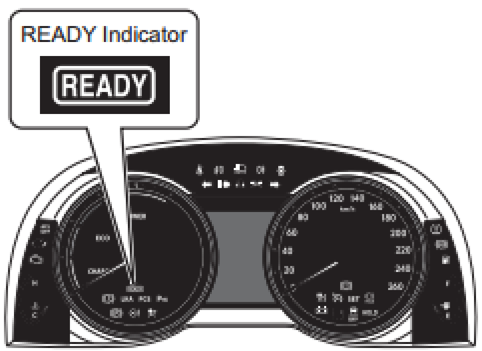
- SAE J2578 example
  (follows NFPA 53 for CNG)

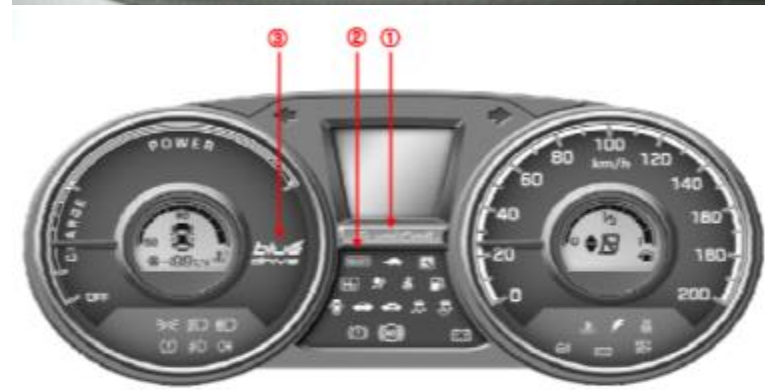


Informal Identification

PLAN

- Never assume the vehicle is off
- Be aware that vehicle is quieter than a typical internal combustion engine vehicle during start up and shut down
- Check the driver instrumentation panel for indication of vehicle operation





Informal Identification

PLAN

Graphics displayed are typical of what you will see on vehicles, but can vary by vehicle.

Informal Identification

PLAN

Fueling receptacle

Design clues

Interior

PLAN

The underside does not resemble a conventional vehicle

PLAN

How Do You Identify Other Types of Vehicles?

PLAN

Vehicle Identification

The Chevrolet Volt badging is one method of identifying the vehicle. The vehicle's logo is located on the right-front and left-front fenders as well as the deck lid.

VOLT

Hydrogen Release Indicators

SIZE-UP → PLAN

Compressed H_2

- Very loud hissing (almost all leaks will be audible)
- TPRD[1] release → controlled high-pressure hydrogen rapid release through safety vent
  - Occurs if tanks are exposed to high-temperature heat (e.g., fire)
  - Avoid cutting into hydrogen lines

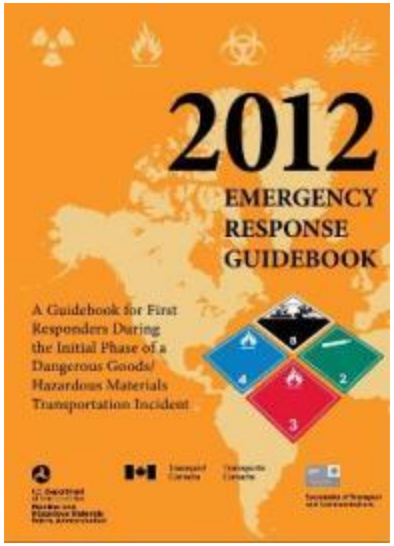
[1] TPRD – Thermally activated pressure relief device

PLAN

Hydrogen Transport Vehicles

Keep unauthorized personnel away. The following guidance is from the DOT/ERG:

- **Small spill/leak.** Isolate area for at least 100 meters (330 feet) in all directions
- **Large spill/leak.** Evacuate downwind for at least 800 meters (half mile)
- **Fire** (a tank, rail car, or tank truck involved in fire). Isolate for 1,600 meters (1 mile) in all directions



Standard vehicle response strategies and tactics are effective

- If the accident involves hydrocarbons on the ground, approach from an uphill and upwind position
- Control any hydrocarbon ground fire before approaching vehicles

Hydrogen Vehicles

PLAN

- If only a hydrogen vehicle is involved, approach per standard procedures, and from a downhill and upwind position
- Listen for venting gas, and watch for thermal waves that would signal hydrogen flames
- If a hydrogen fire is present:
  - Attack with a straight water stream from a distance, but avoid spraying water into the pressure vent
  - Control fire spread and cool exposures
  - Allow hydrogen to burn out if safe to do so, while protecting adjacent exposures; then approach and extinguish
  - If possible, direct venting hydrogen that is not burning away from ignition sources and dissipate if necessary with fog nozzle streams

Hydrogen Vehicles

PLAN

- If safe to do so, isolate high-pressure and high-voltage systems by turning off key and/or cutting negative cable of battery
  - It may take a few minutes for electric motor to completely discharge. This is true for electric and hybrid vehicles as well
  - Be aware of other safety features such as air bags, seat belt pre-tensioners, curtains, etc.
- Allow high-voltage batteries to burn out, or aggressively extinguish with water
- During the overhaul or wrap-up process, if not already performed,
  - Immobilize the vehicle
  - Place vehicle transmission in "park"
  - Chock the wheels
  - Remove the key from the ignition switch
  - Disconnect the 12-volt auxiliary battery

Photo: American Honda Motor Co., Inc.

Hydrogen Lines and High Voltage Systems

SIZE-UP → PLAN

- **Avoid** cutting into hydrogen lines, storage tanks or PRD vent lines
  - No standard markings
  - Most hydrogen fuel lines are silver, stainless steel
- **Do not** cut high-voltage cables
  - **Orange** in color per SAE standard
  - 200 to 500 volts; 200 to 300 amps

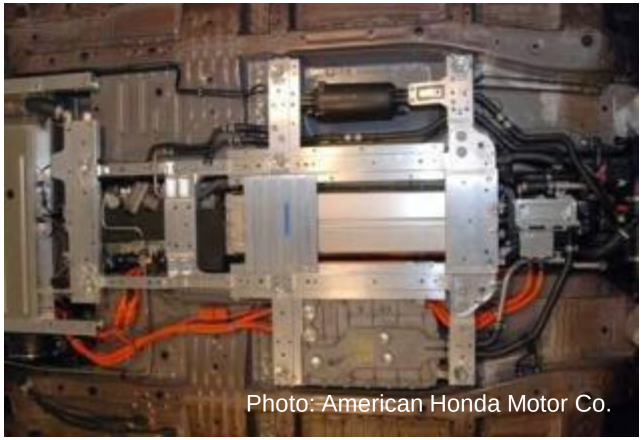


Photo: American Honda Motor Co.

Isolate

ACT

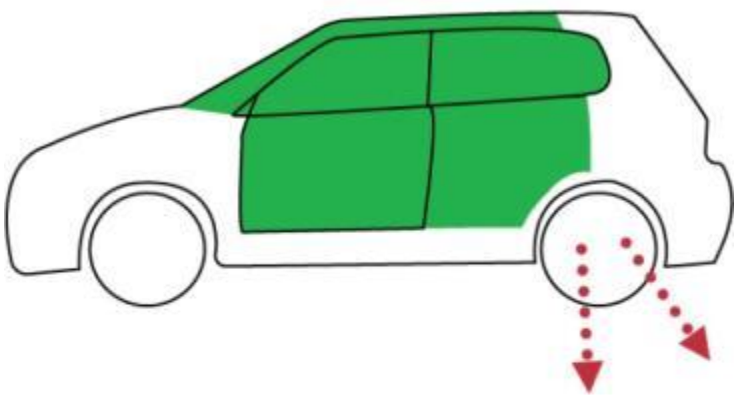
Multiple vehicles and different fuels

- FCEVs heavier than conventional vehicles
- When safe, move the conventional vehicle away from the FCEV
  - Heat from gas fire can trigger TPRD
- Spray foam on gasoline or diesel leaks near FCEV
  - Let hydrogen-fed fires burn out if safe to do so

ACT

Rescue: Extrication

- Avoid the TPRD vent
- Stabilize & disable per SOPs
- Dash roll/push: avoid using cutters or spreaders on rocker panel/channel…
  - May risk cutting into fuel or HV lines
- Use cradle or saddle
- Relief cut above bottom hinge on the A-post is ok (to roll dash using spreaders)



Hydrogen Vehicle
Extrication Considerations

ACT

Extrication Considerations:

- Possible pressure relief device vent locations are shown by arrows – actual vent locations are under the vehicle off the fuel storage system - see manufacturer's information for details
- Only cut passenger compartment; avoid cutting into floor panel
- No hydrogen lines run through the A and B pillars of any model
- Be aware that side and roof air bags and curtains may be present, as with other vehicles

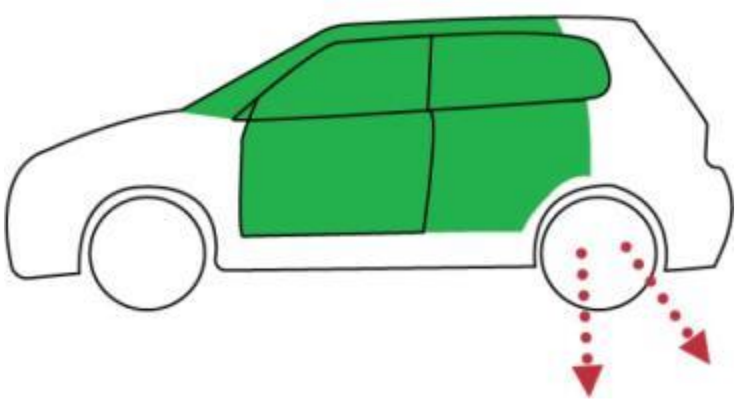


Image: California Fuel Cell Partnership

Extrication Tactics

ACT

Extrication Tactics:

- Use normal extrication techniques
- Check for airbags, hydrogen lines, and high-voltage electrical cables before cutting
- Use only “pinch weld” jacking points for cribbing or raising vehicles with airbags
- Avoid cutting hydrogen lines, hydrogen tanks, or components of the high-voltage system
- High-voltage batteries may contain combustible metals or caustic electrolyte (KOH with a pH of 13.5); use proper protective clothing and neutralize spill
- ***Do not get electrolyte on exposed skin!!!***

Extrication

Dash Roll

ACT

- Dash roll: for a purchase point on the rocker panel…
  - Cradle or saddle
  - Notch the rocker panel
- Relief cut ok
  - Bottom of A post
  - Between hinges
- Avoid cutting through underside of vehicle

Hydrogen Vehicles
Extrication Training

ACT

Extrication Training at Corona Auto-X Event in California with a Hyundai FCV being cut up (April 2010)

Dash roll/push, jacking the dash

Removing the roof; no H_2 vent lines in the C or D pillars/posts, already did the “peel & peek” for airbag cylinders

After the demo: all doors, hood ,and roof removed, and dash rolled

Showing a dash roll by cutting A-pillar and pushing with spreaders (no high voltage cables present)

Removing the back door

ACT

Dash roll and B-pillar blowout on both sides without issue – no components with which to be concerned

ACT

Taking off the roof – no issues

Stationary Facilities

SIZE-UP

Stationary hydrogen facilities will have hazards similar to facilities with other compressed and/or cryogenic gas processing or storage systems

- Gas or liquid storage?
  - High-pressure cylinder storage
  - Cryogenic liquid storage
- Is there a leak or flame present?
  - Gaseous hydrogen: use combustible gas/hydrogen detector and thermal-imaging cameras
  - Liquid hydrogen: look for ice crystals/frozen water vapor
- Is the leak confined by a structure? Ventilation adequate?
- Onsite reforming? Is a methane source present?
- Presence of other fuels (e.g., CNG, propane, gasoline)
- Identify potential ignition sources

Stationary Facilities

PLAN

- Isolate and deny public entry
- Approach from upwind
- Eliminate ignition sources, activate emergency stops if accessible
- Use leak-detection devices and thermal-imaging cameras to assess hazard potential
- Use water fog to dissipate/control escaping gas
- Do not touch/walk through product
- Allow hydrogen to burn if safe to do so
- Deploy master streams to protect exposures
- Do not spray water into pressure relief vents

Vehicle and Facility Incidents

ACT

- Determine if currently assigned personnel and resources will be adequate
- Request additional resources early in process to ensure timely deployment
- For personnel assigned to an individual task, maintain proper span of control (3 to 7 people)
- Assign tactics/tasks

Photo: Volpentest HAMMER Federal Training Center

Vehicle and Facility Incidents

EVALUATE

- Observe effectiveness of strategy and tactics
- Identify whether fire is growing, diminishing, or static
- If fire is static or growing, there may be an unidentified fuel source feeding fire growth
- Watch for presence of new or unidentified hazards
- Adjust strategy and tactics as appropriate

Photo: Volpentest HAMMER Federal Training Center

SECTION 6:
Practical Exercises

This section is intended to provide materials for a practical exercise in a classroom training setting. Instructors assign a single incident scenario to each of several small teams of participants.

- Each team gets a specific amount of time to discuss their assignment and prepare a presentation to the group as a whole.
- Each team presents their findings and the classroom group as a whole is encouraged to comment on the presentations and share their own experiences.

Instructions

- Divide the class into teams.
- Each team is assigned a single incident scenario
- Teams review the assigned scenario and determine a course of action
- Each team will present their findings to the class

Photo: Volpentest HAMMER Federal Training Center

Checklist

What to Think About When You Arrive

Hydrogen Vehicle Incident

Things to consider during incident size-up

- Type of vehicle(s) involved (cars, small trucks, buses)
- Fuels involved (gasoline, diesel, E85, LPG, hydrogen)
- Closed compartments (drive shafts, batteries, LPG tanks, hood or trunk struts, passenger compartments, tires, fuel tanks)
- Exposures (cars, structures, cargo)
- Hydrogen fuel and fuel tank status
  - Is fuel venting or burning?
  - Are flames impinging on the hydrogen tank?
  - Are there potential ignition sources?
- Potential for battery or electrical fire
- Extrication issues

Checklist

What to Think About when You Arrive

Hydrogen Stationary Facility Incident

Things to consider during incident size-up

- Does the facility have gaseous or cryogenic liquid hydrogen storage, or both?
- Where are high-pressure storage cylinders located?
- Where are cryogenic liquid storage units located?
- Determine best methods and approach to determine if a leak exists
- Can any leak be confined by a structure?
- If facility has a natural gas reforming process onsite, consider potential presence of natural gas
- Identify potential ignition sources
- Locate vent stacks

SCENARIO 1:

Single Vehicle Accident

Photo: Milton Fire Department, Inc.

SCENARIO 2:

Single Vehicle Accident with Fire

Photo: Pineville Volunteer Fire Department and Rescue, Inc.

SCENARIO 3:
Multiple Vehicle Accident

Photo: Arizona Daily Sun

SCENARIO 4:

Hydrogen Fueling Station Unintended Release

Photo: Air Products and Chemicals, Inc.

SCENARIO 5:

Unintended Hydrogen Release in an Enclosure

Photo: Volpentest HAMMER Federal Training Center

SCENARIO 6:

Hydrogen Transport Incident

Credit: KTLA

Wrap-up

In this section, we include:

- Publications and presentations
- Acknowledgements
- Contact information

Publications and Presentations

- Fassbender, L.L., Akers, B.M., and Cooper, C., "Introduction to Hydrogen Safety for First Responders," Firehouse®, August 2007, pp 158-159.
- Weiner, S.C., "Hydrogen Safety Training for First Responders," Istituto Superiore Antincendi (Fire Prevention Institute), Rome, Italy, October 5, 2010.
- Elmore, M.R., Fassbender, L.L., Hamilton, J.J. and Weiner, S.C., "Hydrogen Emergency Response Training for First Responders," International Conference on Hydrogen Safety, San Francisco, CA, September 12-14, 2011.
- Weiner, S.C., Fassbender, L.L., Blake, C., Aceves, S., Somerday, B.P. and Ruiz, A., "Web-Based Resources Enhance Hydrogen Safety Knowledge," International Journal of Hydrogen Energy, Volume 38, Issue 18, June 2013, pp 7583-7593.
- Hamilton, J.J., "Development of a Hydrogen and Fuel Cell Vehicle Emergency Response National Template," International Conference on Hydrogen Safety, Brussels, Belgium, September 10, 2013.
- Elmore, M.R., "Hydrogen and Fuel Cell Vehicles: Educating Emergency Responders," NFPA Conference & Expo, Las Vegas, NV, June 9-12, 2014.
- Weiner, S.C., "First Responder Training Resources and Future Direction," International Workshop on Hydrogen Safety Training for First Responders (hyresponse.eu), Aix-en-Provence, France, September 3-4, 2014.

Acknowledgements

The following individuals are gratefully acknowledged for their contributions to developing and reviewing this training resource:

Development and review

- Nick Barilo, Steven Weiner and Monte Elmore – Pacific Northwest National Laboratory
- Jennifer Hamilton and Bill Elrick – California Fuel Cell Partnership

Reviewers

- Aaron Harris – Air Liquide
- Larry Moulthrop – ProtonOnsite
- Rodney Slaughter, – Cal Fire, Office of the State Fire Marshal
- Colin Armstrong – HTEC
- Brian Ladds – Calgary Fire Department
- John Frala – Rio Hondo College
- Spencer Quong – Quong Associates

Contact Information

Please let us know if you have any questions or comments!

Nick Barilo, P.E.

Pacific Northwest NATIONAL LABORATORY

Hydrogen Safety Program Manager
Pacific Northwest National Laboratory
509-371-7894
nick.barilo@pnnl.gov

Jennifer Hamilton

California FUEL CELL PARTNERSHIP DRIVING FOR THE FUTURE

Safety and Education Specialist
California Fuel Cell Partnership
(916) 375-4914
jjhamilton@cafcp.org

WEBINAR: NATIONAL HYDROGEN SAFETY TRAINING RESOURCE FOR EMERGENCY RESPONDERS

Note: The recording includes some interruptions in audio between 0:46:28 and 0:51:44.

Below is the text version of the webinar titled "**National Hydrogen Safety Training Resource for Emergency Responders**," originally presented on March 24, 2015. In addition to this text version of the audio, you can access the **presentation slides**.

Chris Werth:
Welcome to the hydrogen safety webinar. My name is Chris Werth and I am the organizer for this. We'll begin shortly, but first I have a few housekeeping items to tell you about. Today's webinar is being recorded and the recording, along with the slides, will be posted to our website in about ten days. We will send out an email to attendees once those are posted to the site.

[Slide 2]

All attendees will be on mute throughout the webinar, so please submit your questions via the questions box that you should see on your webinar panel. We will cover those questions during the Q&A at the end of the presentation. Since we have multiple speakers today, please indicate who your question is for when submitting your questions. With that, I would like to introduce our DOE host, Will James, joining us from Washington D.C. Will leads the Safety, Codes and Standards Program in the Fuel Cell Technologies Office. Good afternoon, Will.

[Slide 3]

Will James:
Thanks, Chris. As Chris already mentioned, my name is Will James and on behalf of the Fuel Cell Technologies Office, I would like to welcome you to today's webinar. I will be moderating today's webinar and would just like to say a few words before we proceed. This webinar is designed to be the first introduction to the National Hydrogen and Fuel Cell Emergency Response Training Resource that was announced in February by the Fuel Cell Technologies Office, along with its potential

uses and future enhancements.

We are pleased today to have two speakers: Nick Barilo from the Pacific Northwest National Laboratory and Jennifer Hamilton from the California Fuel Cell Partnership. Nick is the hydrogen safety program manager at Pacific Northwest National Laboratory and a licensed fire protection engineer with more than 30 years of experience. Nick has served on the NFPA 2 Hydrogen Technologies Code Committee since its inception in 2006 and was instrumental in organizing the first eight chapters of the initial release of the code in 2011, and he continues to be an active member.

In 2007 Nick joined the Hydrogen Safety Panel and has served as program manager for hydrogen safety, supporting the DOE's Fuel Cell Technologies Office, since 2012. As program manager, Nick directs activities for the Hydrogen Safety Panel, safety knowledge dissemination and first responder training tasks, which include the development of the Hydrogen Tools portal.

Our second speaker will be Jennifer Hamilton from the California Fuel Cell Partnership. She is the safety and education specialist and has led the outreach and education to first responders and permitting officials at the Partnership since 2006. She has reached thousands in the California community where hydrogen fuel cell vehicles and stations exist and will be coming soon.

In addition to working with PNNL on the national emergency responder activities, she has a working relationship with the California Office of the State Fire Marshal, the U.S. Department of Energy, the National Fire Academy, and the NFPA for implementing first responder education. In parallel, Jennifer also actively participates in various safety, codes, and standards groups including SAE International, the CSA group, and ISO on items related to vehicle and fueling station safety.

As a reminder, as Chris mentioned, please don't forget to submit your questions in the box over to the right. And so now I thank you and will now turn it over to Nick.

Nick Barilo:
Thanks, Chris and Will. And welcome, everyone, to this webinar on hydrogen and fuel cell first responder training resources. Next slide.

[Slide 4]

So the national program that DOE has focused on first responder training is to support the successful implementation of hydrogen and fuel cell technologies by providing technically accurate information on hydrogen safety and emergency response information to first responders. This includes three primary parts of the training resources. The first is an online awareness-level training; the second, a classroom and hands-on operations-level training with props; and the third is the recently announced national training resource.

Many of these training resources were developed in collaboration with the California Fuel Cell Partnership and we are currently also partnering with the National Fire Academy to identify ways for broader dissemination of the information. The key here is that a properly trained first responder community is critical to the successful introduction of hydrogen fuel cell applications and their transformation in how we use energy. Next slide.

[Slide 5]

While cars are coming, hydrogen infrastructure remains the greatest challenge to commercialization of hydrogen fuel cell electric vehicles. To address this, in 2013 DOE along with automakers and other key stakeholders launched H2USA, a public private partnership to address the key challenges of hydrogen infrastructure. H2USA currently has 35 participants, including the state of California, as well as developers, car companies, and hydrogen providers. Having properly trained first responders will address a key barrier, ensure safe transition to fuel cell vehicles and hydrogen infrastructure, and pave the way for broader public acceptance. Next slide.

[Slide 6]

The partnership contains four working groups: a locations roadmap working group, a market support and acceleration working group, a financing infrastructure working group, and a hydrogen fueling station working group. This project is in support of the activity of the market support and acceleration working group. Next slide.

[Slide 7]

So this is a rather mature program as you can see from the timeline provided on the screen. The initial activity started in 2002 with the California Fuel Cell Partnership developing an ER education program. In 2007 DOE released the online awareness-level training, followed in 2009 by the operations-level class and props being made available. The National Hydrogen and Fuel Cell Emergency Response Training Resource was announced last month was actually made available on October 1.

We have plans for future enhancements which we'll talk about later. Some of the accomplishments to date: the online training has seen over 31,000 visits; the PNNL based operations-level training, which includes the props, has been attended by 1,000 firefighters; the California Fuel Cell Partnership training has reached over 7,000 first responders. Next slide, please.

[Slide 8]

So let's take a look at the first part of this, which is the online training. As you can see, this is a slide taken from the actual online training. It covers seven topical areas—[coughs] excuse me—including basics, hydrogen vehicles, stationary facilities, emergency response, transportation and storage, hydrogen dispensing, and codes and standards. Next slide, please.

[Slide 9]

So this slide is an example slide of some of the content that is in that online training. And as you can see down in the lower left, there's audio controls for listening into the narration or if you want to read, it's the same text there as well. Okay, next slide.

[Slide 10]

The operations-level training consists of typically two parts, though it can be modified and made to whatever is needed for a particular venue. Classroom content, which covers things like fuel cell basics, vehicles, stationary applications, emergency response, and incident scenarios. Demonstration with hands on prop has also been done. That's part of that 1,000 persons that have taken it and that includes demonstration of the flame characteristics of hydrogen as well as student participation and rescue activities. Next slide.

[Slide 11]

This is out of our table of contents for our instructor's manual for that just to give you a little better feel for what some of that content is. Also, a couple pictures at the right there provide some view of some of the classes in action. That's an IR camera that's picking up the flames and showing the difference between the hydrogen flames and a propane flame. The lower right, so the actual vehicle prop you'll see up there is the silver prop, and the lower picture of the silver car is the prop. And the other cars are there for part of that hands on exercise. Next slide.

[Slide 12]

So all the training that we've done over the years had led us to a place of realizing that we needed to provide materials to enable trainers to perform their own training. As things develop here, it's obvious that we're not going to be able to do all the training and that's not really our central focus or goal. So the Partnership and PNNL got together with the intent of developing a consistent source of accurate information and current knowledge that's adaptable to the specific needs of the training organizations.

So the goal here was to help put a set of information out into the hands of the trainers so that they could have a consistent theme and a consistent message is being said so that we don't get off into themes or messages that may not be accurate. It's also to enable that information to be as up to date as possible. So the course is set up with a template, if you will, and I'll show you a picture of that on the next slide with various levels of how it can be applied. I would stress that we really do need feedback from the users. It will help to make the program better in the future. So if you download that material and you look at it or use it, and you have some feedback, we certainly welcome that and it will help improve it for everyone; so highly encouraged.

[Slide 13]

As you can see on the current slide that the material really came from all our learnings and all our materials that were presented before. So it's approved and vetted material, it's been updated.

There's three levels like I talked about, but while we provide three levels, it's not meant to be prescriptive. You can take and use pieces of that 130-slide deck in whichever way you feel is appropriate for your audience. Next slide.

[Slide 14]

We took an outline approach at really assembling material and developing new material, and this kind of gives you a look at how we developed this outline with the various topics. Next slide.

[Slide 15]

And I mentioned that we've broken it into three levels of what we would call an overview course, a short course, and a full course. So a lot of those topics that you saw on the previous slide, and you'll see on the next two, are actual slides that came out and were developed. And we've kind of tried to give you a recommendation here with the check boxes on which ones would be appropriate for which type of course. It's not meant to be restrictive, though. And you have the freedom to use it in any way you see fit. So next slide.

[Slide 16]

So here we are breaking down the topics a little further. You can see how those topics, as they break down and we bring slides, those are actual slides from the slide deck and shows how some of the subtopics are covered and presented in information. Next slide.

[Slide 17]

In addition, there's also practical exercises at the end to walk through with your group to discuss those. And at this point I'll say before I move too much further that each slide is provided with notes for the instructor to help them understand and apply and present that information. So we don't leave you hanging with just the information itself. We give you some guidelines and help for how to lead the instruction of that material as well. Next slide.

[Slide 18]

And I think at this point I'm going to turn it over to Jennifer, who will take you through the short course and we'll talk a little more at the end when she's finished. Jennifer.

Jennifer Hamilton:
Thank you, Nick, and welcome, everybody. So I am going to go through an example of how the material could be used in the form of sort of the overview level, and so this will, again, be high level. I'm going to go through and sort of give some of the talking points and talk you through as opposed to giving the actual presentation. So next slide.

[Slide 19]

This slide is really, I think, for the instructor to give some background on the program and why we're making this available. I wouldn't necessarily recommend—if the trainer feels the need, to read it to the audience, but not necessary. Next slide.

[Slide 20]

Next slide.

[Slide 21]

Okay, so this is just the title slide and there we go. So, of course, we start with an introduction and background. Each section will have a sort of title slide like this, giving some outline of what the section will cover. Next slide.

[Slide 22]

So we start with a high level fuel cells overview, some of the talking points for this slide—and as Nick said they do come with notes—and the overall message that fuel cells convert chemical fuels directly into electricity and it can go into some of the diverse energy sources for the fuel, the different kinds of fuel cells, and then the diverse applications for fuel cells. So it gives some high level background, some context in terms of where this technology is being used. Next slide.

[Slide 23]

A question that can come up often is why even do hydrogen? So this slide is meant to go over some of the reasons why the industry has—is looking at hydrogen for transportation fuel. Some of the bullets there that highlight, it is a fuel, but it can be just as safe if not safer than gasoline, and it actually has a good safety record in industry for quite some time. And some of the other advantages, you can say, of using hydrogen. Next slide.

[Slide 24]

Also, where hydrogen comes from. People may not be aware that it's actually produced in some pretty great quantities currently and so this slide is meant to talk about the more common methods of producing hydrogen from natural gas and then the fact that moving towards the renewable source for both the energy and the source of hydrogen is where ultimately we'd like to see things going, and that’s where much of the research is headed, in the renewable pathway. Next slide.

[Slide 25]

This is a nice list of current industrial uses for hydrogen. So again, just giving some context. Hydrogen isn't new in the sense that it is used in industry. What might be a fairly new concept for folks is the fact that it's being used as a transportation fuel or for some of these other applications and personal use and portable power and stationary power. And again, highlight the safety record. It has a fairly good safety record in industry.

There are, in the notes, a few resources for the trainers as well on production and hydrogen facts and things like that, so they can dig a little more into this if they like. One of the, I think, main talking points on this is, and people may not realize, is hydrogen is used extensively in the gasoline business for refining fuel. So it just sort of again gives it a little bit of context. Next slide.

[Slide 26]

Then we get into some of the properties of hydrogen and behavior. It is a little bit different in some areas than maybe some other fuels that folks are more used to dealing with. One of the main things is the fact that it's a cryogen. And so there's a few sub bullets there, pointing out that while we're using gaseous hydrogen, compressed for storage on the vehicles, it doesn't have a liquid phase when it's compressed. And it actually needs to be at minus 423 Fahrenheit for it to be liquid.

And the reason that that's different is things like propane or some more commonly used items, pressurizing it does cause it to liquefy. So it's just, I think, an important distinction to point out, a difference of hydrogen than some other fuels. And then another talking point is that last bullet that a kilogram of hydrogen is approximately equal in energy to a gallon of gasoline. So if you were to burn a kilogram of hydrogen and burn a gallon of gas, you'd get about the same Btus. Next slide.

[Slide 27]

So going on further on some of the properties. Looks a little academic, but there's some kind of higher level talking points. Here, we point out the buoyancy, the fact that hydrogen is 14 times lighter than air. Also, again back to the kilogram thing, that it is metered, and we talk about it by weight, and it has more energy by weight than by volume, when comparing it to gasoline.

And for emergency responders, this can be an important point because when you put this together with the fact that fuel cells are very efficient in how they use the fuel, there's a lot less energy that's needed onboard the vehicles to get comparable range. So there's four to six gallons of gas equivalent in energy to get the range in the 250 to 350 plus mile range.

Another talking point here is the fact that hydrogen is odorless. There is of course mercaptan that's used to odorize natural gas, and gasoline has its own odor. So the reasons for that are the buoyancy and small molecular weight of hydrogen, but more importantly, the fact that an odorant can be detrimental to the fuel cell and its function. So there are other methods for detecting hydrogen that would be gone into in a more detailed presentation. Next slide.

[Slide 28]

I think it's important to recognize that, of course, hydrogen is flammable, and here's again a comparison of hydrogen to other fuels that, again, people are a little more used to dealing with. And there are both flammability and explosive limits listed here because for hydrogen, they're actually these two sets of numbers. The important thing to point out is that the hydrogen gas sensors, for example, employed both in vehicles and at stations are going to be reacting and designed to ultimately shut systems down at levels below that lower flammability limit. So while we recognize that hydrogen does have a wide flammability range, there are safety systems to mitigate getting to those kinds of levels of hydrogen and air mixtures.

Well, one of the other things to point out is the most easily ignited mixture in air is quite a bit higher than, again, more familiar fuels. And that while a pure hydrogen flame can be difficult to see with the naked eye, and the radiant heat is lower because there's no carbon there, the internal flame temperature is still quite hot. So that's a comparison on the bottom there, the flame temperatures. Next slide.

[Slide 29]

So then we get into some basics of fuel cells, just again pointing out that there are different types and I believe that one of the talking points on the slide is that it is a PEM fuel cell that's used on-board the vehicles. You can have different types of fuel cells for stationary applications or portable or things like that. But when talking about light-duty passenger vehicles and buses it's a proton exchange membrane hydrogen fuel cell. Next slide.

[Slide 30]

So this is a diagram that has been quite popular in the California Fuel Cell Partnership publication of How it Works. So it's a diagram of obviously how a fuel cell works and we've given this out in our How it Works booklet. Thousands of times, I could say at various outreach events, it's been very useful. And I think it gives a good play-by-play of what's going on inside the fuel cell and how the vehicle is generating its electricity using hydrogen and oxygen. Next slide.

[Slide 31]

So we want to move on to an overview of the kinds of vehicles that someone might see in their community. The fact that these are electric vehicles, only they're not plugged in like a battery electric, and they're a hybrid, only they're not fueled with gasoline or some other fuels, they are fueled with hydrogen. And like an electric vehicle, they're very quiet and they're also zero emission. Of course, we have the bus on there because there are fuel cell buses as well. Next slide.

[Slide 32]

And then to point out some of the vehicles that are being driven by your average everyday consumer. They've been in lease programs in different sizes and areas in California and a few places elsewhere in the U.S. So if someone had seen one of these running around their neighborhood, they can put it into the context here. Next slide.

[Slide 33]

And then, of course, it's always fun to show what may be coming down the pipe, so this is Honda's concept vehicle that they unveiled recently and have been using in some of their outreach. So it's just kind of fun to maybe look at the future a little bit. Next slide.

[Slide 34]

Giving an example of a vehicle system layout and pointing out that, of course, there's going to be variations in how these components are laid out depending on the vehicle, but essentially a fuel cell electric vehicle will have the same components much like a conventional gasoline vehicle has essentially the same components, and so then there's talking points to go through each of these components. And a little bit on their function here. Of course, we have on-board storage, providing fuel to the fuel cell, which is generating the electricity, distributed through power electronics to an electric motor.

There's also the high voltage battery, which captures the regenerative braking energy and we point out that there's still a cooling system on-board the vehicle as well. So again, these might be laid out differently. One thing personally I like to point out is that the fuel tanks are in the same general vicinity that you would expect to find a gasoline tank or the fuel tank on a vehicle, but perhaps, the fuel cell is back, or the electronics can be under the hood or along the floor, and that currently all the vehicles have front-wheel drive, so the electric motor vehicle will be in the front of the vehicle. Next slide.

[Slide 35]

The high voltage system is essentially what first responders may have been seeing already in other hybrid and electric vehicles. The orange is indicating high voltage and that there are safety systems in the form of inertia switches, ground fault monitoring, and so forth that will detect if the system is compromised. And it's essentially designed to short itself out. And something else that's maybe a talking point is that during normal operation, the high voltage and fuel systems are isolated on shutdown of the vehicle. Next slide.

[Slide 36]

Moving on to the fuel storage and hydrogen delivery. This is an example of a couple of the tank setups. So an important point here is that while the vehicles all store hydrogen, it may be in a single tank, it may be multiple tanks; and it just depends on the vehicle. So there's two examples here of a Honda Clarity and a GM vehicle with different tank system set-ups. The bullets there, that the distribution lines are lower pressure. So the pressurized fuel at that high pressure is, for the most part, isolated to the compressed hydrogen storage cylinders. And the pressure in the lines is stepped down and regulated to the fuel cell stacks. I'm also pointing out that there are thermally activated pressure relief devices in each tank, and there are associated vents that can vent independently off of each tank or may be directed to a common vent location. Next slide.

[Slide 37]

And looking at the same sort of thing in a bus. Clearly, with a larger vehicle, there are more tanks. A commonality with, for example, CNG buses, is that they do carry the fuel on the roof. And again, there are thermally activated pressure relief devices and all the associated tubing and so forth, should the tanks have to vent in the case of fire. Next slide.

[Slide 38]

So talking a little more about the fuel storage system. This is a nice photo of Type 3, 35 versus 70 megapascal cylinders and showing the difference in the liner thickness and the carbon fiber overwrap. One of the observations that's often made by first responders is that this type of tank is very similar—different size but very similar to what is in their SCBA that they wear, their packs that they wear for their breathing apparatus, since they're carbon fiber, also. Again, highlighting the TPRDs and the robustness of the tanks. Okay, next slide.

[Slide 39]

So this slide goes a little bit more into the tanks themselves and the fact that they are designed to meet very specific standards and they go through some fairly rigorous testing for certification. They do come with a lifetime and have a safety rating that goes beyond what their actual service pressure is. And this is just some of the main and intense testing that these things go through by batch. Next slide.

[Slide 40]

And finally, this is just, again, to highlight that the tests are part of the design qualification for new tanks, that the qualifying factor is that they vent the contents and don't rupture. So they put them through various insults and then have to maintain the integrity and vent through the TPRD and not rupture. And those are in accordance with the most recent vehicle tank standards. Okay, I think that might be the last—oh, no, we still have to do stationary.

[Slide 41]

Stationary facilities. So this is just to go a little bit over where we're getting this hydrogen fuel and the different kinds of stationary facilities, which can include, of course, the stationary fuel cells, bulk storage, and fueling stations where the vehicles would be getting their fuel. Next slide.

[Slide 42]

Of course, first responders are very familiar with these NFPA placards, but just to highlight that this is what they'd want to look for for either gaseous storage or liquid storage. Next slide.

[Slide 43]

And then here's some examples of actual fueling stations, and in the notes it goes through where each station is located and what their hydrogen source is so that can be anything from on site manufacturing through steam methane reforming, or an electrolyzer, to delivery via gaseous tube trailer, liquid hydrogen, or pipeline. And that actually is the last of the overview. I'll turn it over back to Nick.

[Slide 44]

Nick Barilo:
Thanks, Jennifer. Thank you. Good job. So I do want to talk a little bit about how to download it and that sort of thing. So the resource is available right now, the URL is provided on this slide. That URL is part of the Hydrogen Tools portal, and I'll just take a minute here to give you some input on what that's doing. The Hydrogen Tools portal is slated to come online here very shortly. Its purpose is to bring together a wide variety of hydrogen safety resources and Web based content into a single location to help those designing, approving, using, or responding to incidents understand the safety aspects, maybe do more investigation.

It will have such resources as best practices, lessons learned, compatibility of materials, some codes and standards information as well. And that's just to start. We have hopes and plans to bring additional resources into the portal to make it much more valuable for the users. So that portal, you can download information right now, but the portal itself will be online probably in the next few weeks. Okay, next slide.

[Slide 45]

So this is giving you a little bit of a look at the portal and, again, centralized location. We are actually tailoring the portal to focus in on user groups. There's eight user groups we identified. Those include first responders, AHJ/code officials, project proponents, operations and maintenance folks, that sort of thing.

A responsive design—so we currently have an IOS app, a Hydrogen Tools IOS app that is available and brings many tools together. The responsive design that will be done with this site will allow it to be used on any mobile device, whether it be a phone or a tablet. And that will be across Android, IOS, et cetera. So that's beneficial as well. And really probably one of the more important parts is that the information here is going to be credible and reliable safety information from a trustworthy source.

And one last feature that I'd like to highlight is we're working to develop trusted communities. So what that means is that for first responders, there will be a community set up for first responders that allows those first responders to ask questions, respond to questions, make comments, that sort of thing. One thing we found over the last few years in talking with a variety of folks is that they would really like to have a way to connect with others that have been a part of activities or projects, to understand their learnings and benefit from those learnings and reach out. So this was really a direct result of feedback that we received from those that have had some experience with deployments and dealing with the issues. Okay, next slide.

[Slide 46]

So planning for the future. We're not really going to stop here. We're not drawing a line in the sand. We're really looking at updating the information, keeping it current, adding new types of media and content to make it a richer learning experience as well as bring it to a broader audience. To that purpose, we're finalizing a plan that was done together with a variety of first responders, equipment providers, et cetera, to look at what the options were and identify things like new, smaller props and prop kits that can help address the tactile needs of the participants; developing new and updated videos and enhanced videos; providing new photographs, we recognize that's going to be an ongoing challenge and we really need to keep it in the forefront. And a little bit further down is considering virtual reality tools for immersing students in real world scenarios. There's actually some work going on internationally along that line, and it's a pretty interesting concept, and hopefully we can find a way to bring it to you as well. Next slide.

[Slide 47]

So just to reiterate a little bit of what our vision is, it's really bringing that consistent source of accurate and current information to allow a variety of training regimes to deploy that material in a way that will benefit them. It's also to encourage collaborations among the stakeholders to achieve purposeful results. At the end of the day, the goal here is to remove those barriers, help take down the obstacles for helping deploy the hydrogen and fuel cell technologies, and to bring this to bear on the commercial market and make sure the communities are ready to receive it. Okay, next slide.

[Slide 48]

So I do want to acknowledge that this was done in a collaborative effort with the Partnership and we appreciate all their work. It was also done with funding from the Fuel Cell Technologies Office of the Energy Efficiency and Renewable Energy section of the U.S. Department of Energy. In particular, the manager at the office, Sunita Satyapal, and Will James, Laura Hill, and Kristen Nawoj. And also the reviewers. This shows the list of reviewers and in the planning, we've actually had more folks come on board. So all those that have been involved in helping us bring this to you, we appreciate all their help and encouragement. Last slide.

[Slide 49]

So if you have—certainly questions, we'll take some of those—but if in the future, going out, if you want to send questions to us direct or talk with us about anything, we've provided some contact information, and we look forward to your questions and feedback. So thanks for listening in. We appreciate the time and I'll turn it over to Will to facilitate the questions.

Will James:
Thanks, Nick and Jennifer. Great presentation. Before we get into the Q&A part, I just wanted to remind everybody—I'm not sure if it was discussed at the beginning—there should be a Question Box over when you logged in that popped up over on the right-hand side of your screen. So for those of you that were looking to where exactly do you submit the questions, please submit them there and we'll try to get through them.

So we're going to go into the Q&A portion of the webinar and so the first question was asked whether the material will be available in PDF or not. So we typically will post the presentation as well as the recording within about ten working days from the date of the webinar.

But the next question, probably for Nick, is to basically give an overall perspective from the fuel cell tank size or capacity on how they differentiate between vehicles—light duty vehicles and buses.

Nick Barilo:
So Will, you can feel free to jump in on this one a little bit. The vehicles are typically 10,000 psi tanks with a capacity of around 5 kilograms. I believe the buses go into a higher range of 10 to 15 kilograms, but Will, you're welcome to join in on that one.

Jennifer Hamilton:
Nick, did you mean per tank or total?

Nick Barilo:
Yes, I'm sorry. Per tank, that's correct. And I think actually the tank, so it's five kilograms. Correct me, Jennifer, it's five kilograms on the car, and that could be one or split between two tanks.

Jennifer Hamilton:
Yeah, the range in the vehicles is between about four on the lower side and up toward six right now on the higher side, but probably an average around five or so kilograms total storage in the system. And then buses, I don't know individual tank storage, but total storage is right around the 40 or so kilogram range, 40 to 50 kilograms total storage at 35 megapascals or 5,000 psi.

Will James:
So Jennifer, the next question is for you. The question is, are hydrogen vehicles required to be identified in any specific way so first responders know that a vehicle is hydrogen-powered?

Jennifer Hamilton:
The vehicles are required to be badged accordingly with make and model like you would expect any other vehicle. And there currently is a document in progress within SAE for first and second responders that goes further into some badging suggestions, and that has—there is work to harmonize those badging suggestions with other SAE safety documents for

hydrogen and fuel cell vehicles. So an example is with the current vehicles, for example the Honda Clarity FCX, so it has the letters FC, which would indicate fuel cell. The new Toyota Mirai FCV, so again FC indicating fuel cell.

And something important that I mentioned in speaking with first responders, if a vehicle is a fuel cell vehicle, it will have no other fuel than hydrogen. So while the vehicle may not necessarily indicate hydrogen on it, if it's a fuel cell vehicle, it will be hydrogen. There are also, as an example, of a blue diamond, which follows some previous badging for CNG that might be used, but it's, again, not a requirement.

So look for this document coming from SAE. Well, it's for auto manufacturers but from the perspective of first and second responders being able to manage vehicles in incidents that has suggestions for badging. So I hope that answered the question.

Will James:
I think that does. I know you mentioned secondary responders. Is there any plan to possibly introduce any information into the training material related to secondary responders?

Jennifer Hamilton:
Yeah, Nick, you want to talk about that?

Nick Barilo:
Yeah. So that's kind of been an ongoing on-and-off again topic and certainly one that I don't think we're ready to definitively say in either direction on. It's been recognized that secondary responders really need information and can play an important role. So how that's handled in the future is still really yet to be worked through. And if you have some suggestions on that, we certainly would welcome your feedback. And if you desire to see more of that type of information, please let us know because that may help shape where we go with future content.

Will James:
Great. This question talks about the hands on and rescue course. Is that a residence course conducted somewhere, or is it a traveling-type class that you could bring to a certain location? And that would be for Nick.

Nick Barilo:
That's a really great question. Sorry I didn't address it sooner. Yes, the classroom and hands on course is a traveling course for the most part. We're located in Washington state and we have a facility here, but we also can arrange for that to be given. As a matter of fact, we're having some tentative plans to provide that training in the Northeast probably in the spring of 2016.

So the prop itself is part of a trailer assembly and we take that trailer and we travel to a location and then provide the classroom training along with use of the prop and demonstration; some response, if that's so desired, that sort of thing as well. Yes, it can be taken to locations; and that would be subject to working out the details, resources, and that sort of thing.

Will James:
Great. The next question, I don't know if it would need to go to Nick or Jennifer, but the question is, has a DOT crash-test been developed for the light-duty vehicles?

Jennifer Hamilton:
So Will, feel free to jump in here, too, but to my knowledge, of course, the vehicles have to be crash tested and that is per current FMVSS for hybrid and electric vehicles. And the GTR will ultimately be adopted by NHTSA to be the hydrogen FMVSS, and that is in process. I don't know if you have any other updates on that timeline, Will.

Nick Barilo:
Actually, I don't know if I have the timing of it, but I just know that they're in the process of reviewing the document to convert it to the hydrogen specific FMVSS now.

Will James:
The next question is around coordination; it talks about whether there could be any coordination either with Clean Cities—

[interruption in audio 0:46:28 to 0:49:29]

The next question for Nick is, how does a company become involved in the training aspect in basically giving the training for the first responders?

[interruption in audio 0:49:43 to 0:50:12]

Nick Barilo:
I think—

[interruption in audio 0:50:14 to 0:51:17]

Will James:
Specifically, has there been any learning—

[interruption in audio 0:51:21 to 0:51:33]

Jennifer Hamilton:
Not specifically with CNG trainers, but that is—

[interruption in audio 0:51:40 to 0:51:44]

—along with other alternative vehicle training that's been provided. For example, from L.A. Fire Department, they did an alternative fuel vehicle training within their department and presented all different sorts of alternative fuels and our component was the hydrogen portion. And we're certainly, I think, open to that. And as more alternative fuel vehicles are on the road, it would be, in my opinion, great to be able to incorporate all of those—because one nice thing is the ability to sort of compare across the board, and some of the more detailed slides in the program do that, the similarities of the different types of alternative fuel vehicles and their systems, so it's nice when there's sort of a bigger picture on that.

Will James:

I know in the webinar today, we only saw a small snapshot of the slides, the type of slides that are in the slide package, but are there any materials within the bigger slide package that covers hydrogen sensors or detectors or leak detection?

Jennifer Hamilton:
Not the technology necessarily, but it goes a little bit more into overall safety systems for vehicles and stations and does talk about the fact that they are employed, but it doesn't discuss the specific technology.

Will James:
Just a few more questions and we're starting to wrap up. One question continues to build on coordination—is there any thoughts to, or is there any coordination with the Department of Transportation's training program?

Nick Barilo:
So we haven't worked directly with DOT to develop or implement any materials. It could be an opportunity in the future, just something that up until now hasn't been a direct relationship. Jennifer, I'm not sure if the Partnership has anything directly with DOT.

Jennifer Hamilton:
No. It does remind me that I was given a contact at DOT to essentially connect with on this and that they do have some training there developing or have developed. So I think that's a good reminder for a follow up.

Will James:
And then the next question is for Nick—as you see the hydrogen use grow, do you feel that there could be a specific responder training for fueling stations?

Nick Barilo:
So I'll try and answer the question generally and maybe more specifically if it's directed towards first responders. I think that the material that's there right now probably does an adequate job of covering that topic. If it is for the station providers and getting those station operators, perhaps, some training—maybe general hydrogen safety training and response-to-an-incident type training—right now, there's no plans to develop that kind of material. I think there certainly are bits and pieces in this package that could be pulled out, maybe put with some additional information that could be beneficial, but there's no plans again. Just as the statement was with secondary responders, if someone feels that's a big need, I suggest you make that need known. The other thing is that it really falls on the station, the developers and the builders and the operating agencies, to ensure that that's in place. And a part of it really does become a little bit unique to each one of those type of organizations. Some like to do some things a certain way; others like to do it a little differently.

And so the point that having some information available could be a beneficial thing. But again, it's the resources to develop that—is that more done at a broad national level, or is it more beneficial to do that at the local levels? It's just something that hasn't been, I think, thoroughly evaluated at this point.

Jennifer Hamilton:
If I could, Will, I can offer a little bit more of a comment in that. There was a time when the Partnership was revamping their first responder program, that the idea was to make a parallel program for fueling stations. And the ultimate outcome and consensus was that, kind of along the lines what Nick said, the bulk of it can be covered in the first responder portion. And I

realized we only saw a very high level edition of the materials today, but they're actually is quite a bit more with regard to fueling stations and other stationary applications in the whole slide deck.

And the consensus at that time was that a separate program was not deemed necessary. And another point is that the communities that are getting vehicles, most likely they're going to be getting a station as well. So in doing the first responder training, we of course cover both vehicles and stations and response suggestions to that.

Will James:
Thanks, Jennifer. The last question is for Nick. As you see hydrogen refueling stations and vehicles deploy, both from the U.S. perspective and a global level, do you see a need that these training materials could be standardized or documented internationally?

Nick Barilo:
So yeah, that's a great question and well timed. Yeah, I think there's an opportunity to do that while much of the information has pictures and some of the application and requirement is U.S.-centric, they're certainly is an opportunity for more global international use. We have been contacted by some folks in another country to possibly convert the material over to another language and I've given some positive feedback to that. So they'll be proceeding as well.

So I think yeah, there's a great opportunity there and even some opportunity for potentially for some international collaboration on what material might be in the template material might be beneficial as well.

[Slide 50]

Will James:
Well, thanks, Nick. With that, we're going to wrap up the webinar. Once again, I want to thank Nick and Jennifer for presenting the material and thanks to everyone who participated. I'm going to turn it back over to Chris to wrap it up. Thank you.

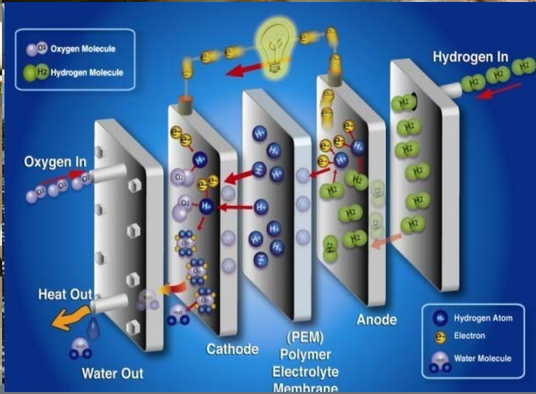
Chris Werth:
Thanks, Will. All right, everyone, that concludes our webinar today. Again, I'd like to thank you for joining in and remind you that the webinar and slides will be available online at our website listed on the slide there in about ten days. If we didn't get to your questions today, we'll take a look at those and try to email some responses back out to you. So look for those in the coming days. All right. That's it. Have a great week everybody. Good bye.

Office of Energy Efficiency & Renewable Energy
Forrestal Building
1000 Independence Avenue, SW
Washington, DC 20585

U.S. DEPARTMENT OF ENERGY FUEL CELL TECHNOLOGIES OFFICE

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy





National Hydrogen Safety Training Resource for Emergency Responders

3/24/15

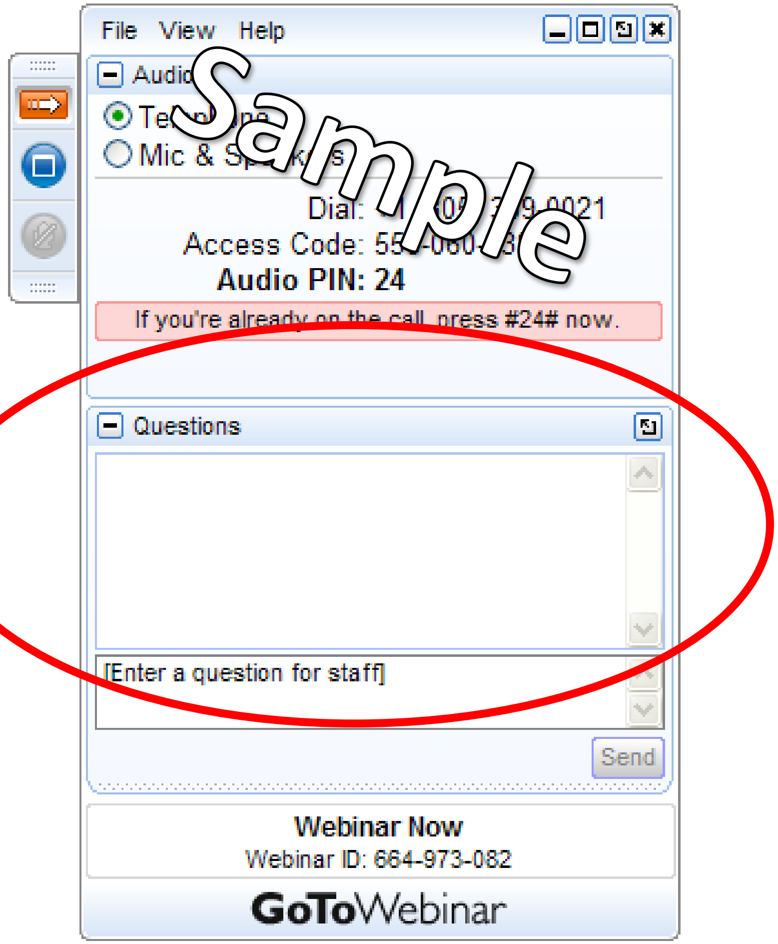
Presenter(s):

Nick Barilo

Jennifer Hamilton

Question and Answer

- Please type your questions into the question box



HYDROGEN
Emergency Response
Training Resources

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

California Fuel Cell Partnership
DRIVING FOR THE FUTURE

Hydrogen and Fuel Cell First Responder Training Resources

Nick Barilo (PNNL) and Jennifer Hamilton (CaFCP)

Pacific Northwest National Laboratory and the California Fuel Cell Partnership

March 24, 2015, 12:00 PM – 1:00 PM EDT

DOE First Responder H_2 Safety Training

- **National Goal**
  - Support the successful implementation of hydrogen and fuel cell technologies by providing technically accurate hydrogen safety and emergency response information to first responders
- **Integrated Activities**
  - Online, awareness-level training
  - Classroom and hands-on operations-level training
  - National training resource (enabling trainers)
- **Collaboration and Partnerships**
  - Pacific Northwest National Laboratory (PNNL)
  - California Fuel Cell Partnership (CaFCP)
  - National Fire Academy

A properly trained first responder community is critical to the successful introduction of hydrogen fuel cell applications and their transformation in how we use energy.

Supporting the Mission of H2USA

- The mission of H2USA is to promote the commercial introduction and widespread adoption of FCEVs across America through creation of a public-private collaboration to overcome the hurdle of establishing hydrogen infrastructure.
- Having properly trained first responders will address a key barrier, ensure a safe transition to fuel cell vehicles and H2 infrastructure, and pave the way for broader public acceptance.

H2USA's public-private partnership

U.S. Department of Energy
GlobalAutomakers
NESCAUM
Fuel Cell & Hydrogen Energy Association
AGA American Gas Association
California Fuel Cell Partnership – Driving for the Future
GM
Honda – The Power of Dreams
Hyundai
Mercedes-Benz
Nissan
Toyota
Air Liquide
arc:hydrogen
Argonne National Laboratory
EDTA Electric Drive Transportation Association
HNEI
Hydrogenics – Advanced Hydrogen Solutions
Intelligent Energy
ITM Power – Energy Storage | Clean Fuel
Kobelco – Kobelco Compressors(America), Inc.
The Linde Group – Linde
Massachusetts Hydrogen Coalition
NACS
NREL National Renewable Energy Laboratory
Nuvera – Making hydrogen make sense.
Pacific Northwest National Laboratory
PDC
Plug Power
Proton – The leader in on site gas generation.
Sandia National Laboratories
SRNL
SCRA
INL Idaho National Laboratory
Chrysler

Key Early Market Challenges Addressed by H2USA

Photo Credits Top: NREL, Middle: NREL, Bottom: Hexagon Lincoln

- **Station Cost Reduction**
  - Fueling resources & delivery
  - State and local regulations
- **Station Locations**
  - Identify and prioritize markets
  - Regulatory barriers (zoning)
  - Station rollout timing
- **Investment and Finance**
  - Private sector financing
  - Government support
- **Market Support and Acceleration**
  - Product launch and timeline
  - Codes and standards (non-vehicle related)
  - Public education

Training Resources Timeline and Accomplishments

2002
CaFCP developed an ER education program

2007
DOE releases online awareness level training

2009
DOE makes operations level class and props available

2014
DOE/CaFCP release the National Hydrogen and Fuel Cells ER Training Resource

Future
Enhancements to the training resources

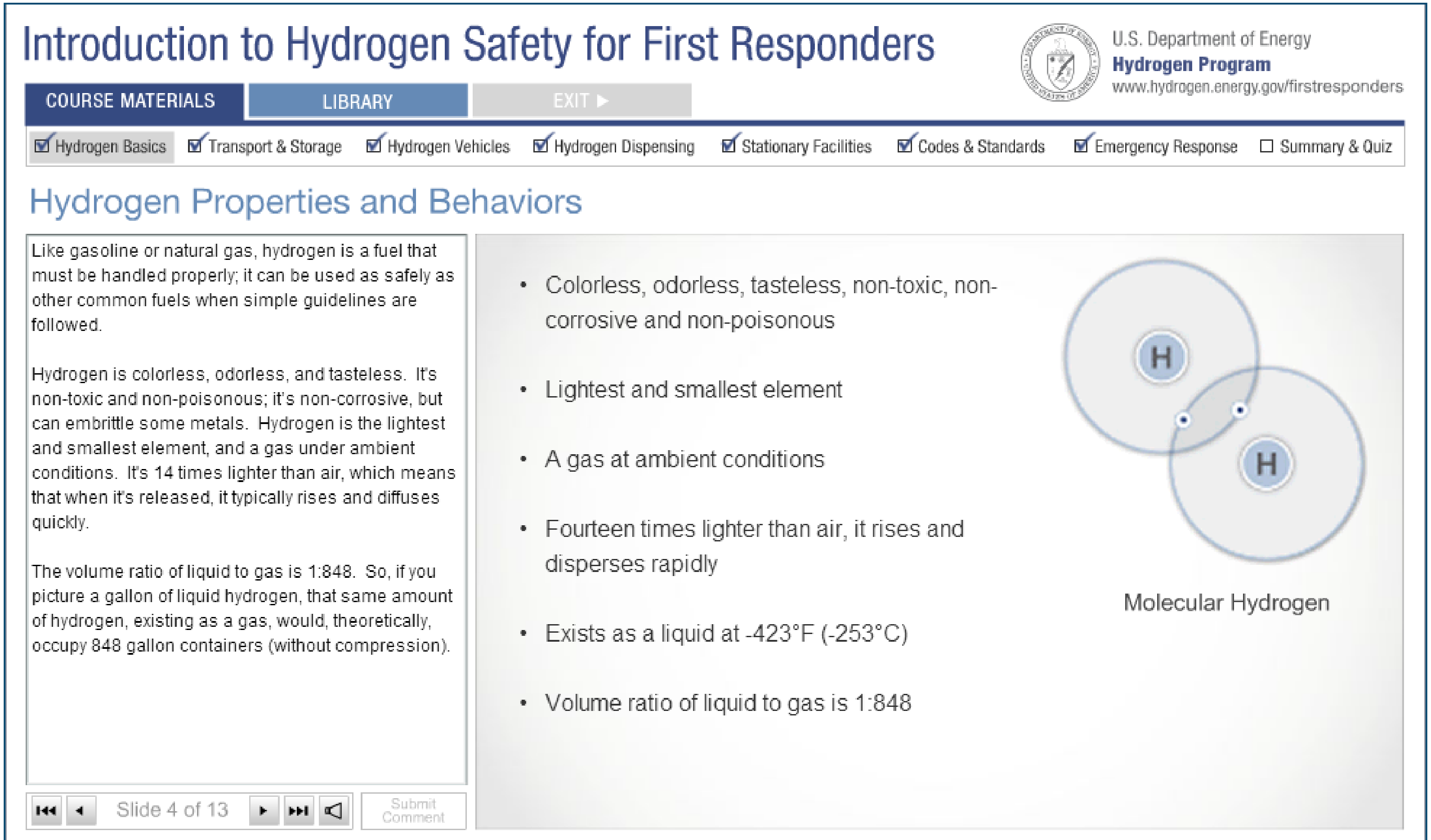
<u>Accomplishments</u>

- Online training – over 31,000 visits
- Operations-level (in-person) training has been attended by 1,000 firefighters
- CaFCP training has reached over 7,000 first responders

Online Training

http://hydrogen.pnl.gov/FirstResponders/

Online Training Example Slide



Operations Training

- **Classroom Content**
  - Hydrogen and Fuel Cell Basics
  - Hydrogen Vehicles
  - Stationary Facilities
  - Emergency Response
  - Incident Scenarios
- **Demonstrations/Hands-on Exercise with FCEV Prop**
  - Demonstration of Hydrogen Flame Characteristics
  - Student Participation in Rescue Evolutions

Multiple instructors for classroom training

A "rescue" at Sunnyvale (CA) Department of Public Safety

Course Content and Hands-on Activities

Hydrogen Emergency Response

Table of Contents

Instructor Manual

Module 1: Introduction and Course Overview

Module 2: Hydrogen and Fuel Cell Basics

Module 3: Hydrogen-Fueled Vehicles

Module 4: Stationary Facilities

Module 5: Managing Hydrogen-Related Emergencies

Module 6: Practical Exercise

Module 7: Quiz

Module 8: Hands-On Exercise With FCV Prop

Presented by

Pacific Northwest NATIONAL LABORATORY

VOLPENTEST HAMMER TRAINING AND EDUCATION CENTER

What and Why – National Hydrogen and Fuel Cell Emergency Response Training Resource

- Hydrogen and fuel cell-related first responder training utilizing a national emergency response education program as a **consistent source of accurate information and current knowledge**.
- A resource **adaptable to the specific needs** of first responders and presentation styles of training organizations and meant to complement extensive training programs already in place.
- The nationally-focused training template intended to serve as a resource and guide for the delivery of a variety of training regimens to various audiences.
- The template delineates this concept as L1-Overview, L2-Short Course and L3-Full Course and suggests training materials accordingly.
- Feedback from presenters and audiences to the developers of the National Hydrogen and Fuel Cells Emergency Response Education Program will help ensure that the development of new and updated training content and techniques serves to continually enhance the value of this resource.

History of the National Program's Development

- Used existing materials from DOE and CaFCP programs
  - Approved, vetted information
  - Made updates as necessary
- Three 'levels' of information in 130 slides
  - Accompanying template document with guidance on use
  - Slides suggested for three levels of information:
    - Introductory course
    - Short course
    - Extended course
- Not prescriptive; trainer can select any/all of the slides that are appropriate for the audience

Hierarchy of the Training Template Approach

An outline was developed to topically to cover the following:

FR Template

1. Introduction and Background
2. Hydrogen and Fuel Cell Basics
3. Hydrogen-Fueled Vehicles (light duty and transit)
4. Stationary Facilities
5. Managing Hydrogen-Related Emergencies
6. Practical Exercises

National Hydrogen Emergency Response Education Program

Collaboration with the California Fuel Cell Partnership — Driving for the Future

Illustrating the use of the template

First Responder Training Template

- Slide #1 National Hydrogen Emergency Response Education Program
- Slide #2 What and Why

	Level 1 Overview	Level 2 Short Course	Level 3 Full Course
1. Introduction and Background (Slide #3)			
• Slide #4 Fuel cells overview and benefits	✓	✓	✓
• Slide #5 Fuel cells – Where are we today?		✓	✓
• Slide #6 Diverse fuel cell transportation applications		✓	✓
2. Hydrogen and Fuel Cell Basics (Slide #7)			
2.1 Hydrogen – Where does it come from and how do we use it today?			
2.2 Properties of hydrogen and its safe use			

Managing Hydrogen-related Emergencies

FR Template

1. Introduction and Background
2. Hydrogen and Fuel Cell Basics
3. Hydrogen-Fueled Vehicles (light duty and transit)
4. Stationary Facilities
5. Managing Hydrogen-Related Emergencies
   - 5.1 Vehicle incidents
     - 5.1.1 Size up
     - 5.1.2 Plan (Identify)
     - 5.1.3 Act
   - 5.2 Stationary Systems/Facility Incidents
   - 5.3 Vehicle an Stationary Facility Responses
6. Practical Exercises

Examples of slides covering a few topics/subtopics

National Fire Academy (NFA) Command Sequence

1. Size Up (Think) SIZE UP
2. Identify Strategy/Tactics PLAN
3. Assign Tasks ACT
4. Review Results of Actions/Critique EVALUATE

Photo: Volpentest HAMMER Training and Education Center

Follow SOPs for vehicle response, paying particular attention to unique systems and characteristics for hydrogen-powered fuel cell vehicles

Stationary facilities SIZE UP

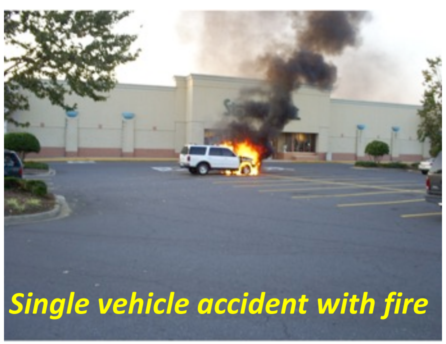
Stationary hydrogen facilities will have hazards similar to facilities with other compressed and/or cryogenic gas processing or storage systems

- Gas or liquid storage?
  - High-pressure cylinder storage
  - Cryogenic liquid storage
- Is there a leak or flame present?
  - Gaseous hydrogen: use CGI/hydrogen detector and thermal-imaging cameras
  - Liquid hydrogen: look for ice crystals/frozen water vapor
- Is the leak confined by a structure? Ventilation adequate?
- Onsite reforming? Is a methane source present?
- Presence of other fuels (e.g., CNG, propane, gasoline)
- Identify potential ignition sources

Accident Scenarios Provided for Group Discussion

FR Template

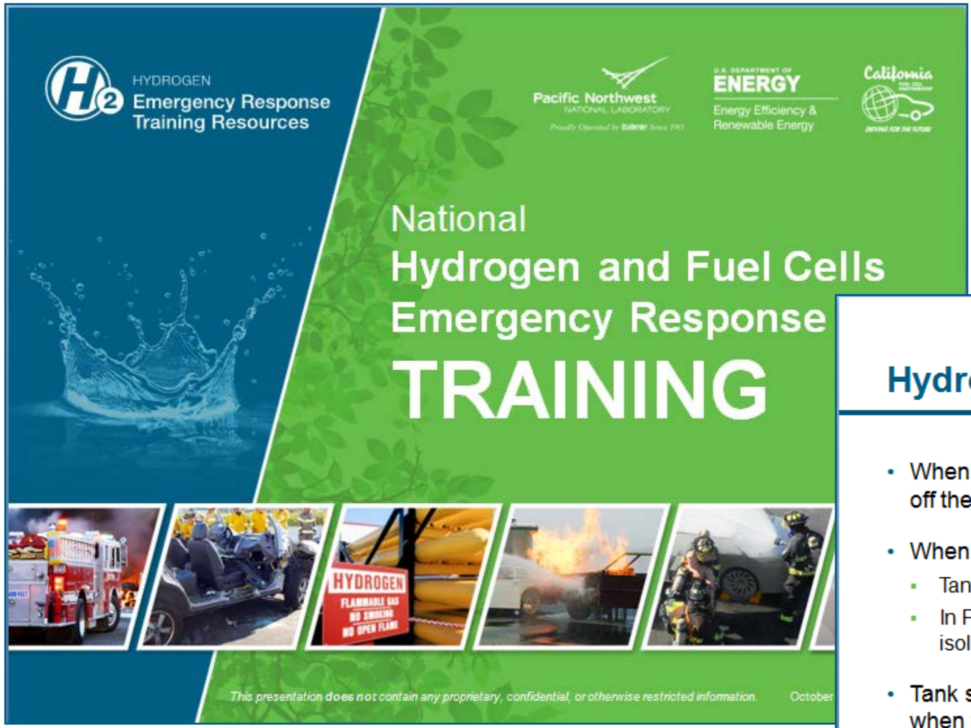
1. Introduction and Background
2. Hydrogen and Fuel Cell Basics
3. Hydrogen-Fueled Vehicles (light duty and transit)
4. Stationary Facilities
5. Managing Hydrogen-Related Emergencies
6. Practical Exercises


Single vehicle accident with fire

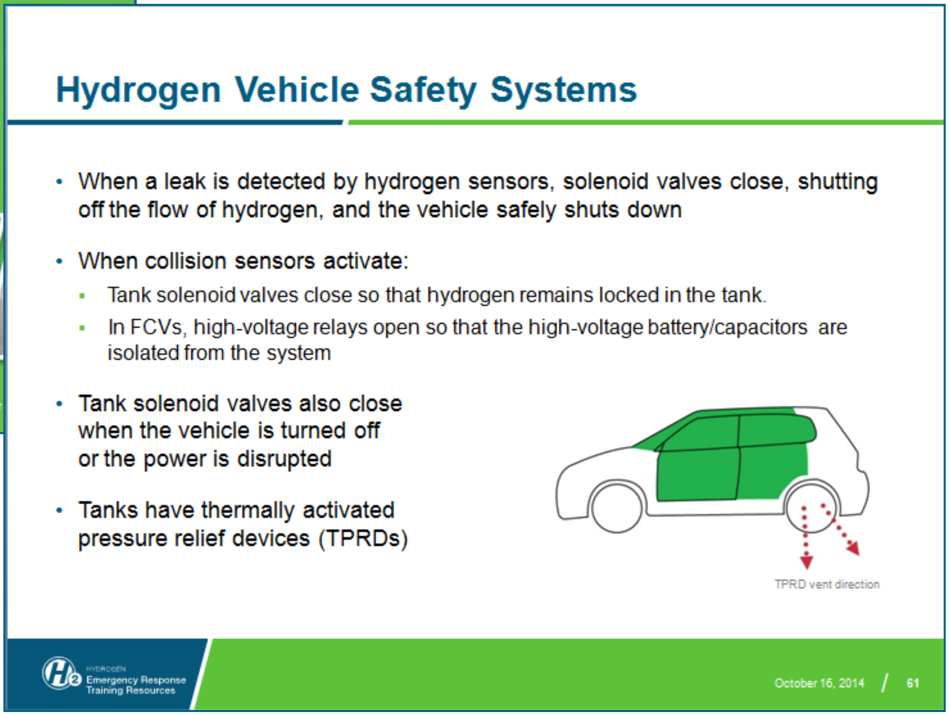

Multiple vehicle accident


Unintended hydrogen release in an enclosure

Let’s Take a Look at How the Material Could Be Used



Our example will be a “short course” awareness level training session



What and Why?

National Hydrogen and Fuel Cell Emergency Response Training

A properly trained first responder community is critical to the successful introduction of hydrogen fuel cell applications and their transformation in how we use energy. We envision that hydrogen and fuel cell-related first responder training will be delivered locally to serve missions to protect life and preserve property, utilizing this national emergency response training resource as a consistent source of accurate information and current knowledge. These training materials are adaptable to the specific needs of first responders and training organizations and are meant to complement the extensive training programs already in place to serve their missions. **The note pages format of these slides provides more details for the instructor to conduct the training. Instructors should share this information when presenting the slides.**

The nationally-focused training template that accompanies these materials is intended to serve as a resource and guide for the delivery of a variety of training regimens to various audiences. These materials are adaptable for different presentation styles, ranging from higher level overview formats to more comprehensive classroom training. Three example uses of the slides are provided in the companion Word file.

Feedback from presenters and audiences to the developers of the National Hydrogen and Fuel Cells Emergency Response Training will help ensure that the development of new and updated training content and techniques serves to continually enhance the value of this resource.

Revision Date: January 8, 2015

HYDROGEN
Emergency Response
Training Resources

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

U.S. DEPARTMENT OF
ENERGY
Energy Efficiency &
Renewable Energy

California
FUEL CELL
PARTNERSHIP
DRIVING FOR THE FUTURE

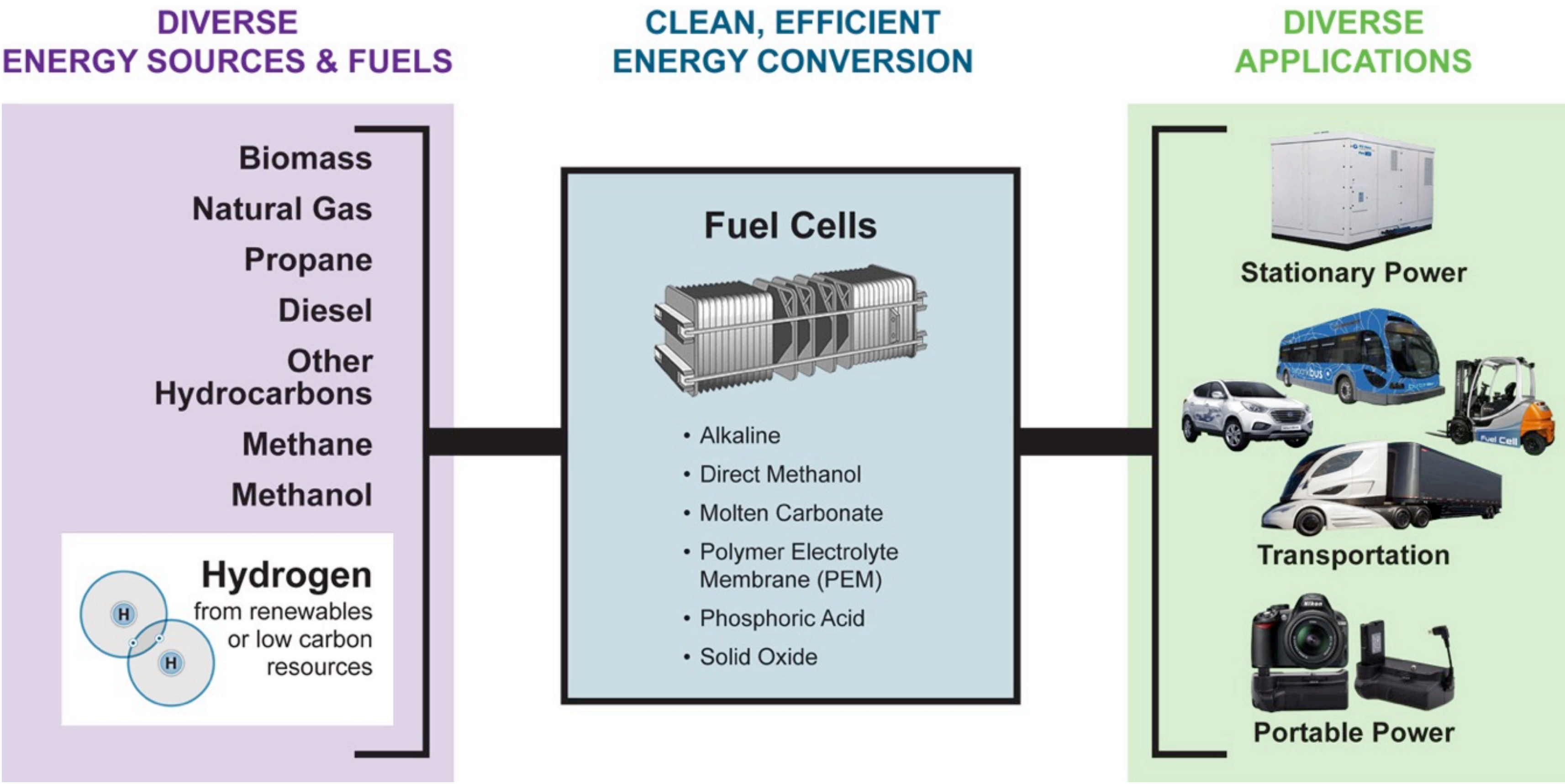
National
Hydrogen and Fuel Cells Emergency Response
TRAINING

Introduction and Background

This section introduces the user to:

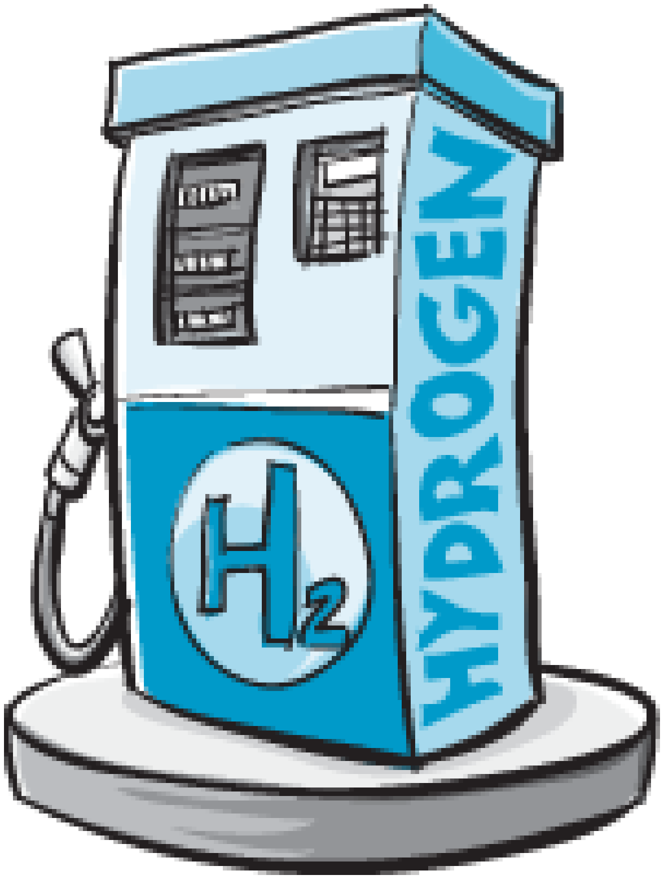
- An overview of the role of fuel cells and their benefits
- A picture of today's hydrogen production and delivery, current markets for fuel cells
- A diverse set of fuel cell transportation applications

Fuel Cells Overview



Why Hydrogen?

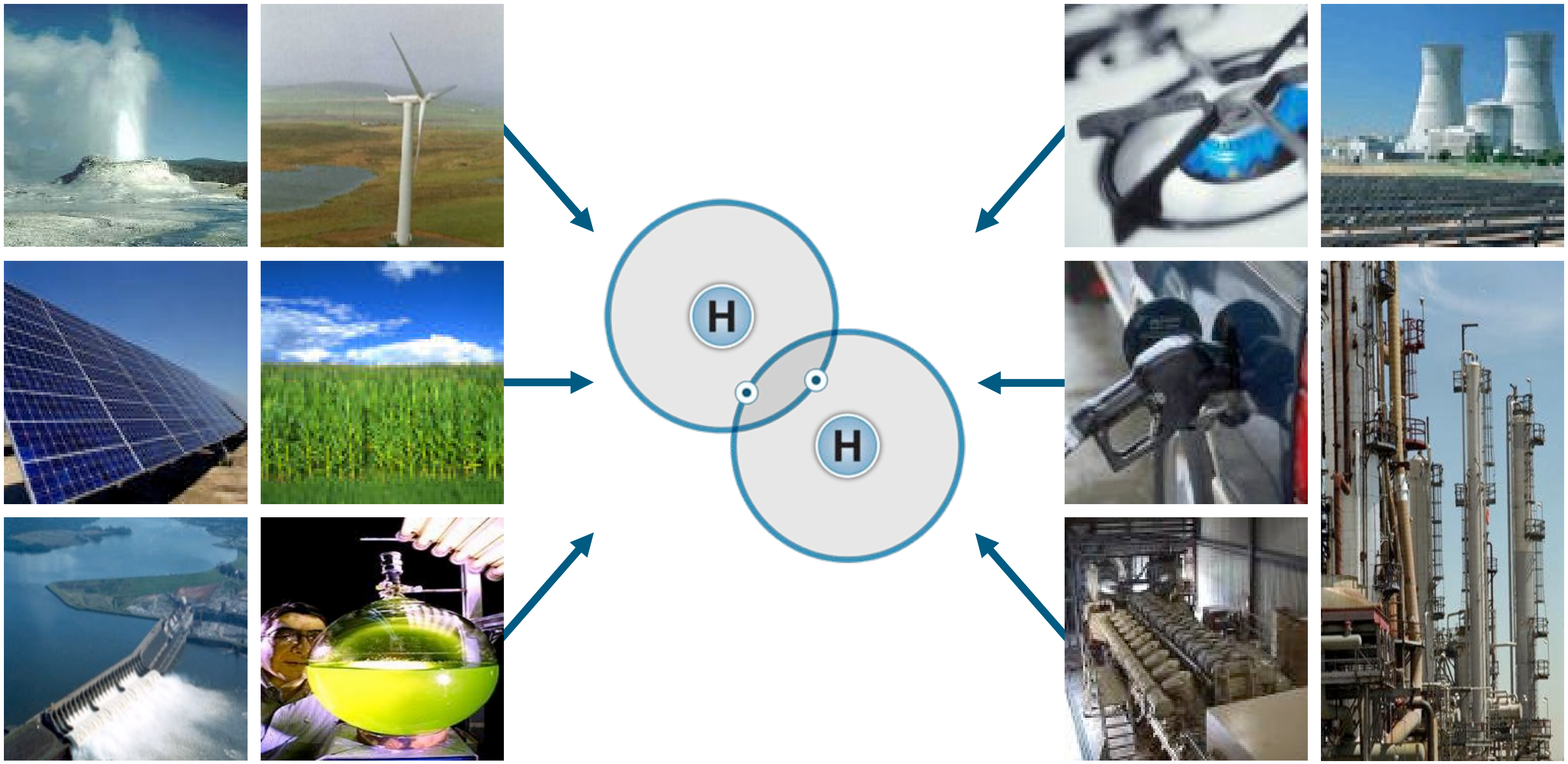
- Excellent energy carrier
- Nonpolluting
- Economically competitive
- As safe as gasoline
- Used safely for over 50 years
- Produced from a variety of sources



Where Do We Get Hydrogen?

Renewable Sources

Traditional Sources



Solar, wind, geothermal, hydro, biomass, algae

Natural gas, gasoline, nuclear, coal

Hydrogen Uses

The use of hydrogen is not new; private industry has used it safely for many decades. Nine million tons of hydrogen are safely produced and used in the United States every year. 56 billion kg/yr are produced globally. For example, H_2 is used for:

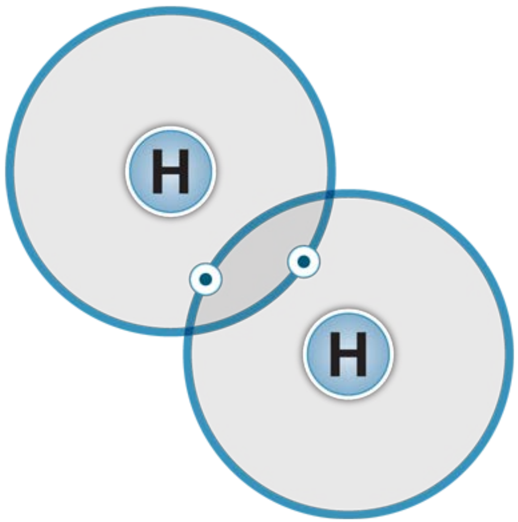
- Petroleum refining
- Glass purification
- Aerospace applications
- Fertilizers
- Annealing and heat treating metals
- Pharmaceutical products

The Air Products and Chemicals hydrogen production facilities in Port Arthur, Texas, is funded by the Energy Department through the 2009 Recovery Act. | Photo credit Air Products and Chemicals hydrogen production facilities.

- Petrochemical manufacturing
- Semiconductor industry
- Hydrogenation of unsaturated fatty acids in vegetable oil
- Welding
- Coolant in power generators

Hydrogen Properties and Behavior

- A gas at ambient conditions
- Hydrogen is a cryogen: exists as a liquid at -423°F (-253°C).
  - Compressing the gas does not liquefy it
  - No liquid phase in a compressed gaseous hydrogen storage tanks
- LH2 storage at relatively low pressure (50 psi)
- Double walled, vacuum insulated tanks with burst disks, vents, and pressure relief devices
- Volumetric ratio of liquid to gas is 1:848
  - Compare water to steam (1:1700)
- Energy content of 1kg of H_2 is approximately equal to 1 gal of gasoline (in BTUs)



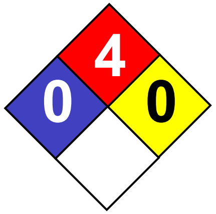
Molecular Hydrogen

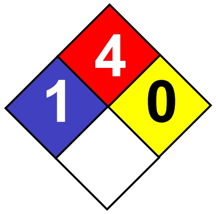
Hydrogen Properties: A Comparison

	Hydrogen	Natural Gas	Gasoline
Color	**No**	**No**	**Yes**
Toxicity	**None**	**Some**	**High**
Odor	**Odorless**	**Mercaptan**	**Yes**
Buoyancy Relative to Air	**14X** Lighter	**2X** Lighter	**3.75X** Heavier
Energy by Weight	**2.8X** > Gasoline	**~1.2X** > Gasoline	**43** MJ/kg
Energy by Volume	**4X** < Gasoline	**1.5X** < Gasoline	**120** MJ/Gallon

Source: California Fuel Cell Partnership

Comparison of Flammability





	Hydrogen	Natural Gas	Gasoline
Flammability in air (LFL – UFL)	4.1% - 74%	5.3% - 15%	1.4% - 7.6%
Explosive limits in air (LEL – UEL)	18.3% - 59%	5.7% - 14%	1.4% - 3.3%
Most easily ignited mixture in air	29%	9%	2%
Flame temperature (°F)	4010	3562	3591

Fuel Cell Basics

- The type of electrolyte determines the kind of fuel cell
  - The polymer electrolyte membrane fuel cell is the most promising for light-duty transportation
  - Other fuel-cell types, such as solid oxide, molten carbonate, and phosphoric acid fuel cells, use different electrolytes
- To increase the amount of electricity generated, individual fuel cells are combined into a fuel-cell "stack," which may consist of hundreds of individual fuel cells

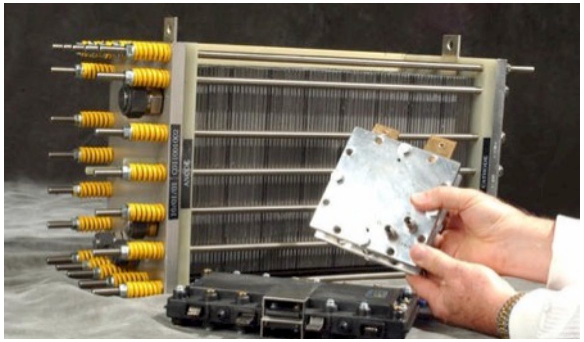
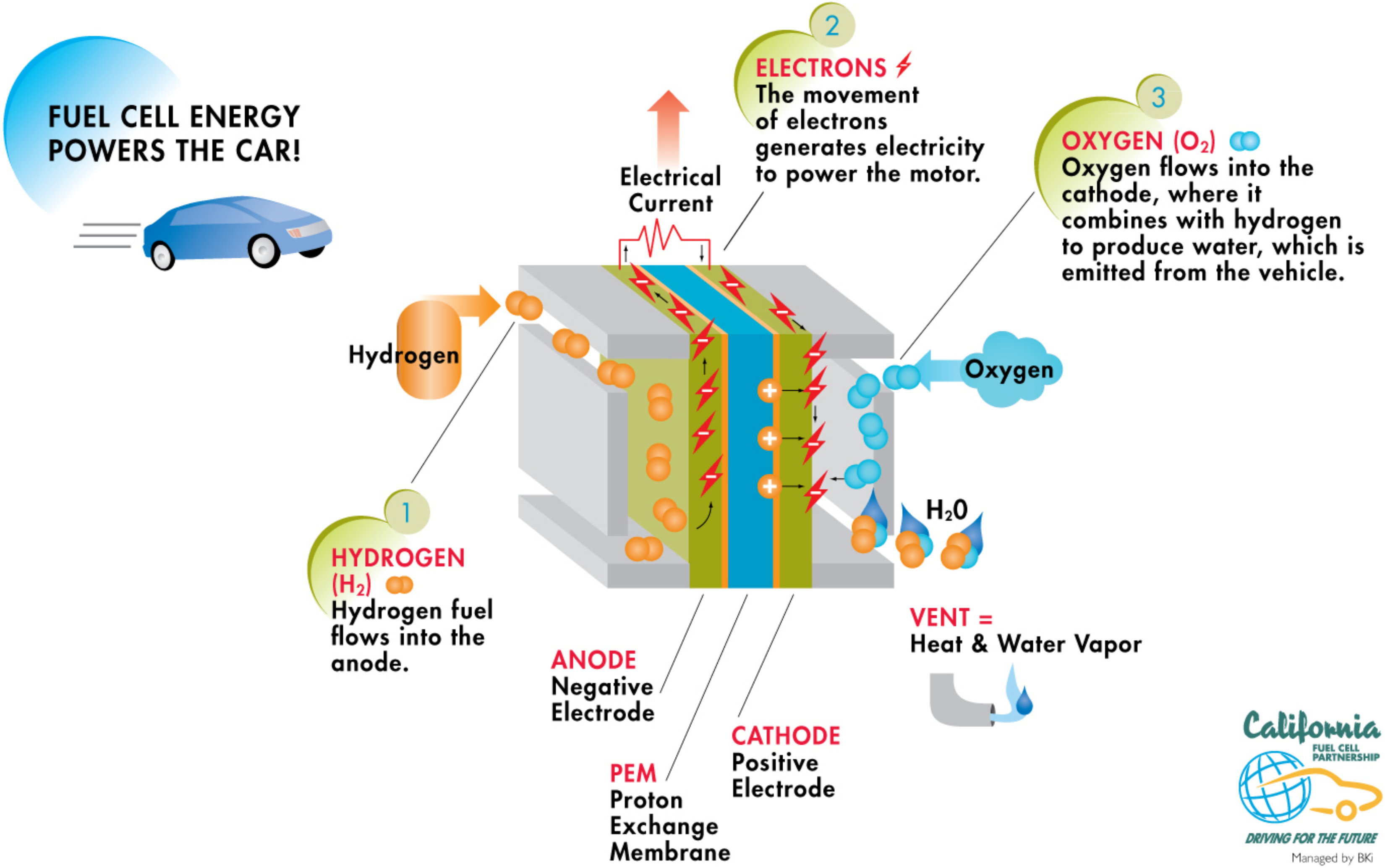


Photo: National Renewable Energy Laboratory

Photo: California Hydrogen Business Council

How a Fuel Cell Works



California Fuel Cell Partnership
DRIVING FOR THE FUTURE
Managed by BKi

Fuel Cell Electric Vehicles (FCEV)

- Run on hydrogen
- Use a fuel cell and electric motor, no engine
- Quiet, mostly air compressor and valves
- Emit zero pollutants

Mercedes-Benz

Nissan

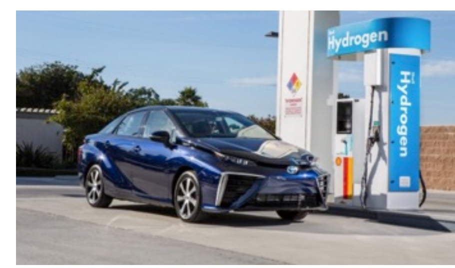
General Motors

Hyundai / Kia

Honda

AC Transit

Volkswagen / Audi



Toyota

Public Vehicles

Photos provided by equipment providers

FCEV Concepts

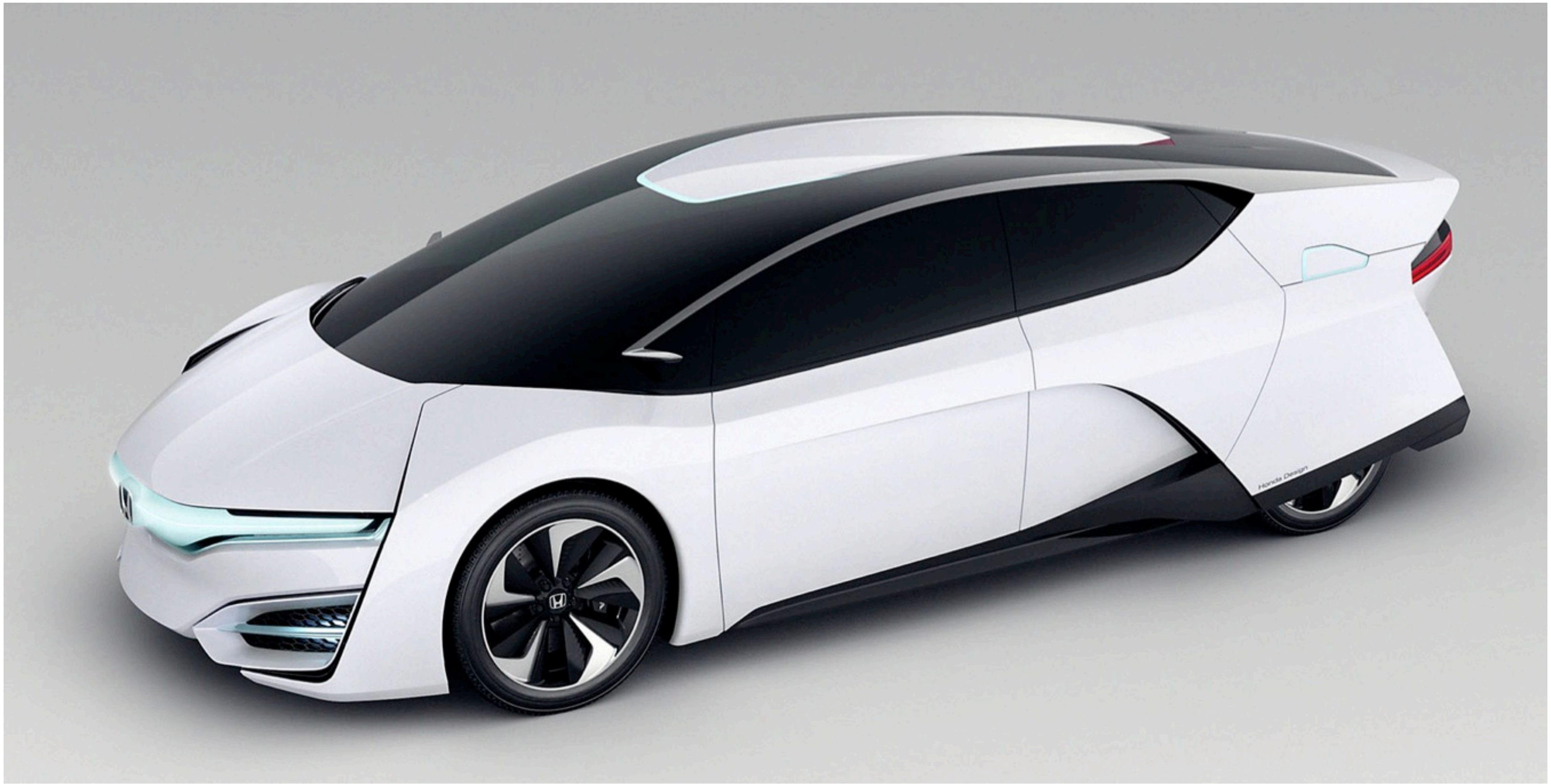
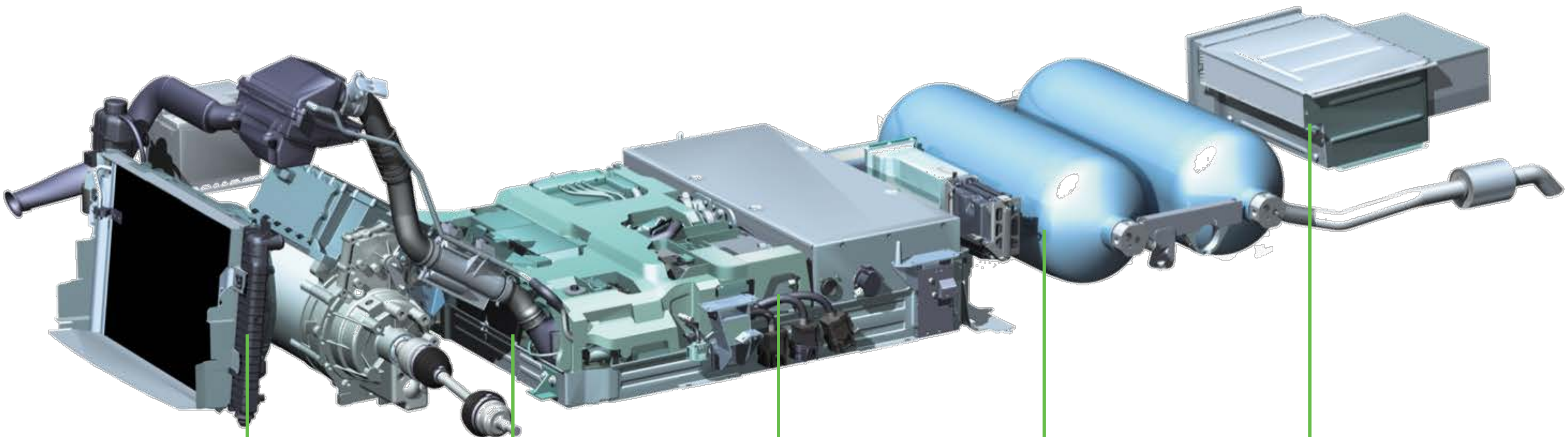


Image courtesy of Honda

FCEV System Layout



Cooling System
Typically, slightly larger radiators than conventional

Electric Motor
Electrical component; drives vehicle by electricity

Power Electronics
Electrical component; distributes electricity

Fuel Cell
Electrical component; generates electricity from hydrogen

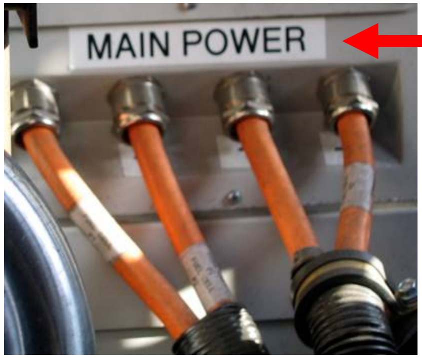
Hydrogen Tanks
Compressed, gaseous fuel; vehicle fueled with hydrogen

High Voltage Battery
Electrical component; captures regen braking, supports acceleration

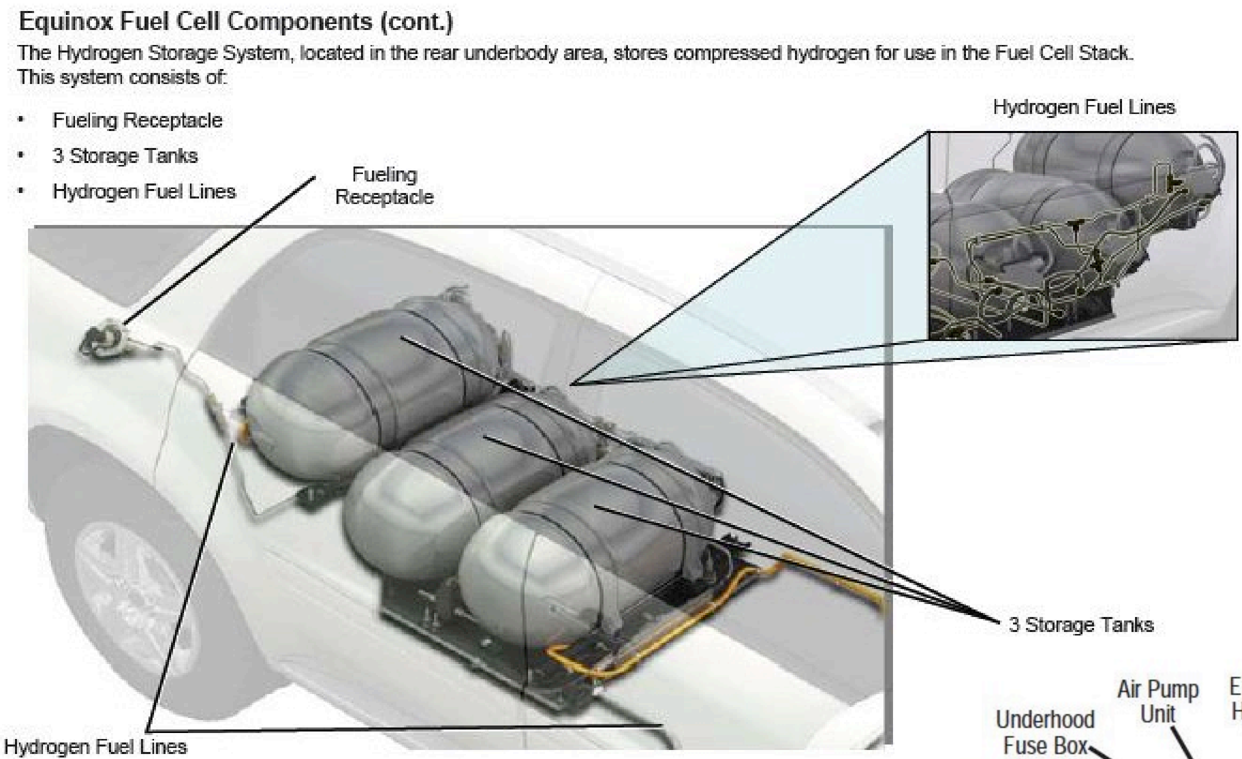
Source: California Fuel Cell Partnership

High Voltage System

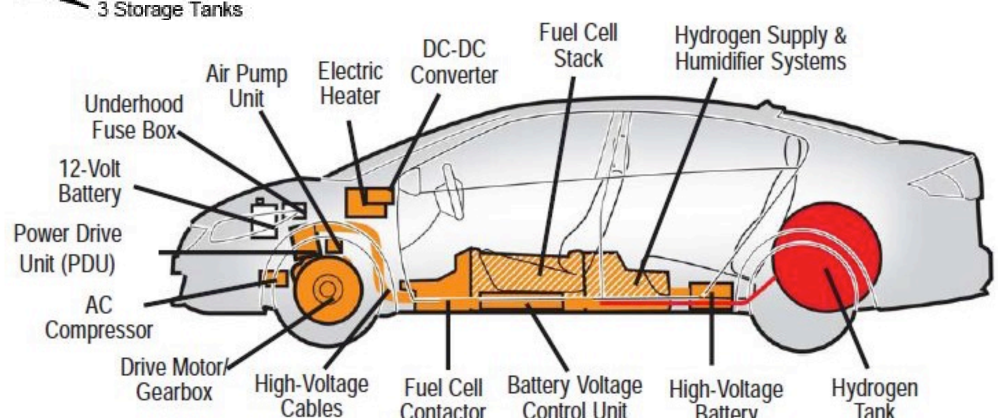
- Same technology as other alt fuel vehicles (gas/electric hybrids)
- Orange high-voltage wiring per SAE
- Isolated + and – sides (not grounded to the chassis)
- Automatic high voltage system disconnect
  - Inertia switch
  - Ground fault monitoring



Hydrogen Delivery System

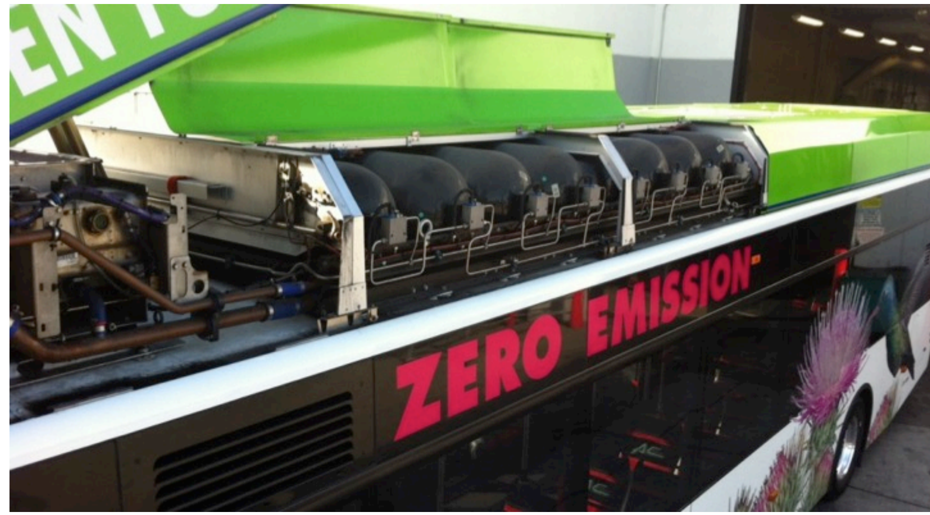


- Single tank and multi-tank set-ups
- Distribution lines contain lower pressures than tanks
- Tank TPRDs vent directly or are connected to fuel vent line(s)



Hydrogen Delivery System – Bus

- Bus fuel tanks on roof
- All equipped with thermally activated pressure relief devices and vent lines
- Larger capacity storage



Compressed Hydrogen Storage Systems

- Carbon fiber wrapped, metal or polymer lined tanks
- Equipped with temperature activated pressure relief devices (TPRD)
- Stronger than conventional gasoline tanks
  - Absorb 5X crash energy of steel

Wall thickness comparison:
35 MPa vs. 70 MPa cylinders

(Photo courtesy of Powertech)

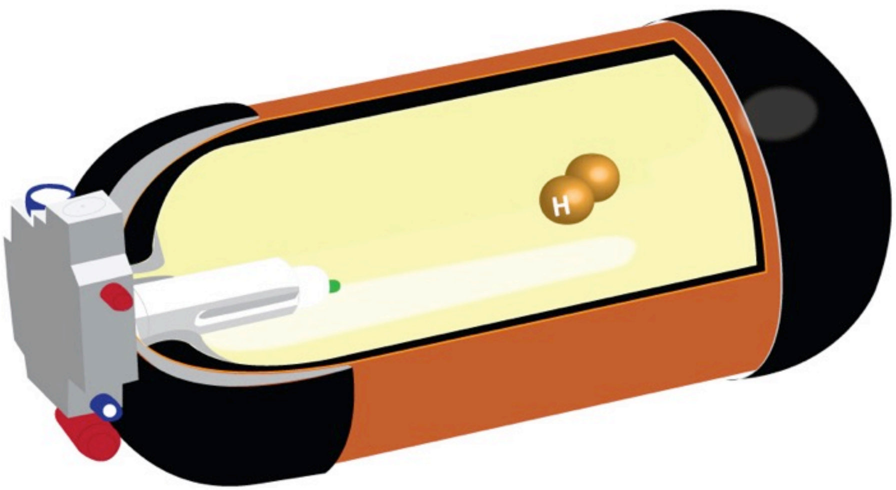
Compressed Hydrogen Tank Testing

Tank testing is on a national (SAE International/FMVSS) and international scale (Global Technical Regulation) for the types of tests and tank lifetimes (15 years is typical, but could qualify for 20+ years with additional testing).

- Bonfire
- Drop
- Gun fire
- Pressure cycling
- Overpressure
- Temperature
- Impact
- Permeation
- "Tank life" – at least 15 years
- Rated for 2.25x service pressure

Compressed Hydrogen Tank Testing

- In accordance with latest proposed hydrogen vehicle tank standards (SAE J2579, CSA HGV2)
- Tests conducted as part of the design qualification testing for new tanks
- The tank should only vent and not rupture



Types of Stationary Facilities

Stationary facilities include:

- Stationary fuel cells
- Bulk hydrogen storage
- Hydrogen fueling stations

Photo: Air Products and Chemicals, Inc.

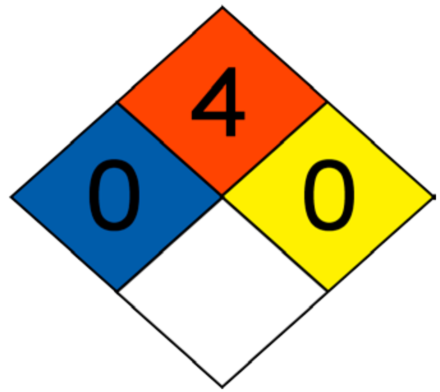
Photo: Plug Power, Inc.

Photo: California Fuel Cell Partnership

Identifying Stationary Facilities

NFPA 704 Hazard Placards

- Red = Flammability
- Blue = Health
- Yellow = Reactivity
- White = Special Precautions



Gaseous Hydrogen

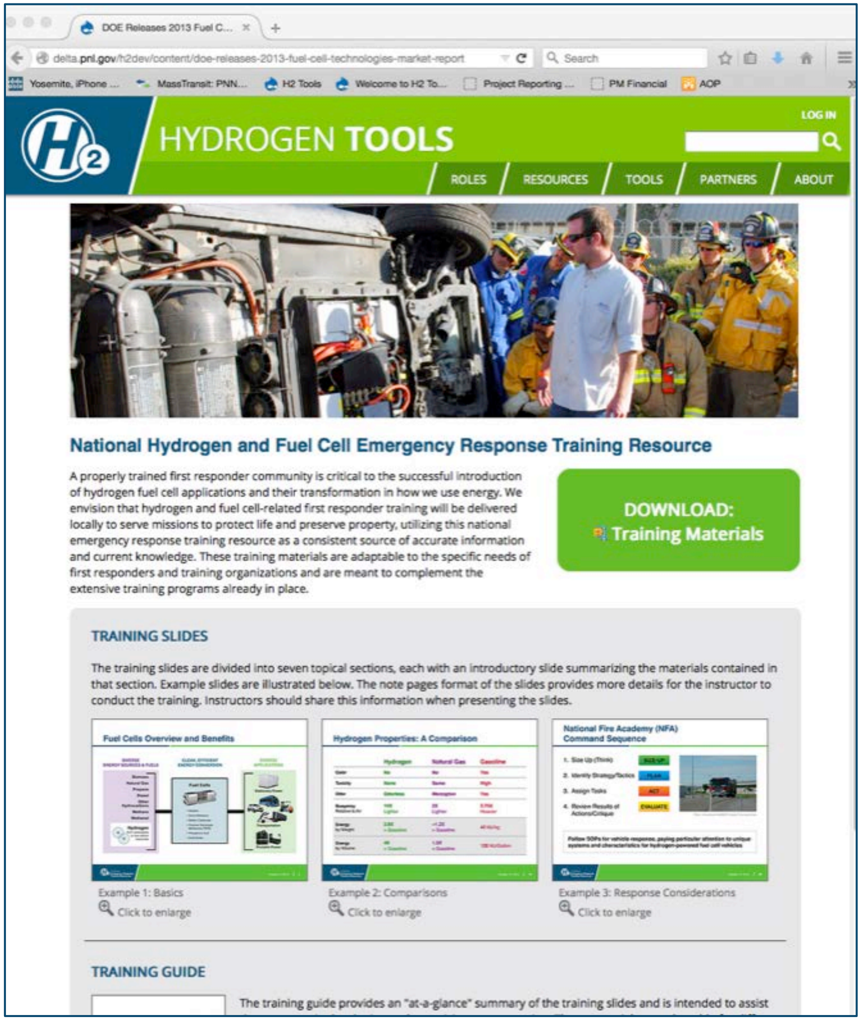
Liquid Hydrogen

Hydrogen Fueling Stations

Pictures provided by CaFCP

Downloading the Resource…

- The National Hydrogen and Fuel Cell Emergency Response Training Resource is one of many resources available from the Hydrogen Tools Portal at http://h2tools.org/fr/nt/.
- The Hydrogen Tools Portal brings together and enhances the utility of a variety of tools and web-based content on the safety aspects of hydrogen and fuel cell technologies. It is intended to help inform those tasked with designing, approving, or using systems and facilities, as well as those responding to incidents.



Hydrogen Tools

A Transformative Step Towards Hydrogen Adoption

CENTRALIZED LOCATION — organizes current H_2 resources in one robust location—including **more than 20** existing tools, with plans for adding future content

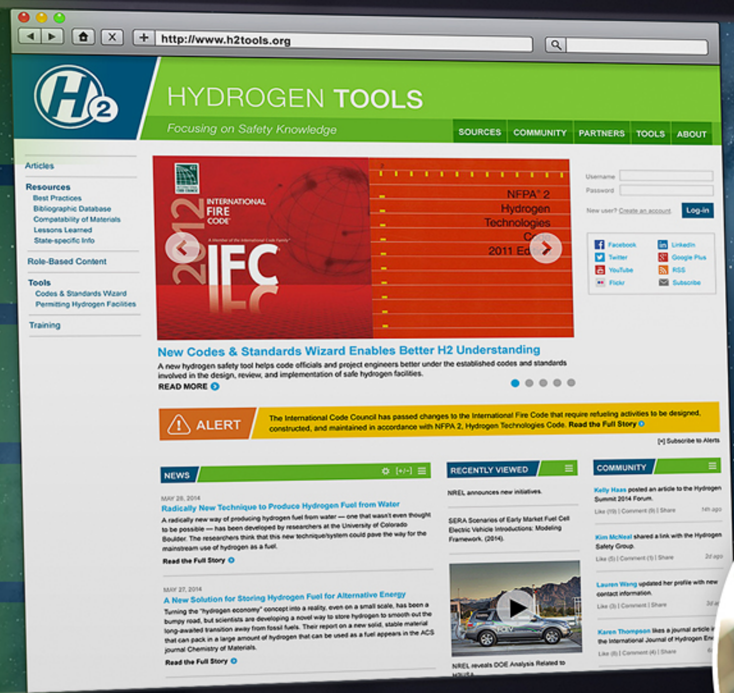
FOCUSED CONTENT — tailored to the specialized needs of H_2 user groups

CUSTOMIZABLE INTERFACE — allows content to display based on the H_2 user's role or interests

RESPONSIVE DESIGN — enables H_2 safety work across both desktop and mobile devices

TRUSTED COMMUNITIES — fostered through social networking around H_2 subject matter expertise

EXPANDABLE FORMAT — built with frequently requested future feature sets in mind



› **Credible** and **reliable** safety information from a **trustworthy** source

Planning for Future Activities

- Updating and maintaining information and media in the National Hydrogen and Fuel Cell Emergency Response Training Resource is critical
- Developing new, smaller props and prop kits can help address the tactile needs of the participants
- Giving preference to videos and enhanced videos when updating or developing new materials
- Updating and providing new photographs can provide significant value
- Considering new virtual reality tools for immersing students in real-world scenarios

Reiterating the Vision for the National Hydrogen and Fuel Cell Emergency Response Training Resource

Hydrogen and fuel cell-related first responder training is delivered locally to serve missions to protect life and preserve property, utilizing a national emergency response education program as a consistent source of accurate information and current knowledge.

A training template approach is utilized to achieve this vision by facilitating

- delivery of a variety of training regimens to various audiences,
- development of new and updated training content and techniques and
- encouragement of collaborations among various stakeholders to achieve purposeful results.

Acknowledgements

The National Hydrogen and Fuel Cells Emergency Response Training Resource was developed by PNNL and the CaFCP with funding from the US DOE Office of Energy Efficiency and Renewable Energy's Fuel Cell Technologies Office.

The following individuals are gratefully acknowledged for their contributions to developing and reviewing this training resource:

U.S. Department of Energy

- Sunita Satyapal, Director, Fuel Cell Technologies Office
- Will James, Laura Hill and Kristen Nawoj

Development and review

- Nick Barilo, Steven Weiner and Monte Elmore – Pacific Northwest National Laboratory
- Jennifer Hamilton and Bill Elrick – California Fuel Cell Partnership

Reviewers

- Aaron Harris – Air Liquide
- Larry Moulthrop – ProtonOnsite
- Rodney Slaughter, – Cal Fire, Office of the State Fire Marshal
- Colin Armstrong – HTEC
- Brian Ladds – Calgary Fire Department
- John Frala – Rio Hondo College
- Spencer Quong – Quong Associates

Contact Information

Please let us know if you have any questions or comments!

Nick Barilo, P.E.

Hydrogen Safety Program Manager
Pacific Northwest National Laboratory
509-371-7894
nick.barilo@pnnl.gov

Jennifer Hamilton

Safety and Education Specialist
California Fuel Cell Partnership
(916) 375-4914
jjhamilton@cafcp.org

Thank You

Chris.Werth@ee.doe.gov

Presenter: Jennifer Hamilton (jjhamilton@cafcp.org)
Nick Barilo (nick.barilo@pnnl.gov)

DOE Host: Will James Jr.(Charles.James@EE.Doe.Gov)

hydrogenandfuelcells.energy.gov