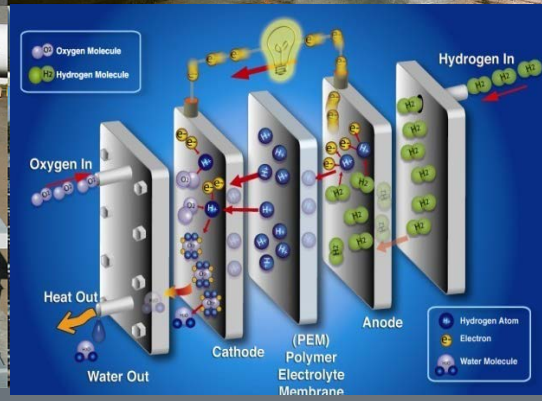
U.S. DEPARTMENT OF ENERGY
FUEL CELL TECHNOLOGIES OFFICE

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



National Hydrogen Safety Training Resource for Emergency Responders

3/24/15

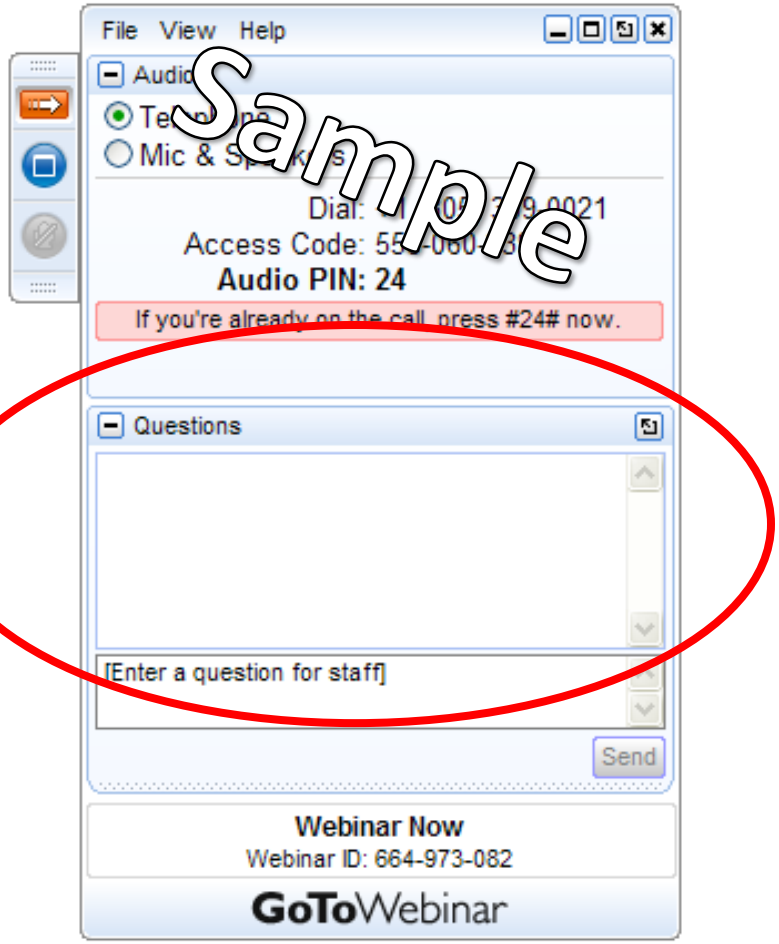
Presenter(s):

Nick Barilo

Jennifer Hamilton

Question and Answer

- Please type your questions into the question box



HYDROGEN
Emergency Response
Training Resources

Pacific Northwest
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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 H_2USA

- 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.

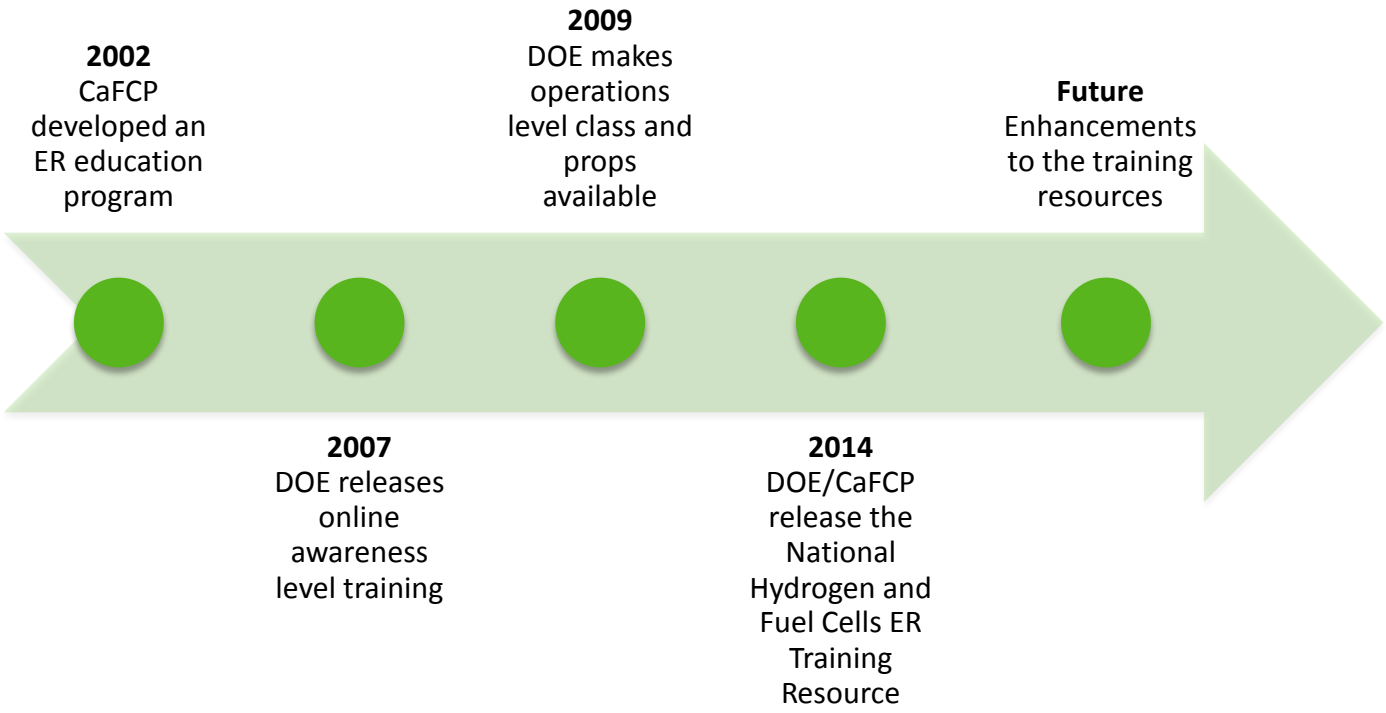
H2USA's public-private partnership

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



Accomplishments

- 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

Introduction to Hydrogen Safety for First Responders

U.S. Department of Energy
Hydrogen Program
www.hydrogen.energy.gov/firstresponders

COURSE MATERIALS | LIBRARY | EXIT ▶

☑ Hydrogen Basics ☑ Transport & Storage ☑ Hydrogen Vehicles ☑ Hydrogen Dispensing ☑ Stationary Facilities ☑ Codes & Standards ☑ Emergency Response ☐ Summary & Quiz

Hydrogen Properties and Behaviors

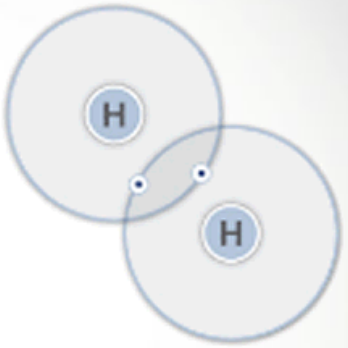
Like gasoline or natural gas, hydrogen is a fuel that must be handled properly; it can be used as safely as other common fuels when simple guidelines are followed.

Hydrogen is colorless, odorless, and tasteless. It's non-toxic and non-poisonous; it's non-corrosive, but can embrittle some metals. Hydrogen is the lightest and smallest element, and a gas under ambient conditions. It's 14 times lighter than air, which means that when it's released, it typically rises and diffuses quickly.

The volume ratio of liquid to gas is 1:848. So, if you picture a gallon of liquid hydrogen, that same amount of hydrogen, existing as a gas, would, theoretically, occupy 848 gallon containers (without compression).

⏮ ◂ Slide 4 of 13 ▸ ⏭ 🔊 Submit Comment

- Colorless, odorless, tasteless, non-toxic, non-corrosive and non-poisonous
- Lightest and smallest element
- A gas at ambient conditions
- Fourteen times lighter than air, it rises and disperses rapidly
- Exists as a liquid at -423°F (-253°C)
- Volume ratio of liquid to gas is 1:848



Molecular Hydrogen

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

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:

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			

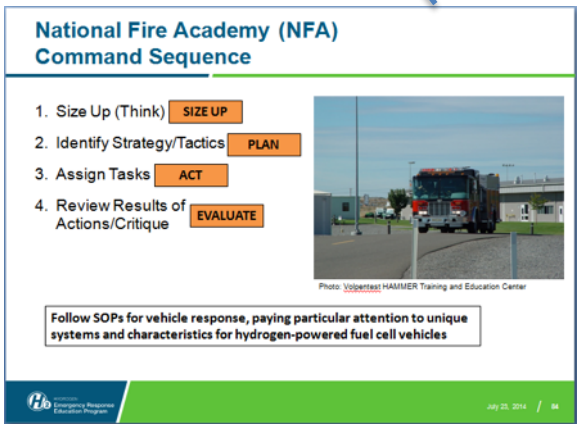
Managing Hydrogen-related Emergencies

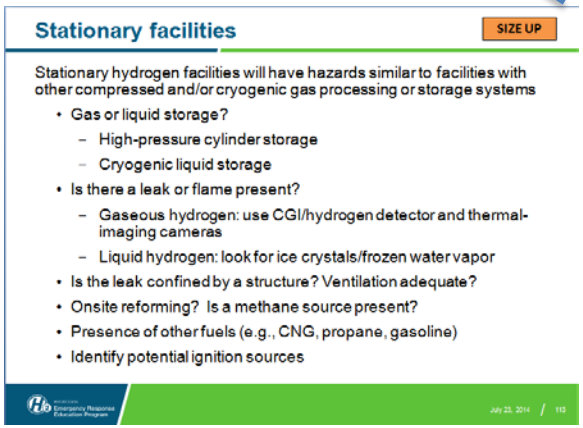
FR Template

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
6. Practical Exercises

Examples of slides covering a few topics/subtopics

- 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

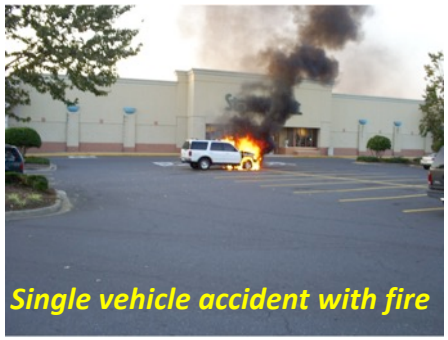




Accident Scenarios Provided for Group Discussion

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

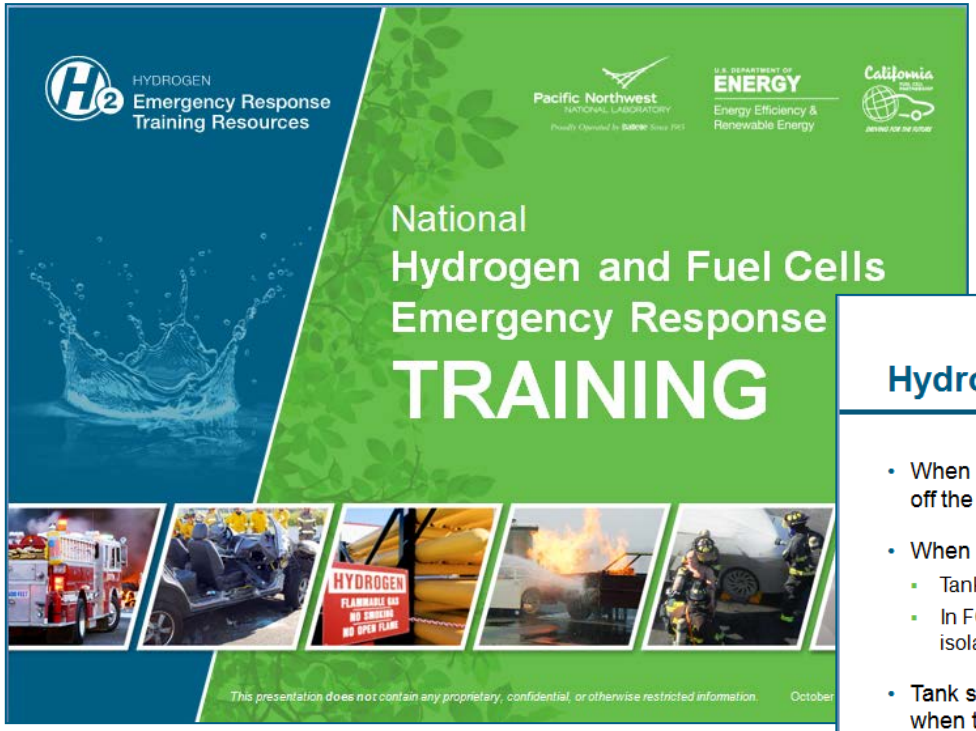


Single vehicle accident with fire

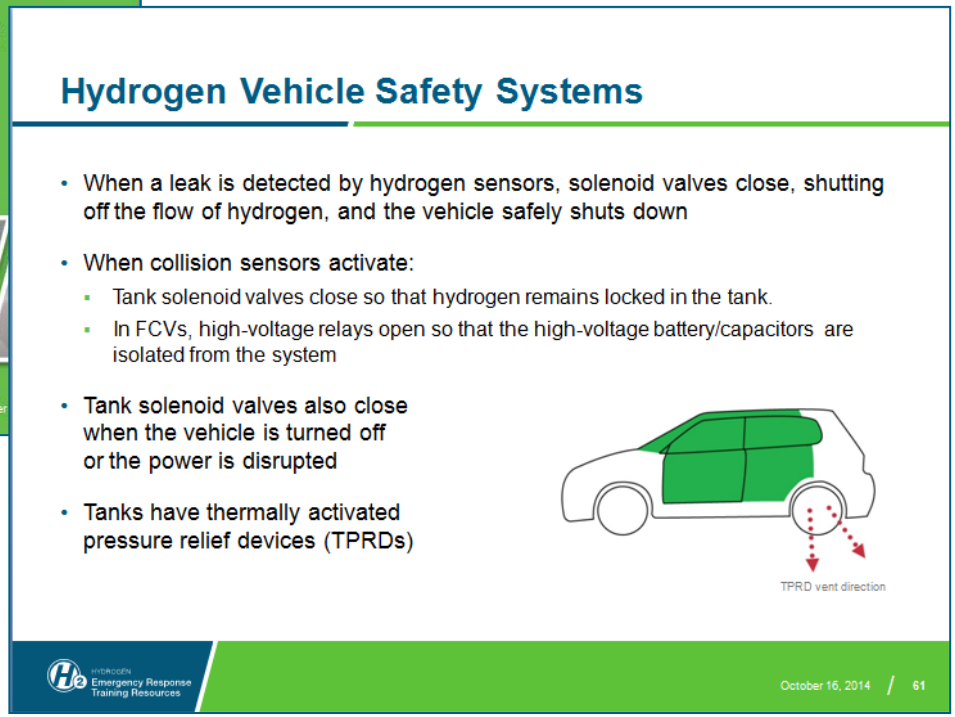
Multiple vehicle accident

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

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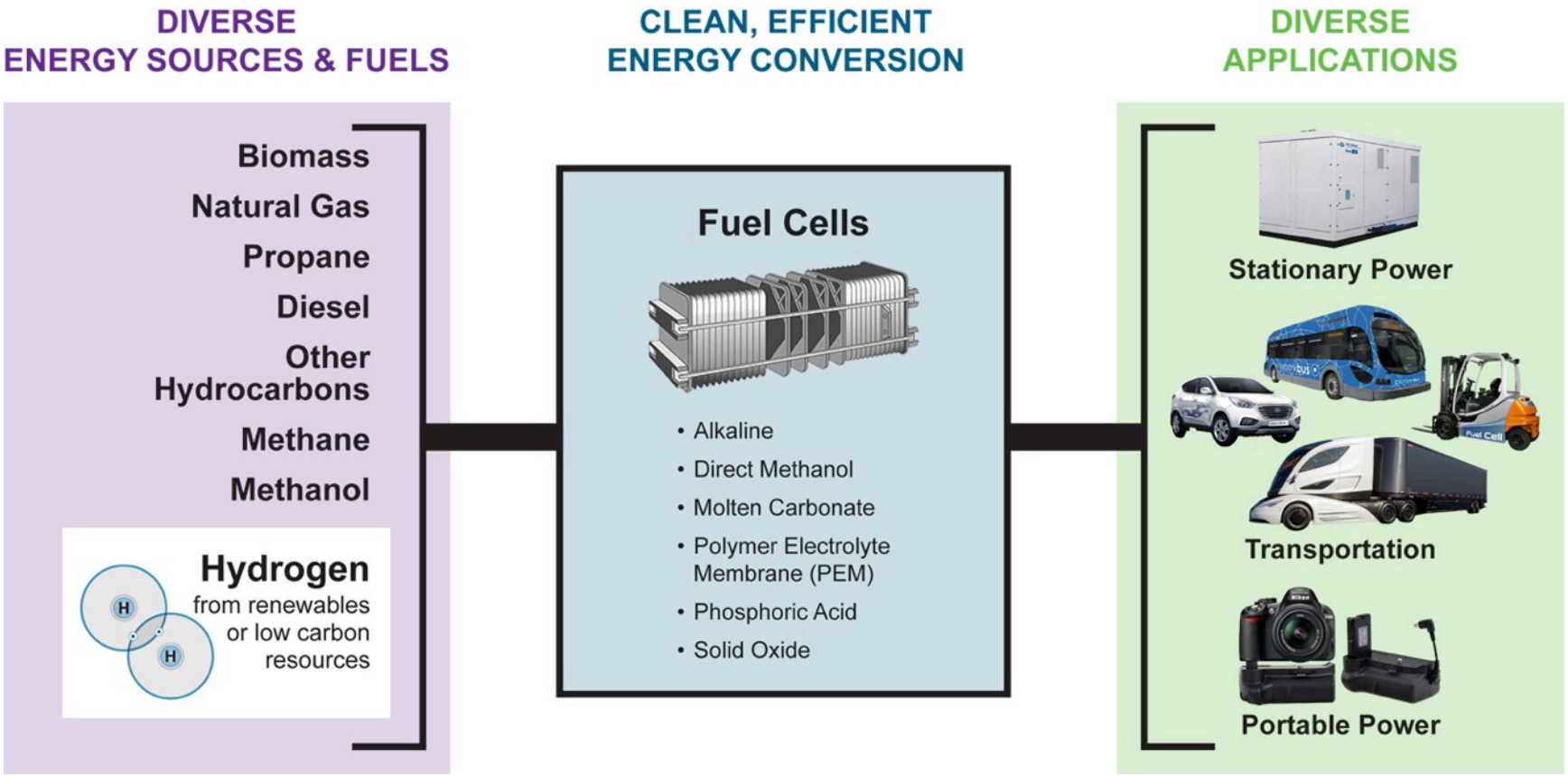
National
Hydrogen and Fuel Cells Emergency Response
TRAINING

Introduction and Background

This section introduces the user to:

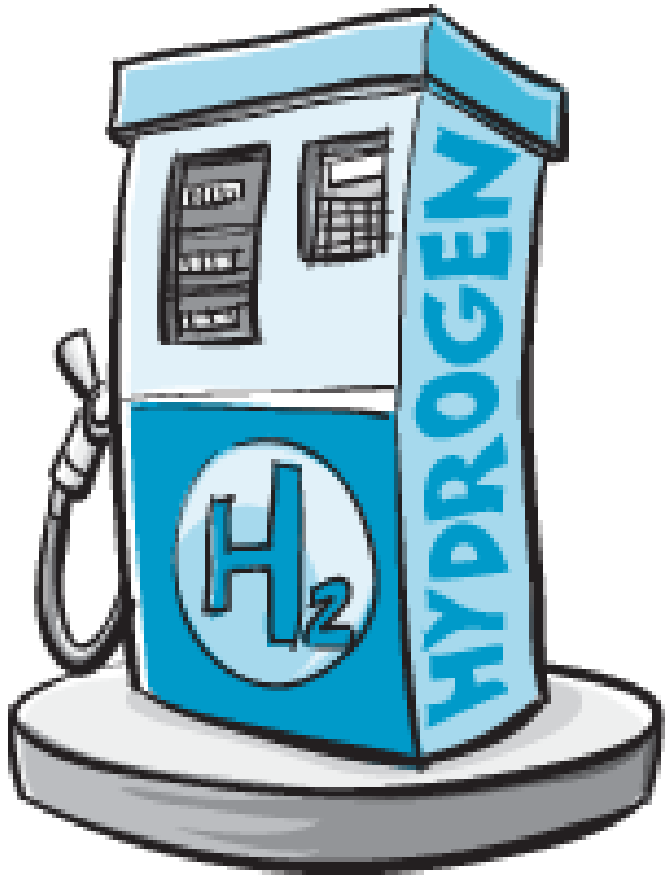
- An overview of the role of fuel cells and their benefits
- A picture of today's hydrogen production and delivery, current markets for fuel cells
- A diverse set of fuel cell transportation applications

Fuel Cells Overview



Why Hydrogen?

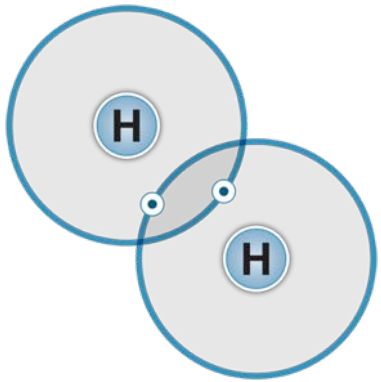
- Excellent energy carrier
- Nonpolluting
- Economically competitive
- As safe as gasoline
- Used safely for over 50 years
- Produced from a variety of sources



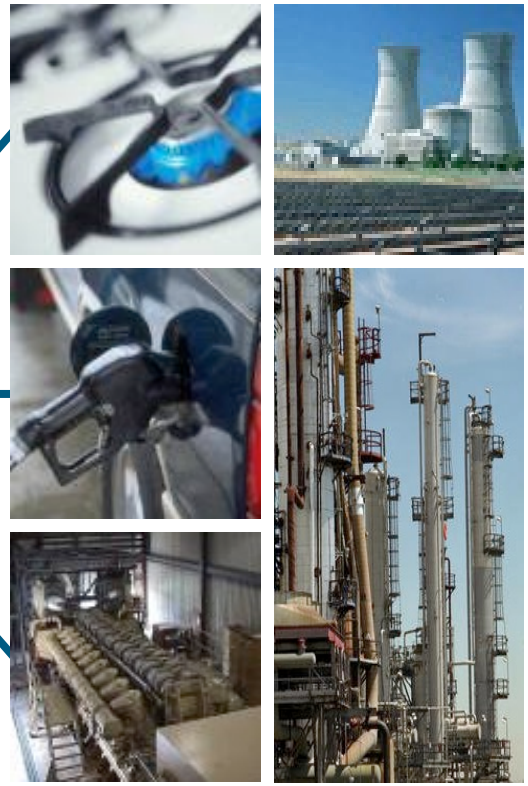
Where Do We Get Hydrogen?

Renewable Sources

Solar, wind, geothermal, hydro, biomass, algae



Traditional Sources



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:

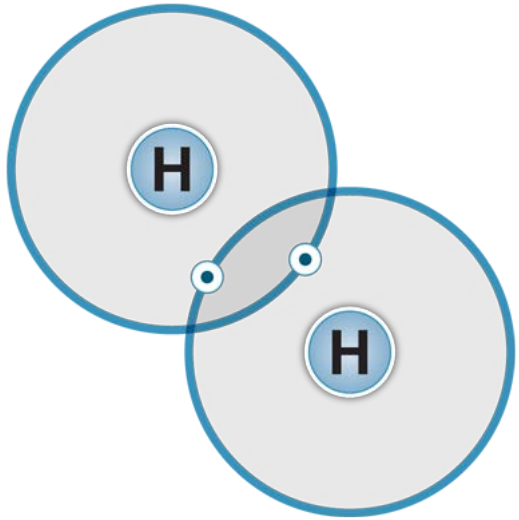
- Petroleum refining
- Glass purification
- Aerospace applications
- Fertilizers
- Annealing and heat treating metals
- Pharmaceutical products

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)



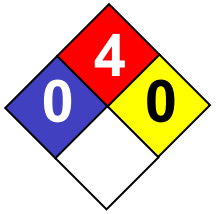
Molecular Hydrogen

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

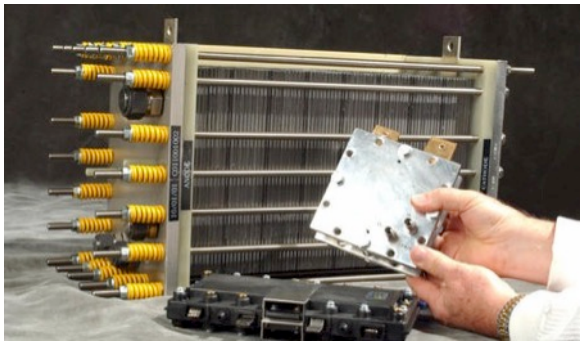
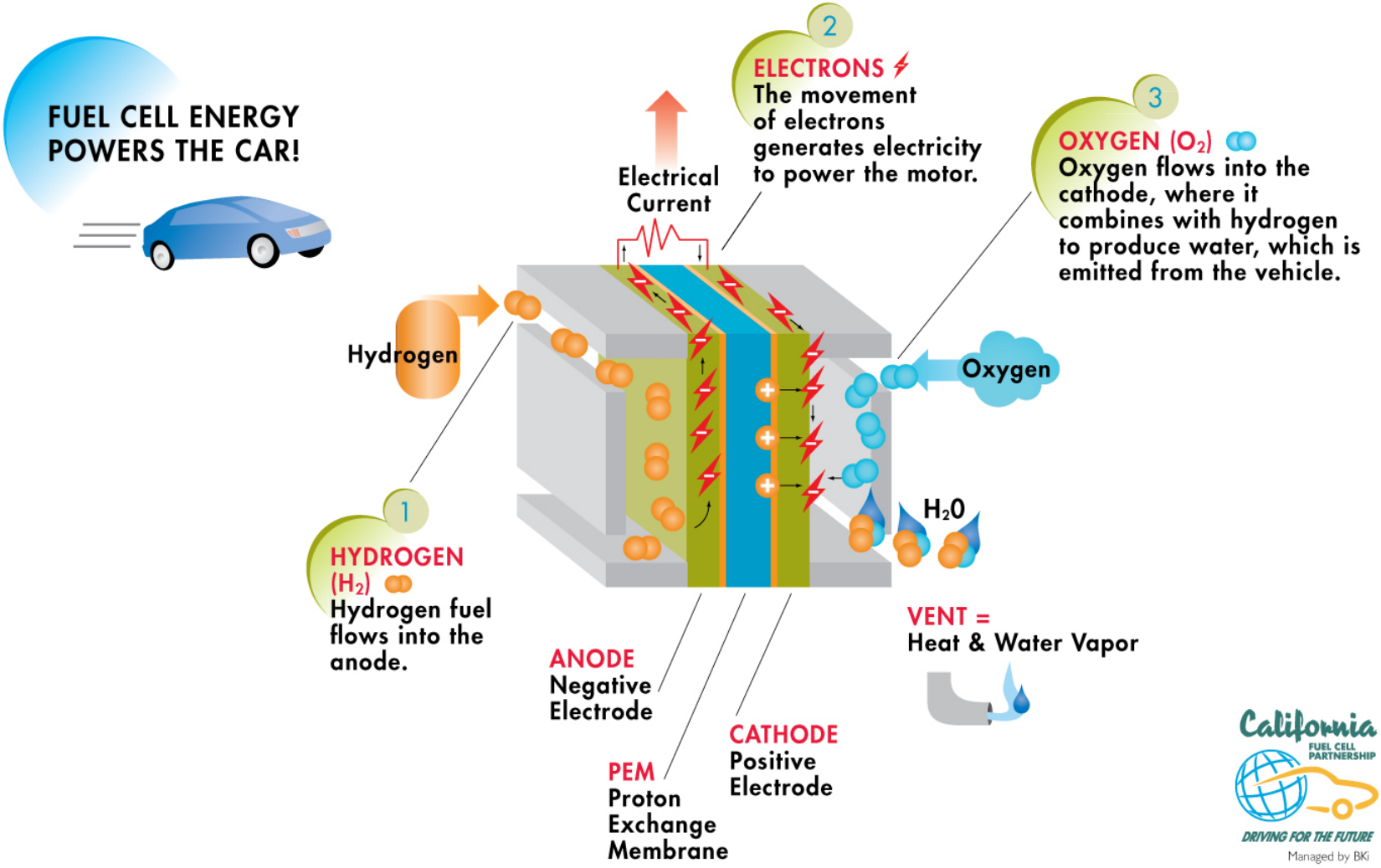


Photo: National Renewable Energy Laboratory

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

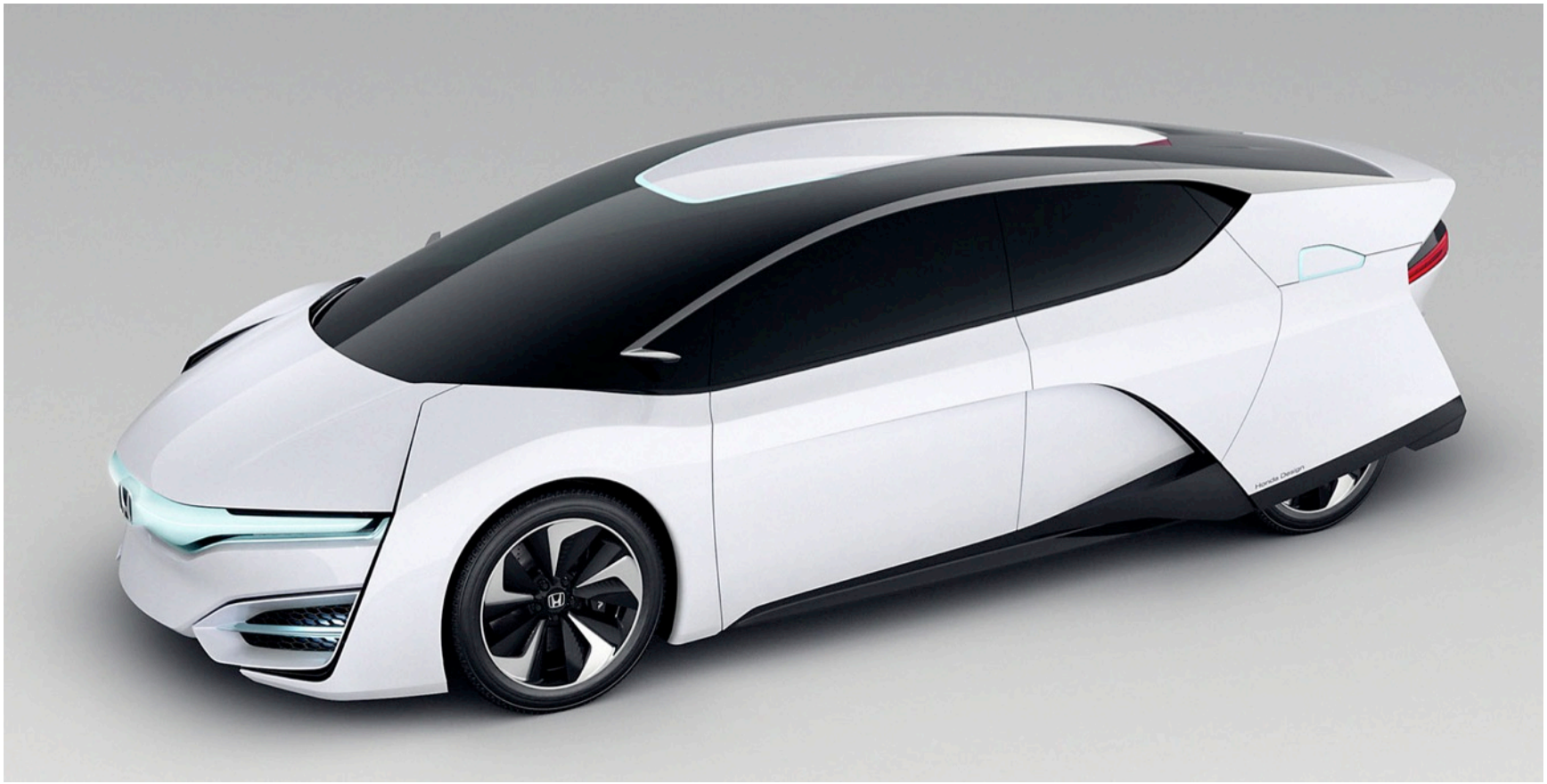
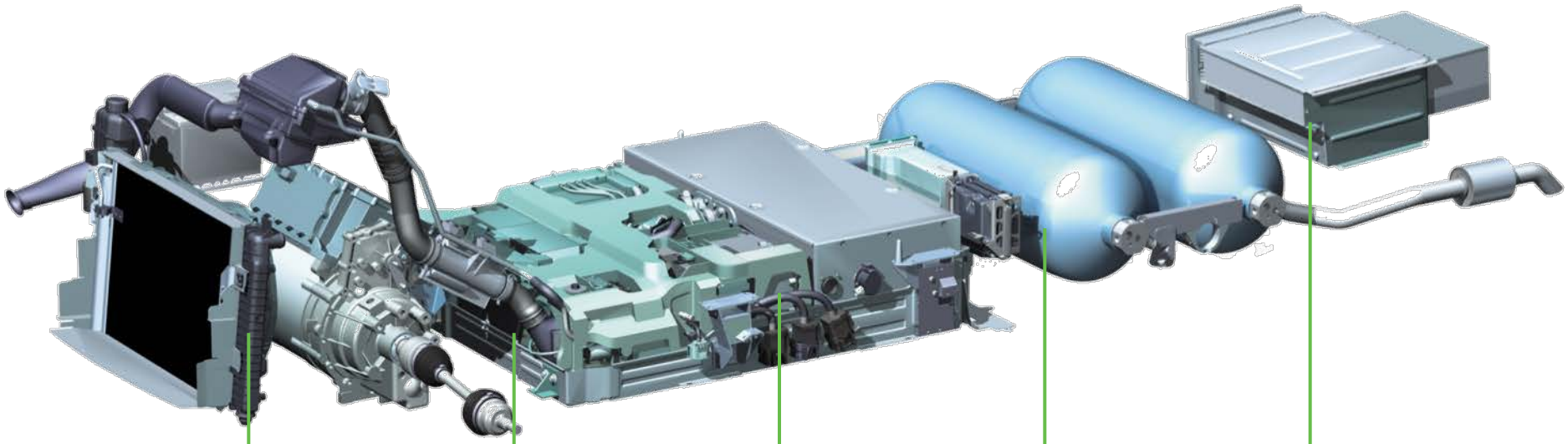


Image courtesy of Honda

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

Light Duty Vehicle

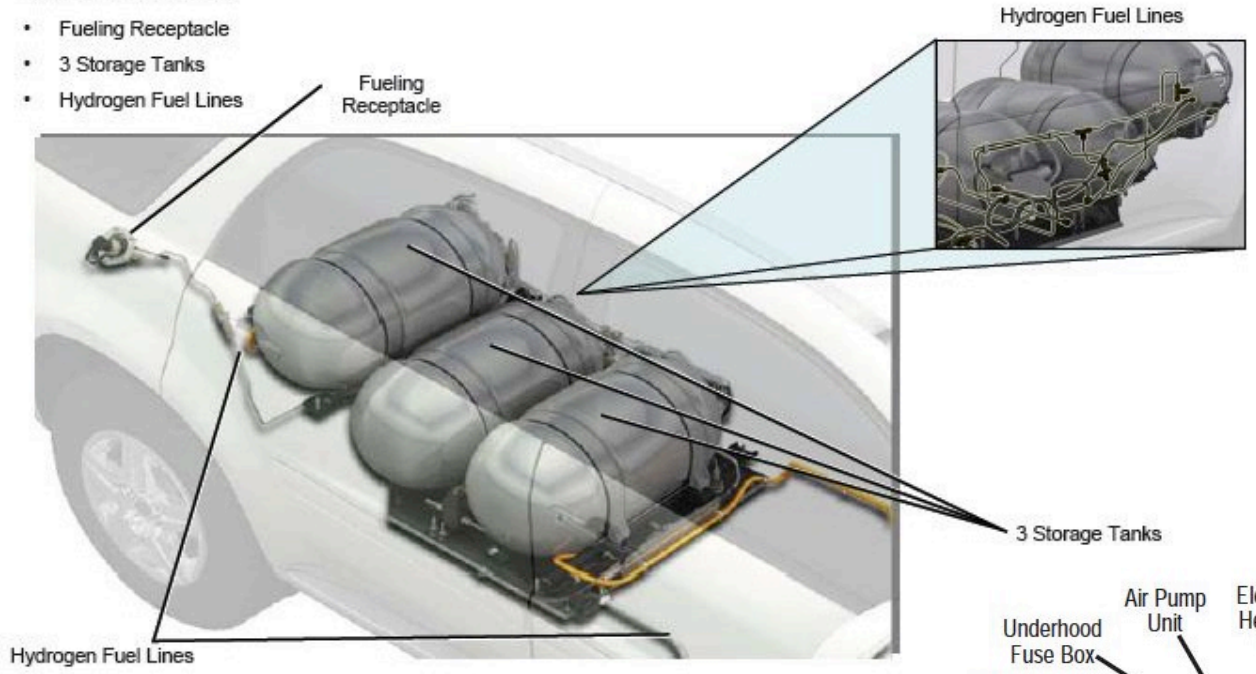
Transit Bus

Hydrogen Delivery System

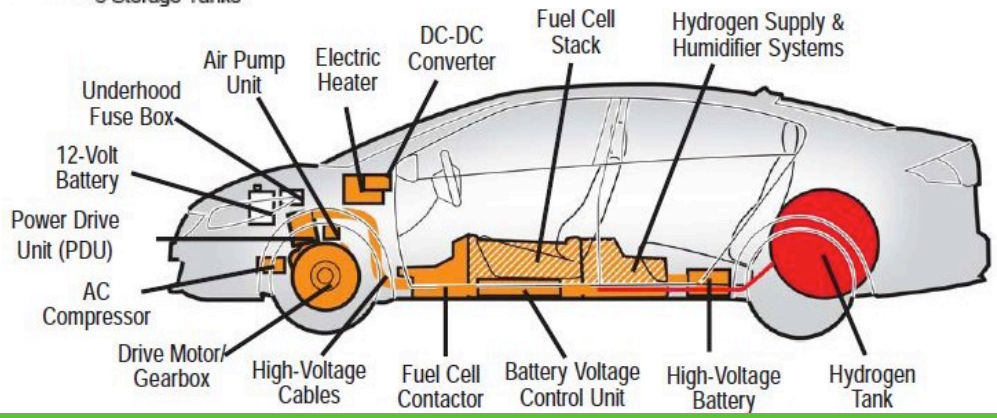
Equinox Fuel Cell Components (cont.)

The Hydrogen Storage System, located in the rear underbody area, stores compressed hydrogen for use in the Fuel Cell Stack. This system consists of:

- Fueling Receptacle
- 3 Storage Tanks
- Hydrogen Fuel Lines

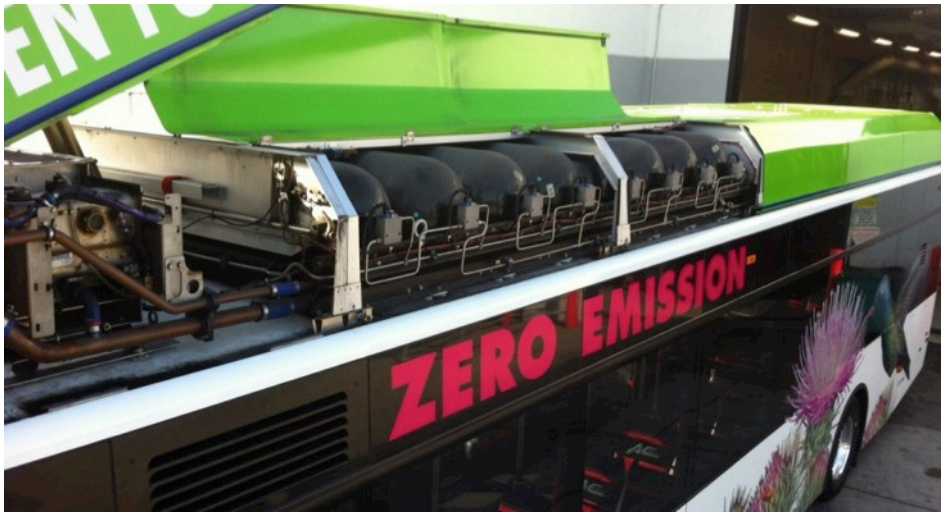


- Single tank and multi-tank set-ups
- Distribution lines contain lower pressures than tanks
- Tank TPRDs vent directly or are connected to fuel vent line(s)



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)

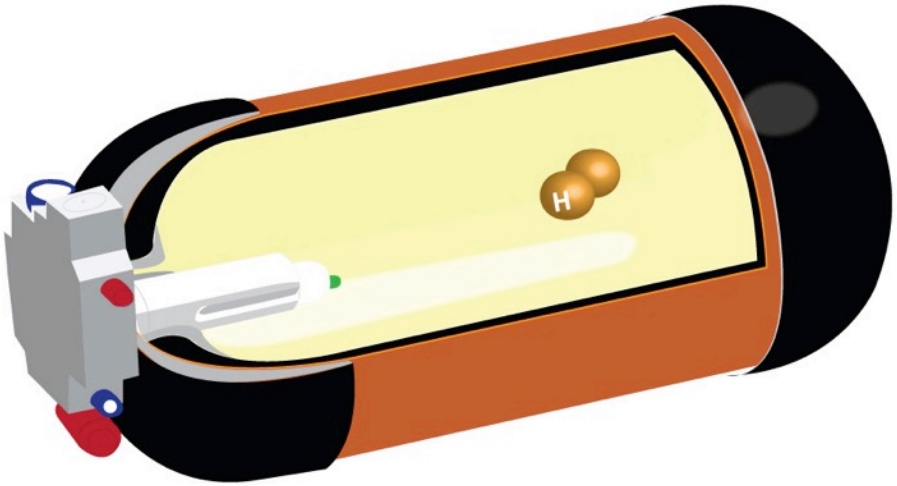
Compressed Hydrogen Tank Testing

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.

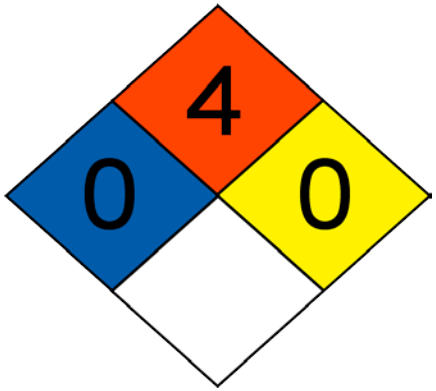
Photo: Plug Power, Inc.

Photo: California Fuel Cell Partnership

Identifying Stationary Facilities

NFPA 704 Hazard Placards

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



Gaseous Hydrogen

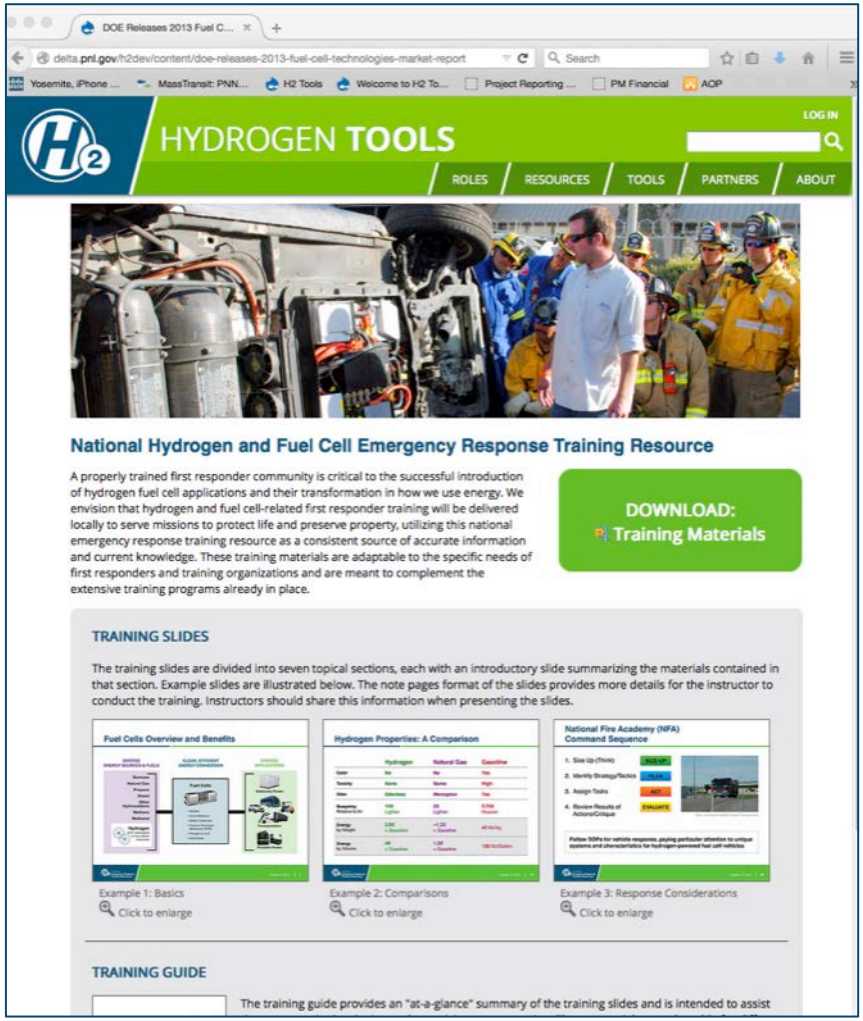
Liquid Hydrogen

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.

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Thank You

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