HYDROGEN
Safety Panel

Safety Considerations for Hydrogen and Fuel Cell Applications

Nick Barilo

PNNL Hydrogen Safety Program Manager

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PNNL Hydrogen Safety Program

Hydrogen Safety Panel

- Identify Safety-Related Technical Data Gaps
- Review Safety Plans and Project Designs
- Perform Safety Evaluation Site Visits
- Provide Technical Oversight for Other Program Areas

HYDROGEN Safety Panel

Safety Knowledge Tools and Dissemination

- Hydrogen Lessons Learned
- Hydrogen Best Practices
- Hydrogen Tools (iPad/iPhone mobile application)
- Hydrogen Tools Portal (http://h2tools.org)

HYDROGEN Tools

Hydrogen Safety First Responder Training

- Online Awareness Training
- Operations-level Classroom/Hands-on Training
- National Hydrogen and Fuel Cell Emergency Response Training Resource

HYDROGEN Emergency Response Training Resources

Outline for Today's Presentation

- Fuel Cell Basics and Applications
- Properties of Hydrogen
- Primary Codes and Standards
- Fundamental Safety Considerations
- Hydrogen Safety Resources
- Concluding Thoughts

Fuel Cell Basics and Applications

Why Hydrogen?

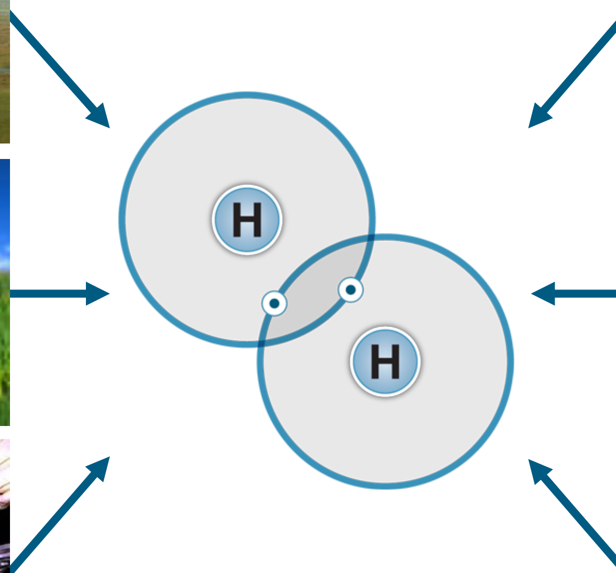
- Excellent energy carrier
- Nonpolluting
- Economically competitive
- As safe as gasoline
- Used safely for over 50 years
- Produced from a variety of sources

Photo courtesy of the California Fuel Cell Partnership

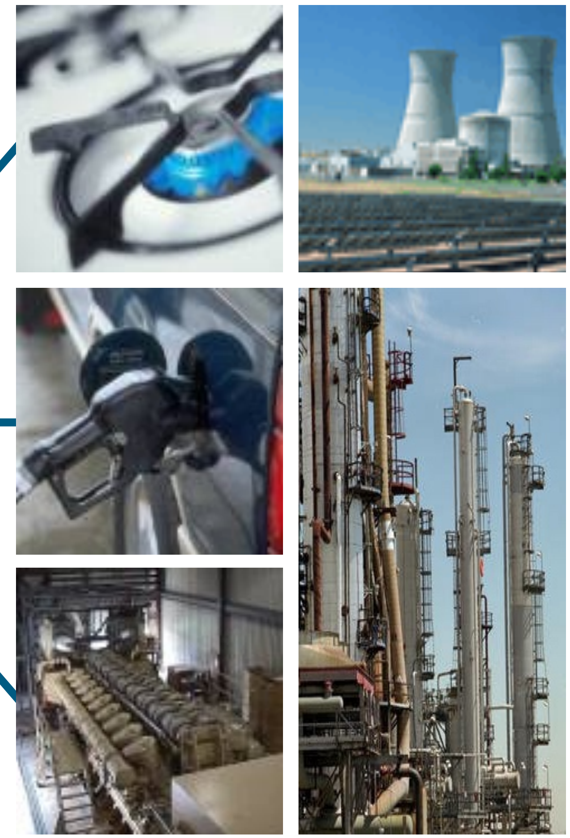
Where Do We Get Hydrogen?

Renewable Sources

Solar, wind, geothermal, hydro, biomass, algae



Traditional Sources



Natural gas, gasoline, nuclear, coal

Hydrogen Uses

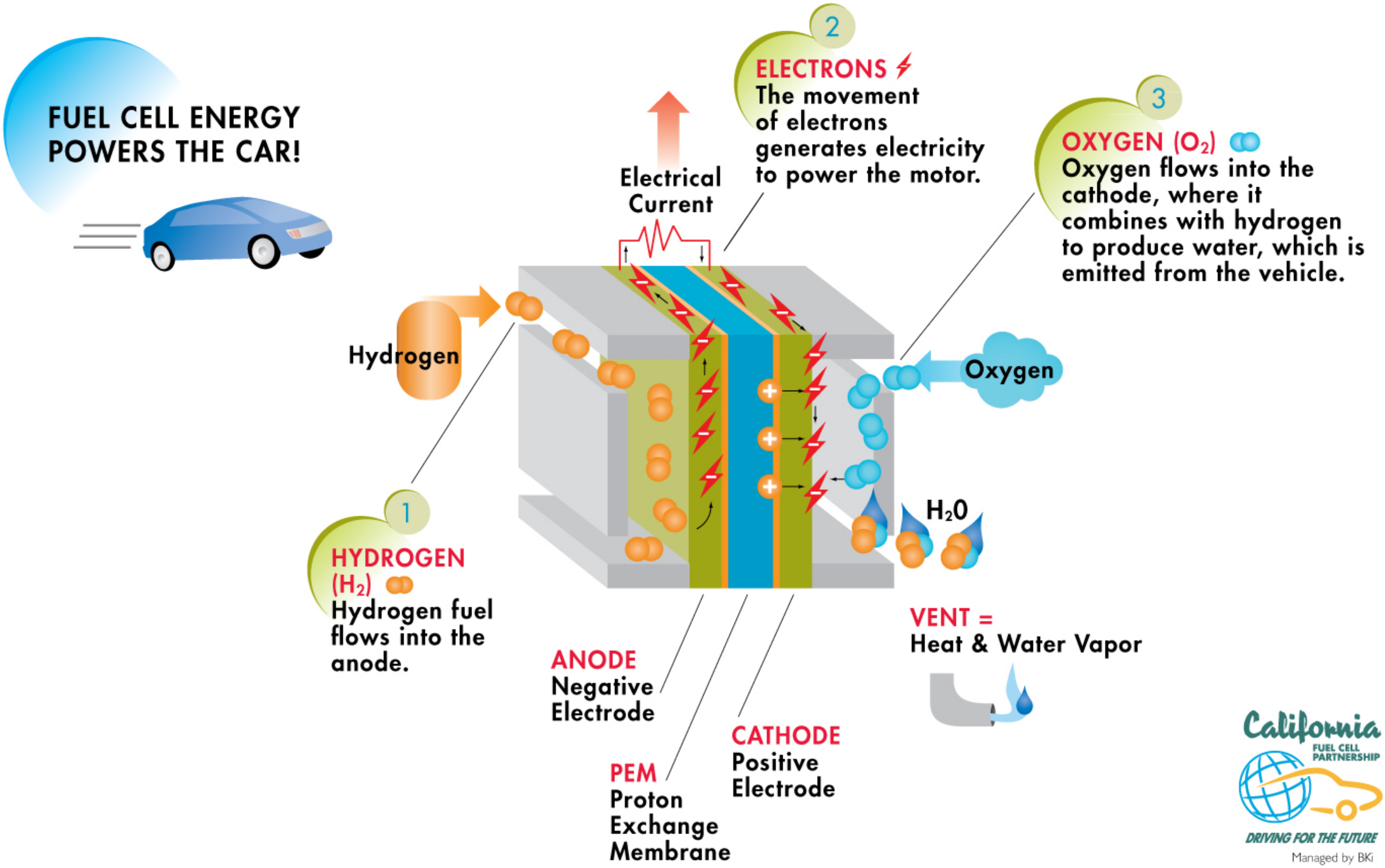
The use of hydrogen is not new; private industry has used it safely for many decades. Nine million tons of hydrogen are safely produced and used in the United States every year. 56 billion kg/yr are produced globally. For example, H_2 is used for:

- 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

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

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 forklifts

More than 35,000 fuel cells shipped in 2013
(~a consistent 30% annual growth since 2010)

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

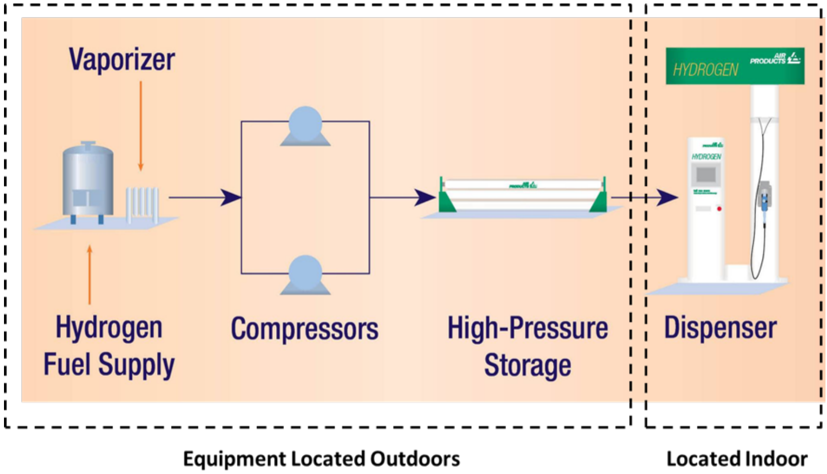
24 x 7 Reliable Large Industrial-scale Fuel Cell Power

- 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

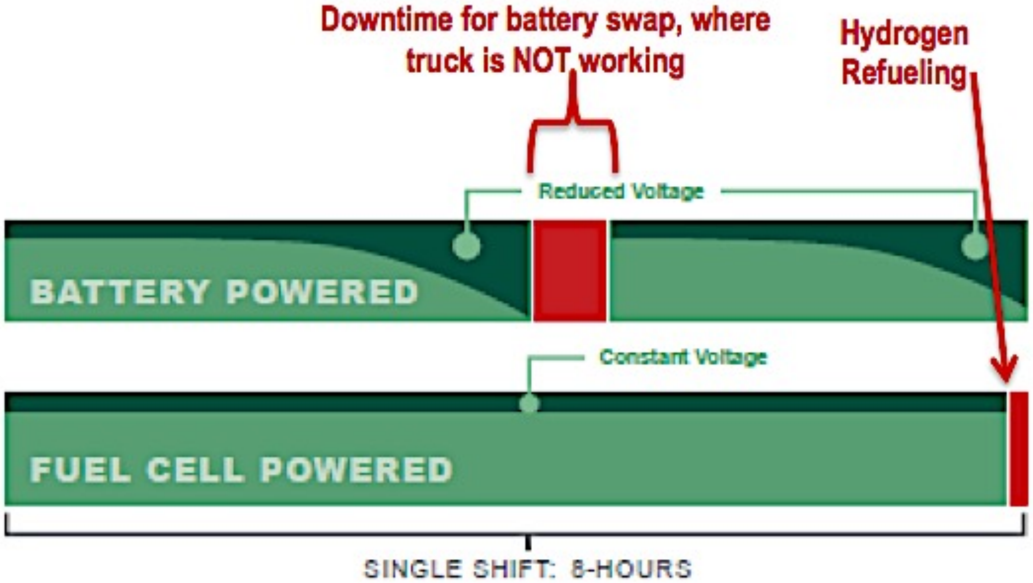
Photo: FuelCell Energy

Industrial Trucks

Forklift Equipped with Fuel Cells



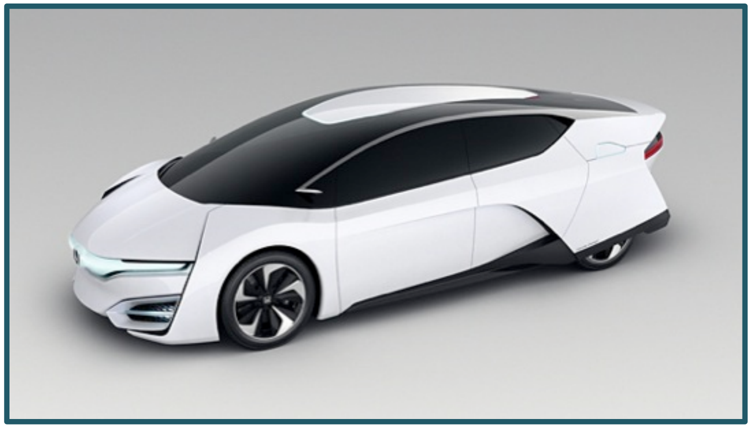
Typical Hydrogen Fueling Infrastructure (Courtesy of Air Products and Chemicals, Inc.)



- 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.

Fuel Cell Cars are Here!

FCEVs on display at North American auto shows.

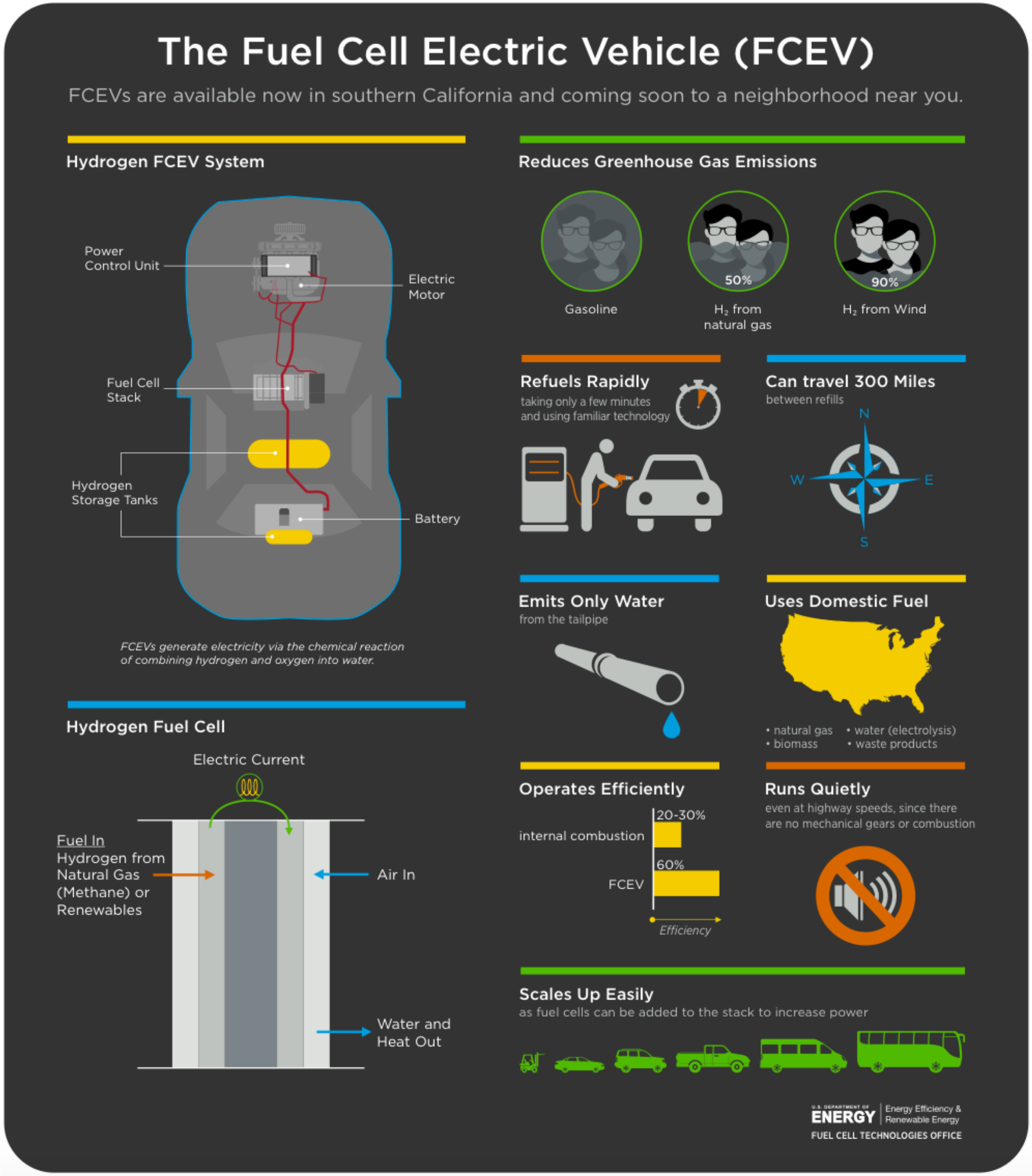


Honda Fuel Cell Electric Vehicle

Toyota Mirai Fuel Cell Electric Vehicle

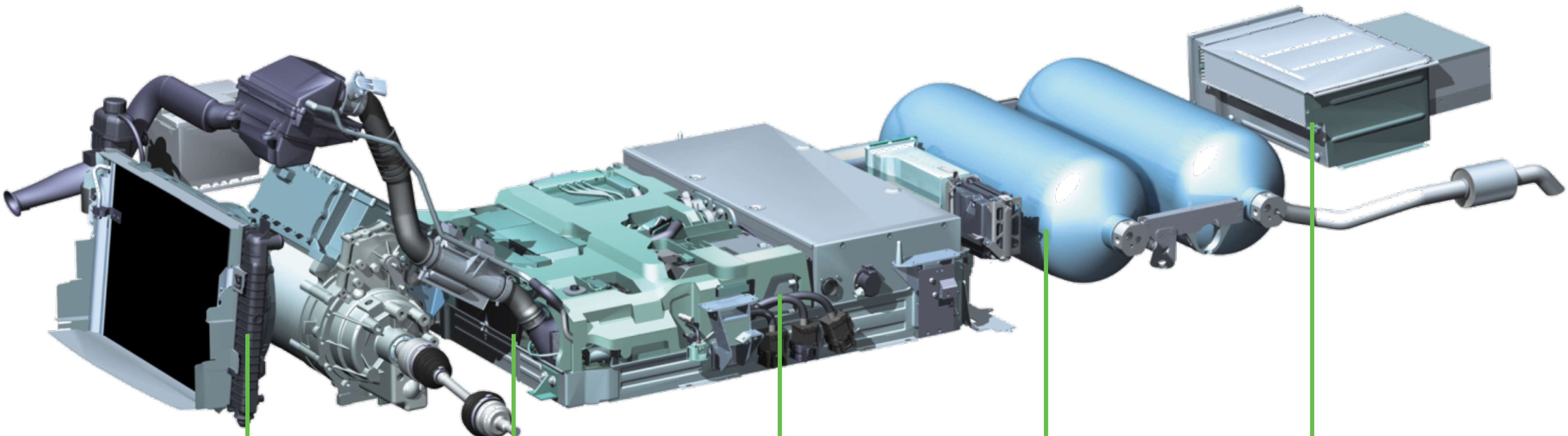
Hyundai's first mass-produced Tucson Fuel Cell SUVs arrived in Southern California May 20, 2014

Lease includes **free H_2 and maintenance**.



The Fuel Cell Electric Vehicle (FCEV)
FCEVs are available now in southern California and coming soon to a neighborhood near you.
Hydrogen FCEV System
Power Control Unit
Electric Motor
Fuel Cell Stack
Hydrogen Storage Tanks
Battery
FCEVs generate electricity via the chemical reaction of combining hydrogen and oxygen into water.
Hydrogen Fuel Cell
Electric Current
Fuel In
Hydrogen from Natural Gas (Methane) or Renewables
Air In
Water and Heat Out
Reduces Greenhouse Gas Emissions
Gasoline
50%
H_2 from natural gas
90%
H_2 from Wind
Refuels Rapidly
taking only a few minutes and using familiar technology
Can travel 300 Miles
between refills
N
W
E
S
Emits Only Water
from the tailpipe
Uses Domestic Fuel
• natural gas
• biomass
• water (electrolysis)
• waste products
Operates Efficiently
internal combustion
20-30%
FCEV
60%
Efficiency
Runs Quietly
even at highway speeds, since there are no mechanical gears or combustion
Scales Up Easily
as fuel cells can be added to the stack to increase power
U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
FUEL CELL TECHNOLOGIES OFFICE

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

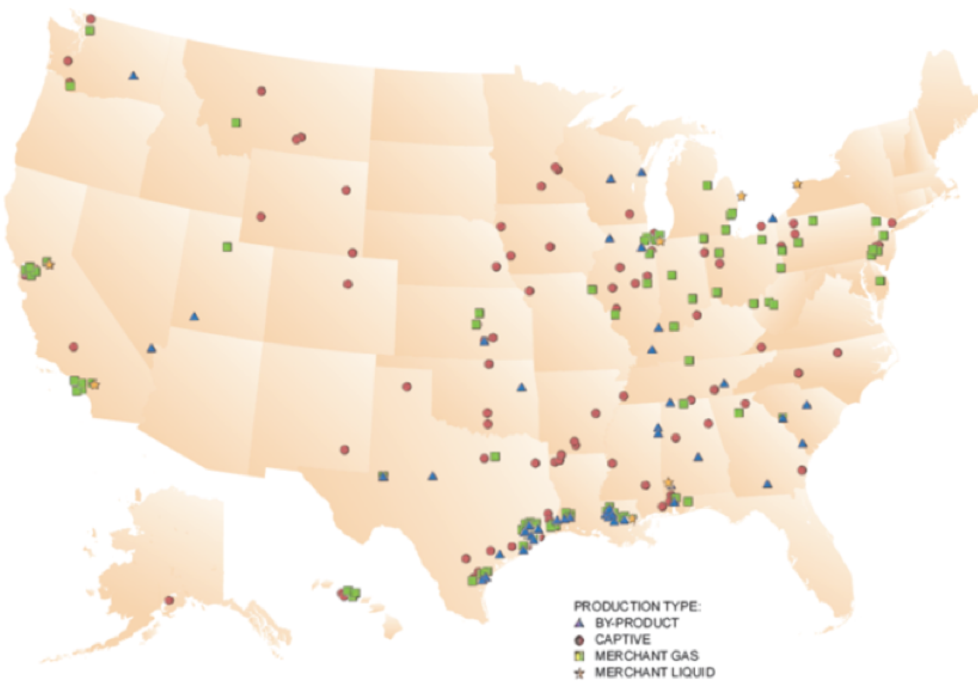
Source: California Fuel Cell Partnership

Hydrogen Fueling Stations

H_2 Infrastructure Development and Status

Nationwide

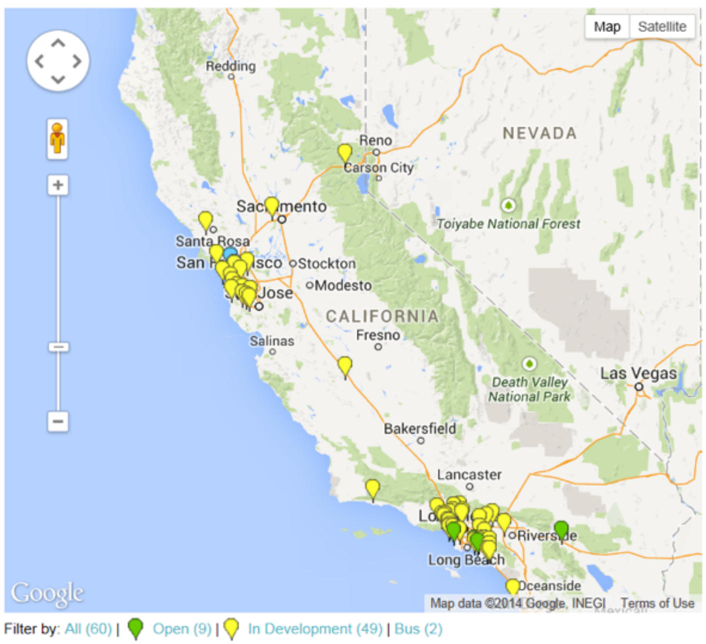
- **1500 mi.** of H_2 pipeline
- **>9M** metric tons produced per year
- **~50 stations** (~10 public)



Centralized H_2 Production Facilities (source: NREL)

States

- CA- **100 stations, ~$100M** planned through 2023
- 8 State MOU- **3.3M ZEVs** by 2025
- **Northeast states, Hawaii**



H_2 stations in CA (source: CAFCP)

NE states, California and Hawaii have H_2 infrastructure efforts underway

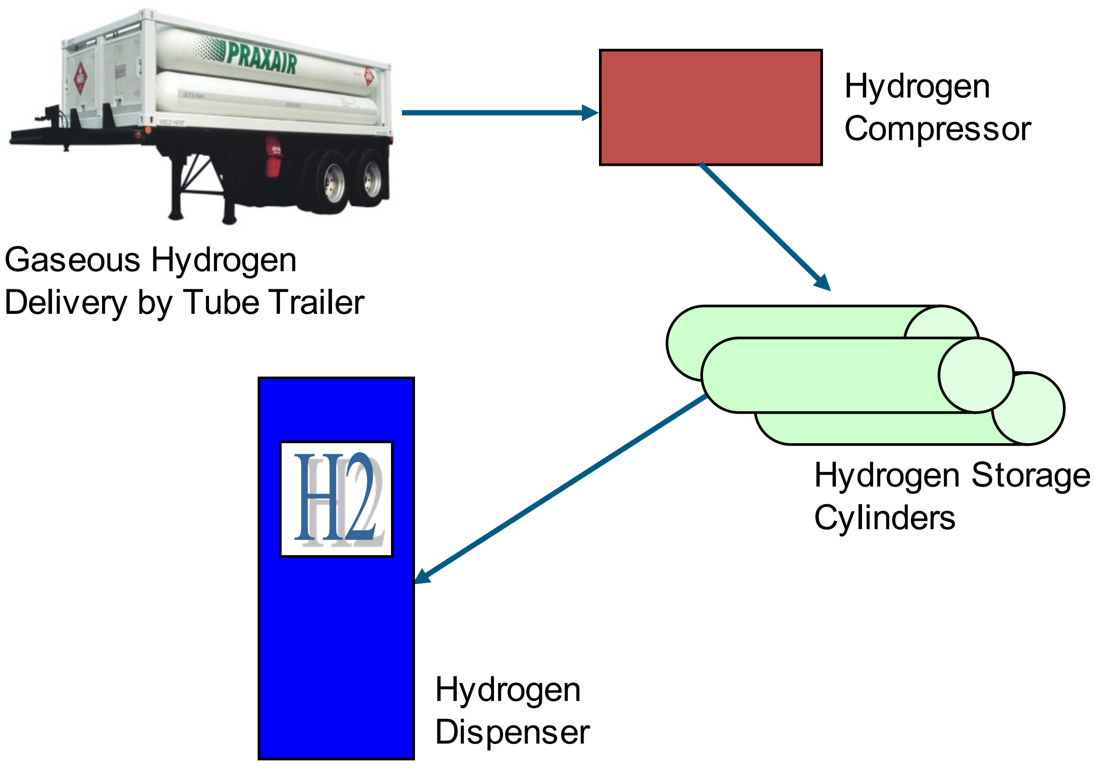
Typical Station Configurations

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

Hydrogen Fueling Stations
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

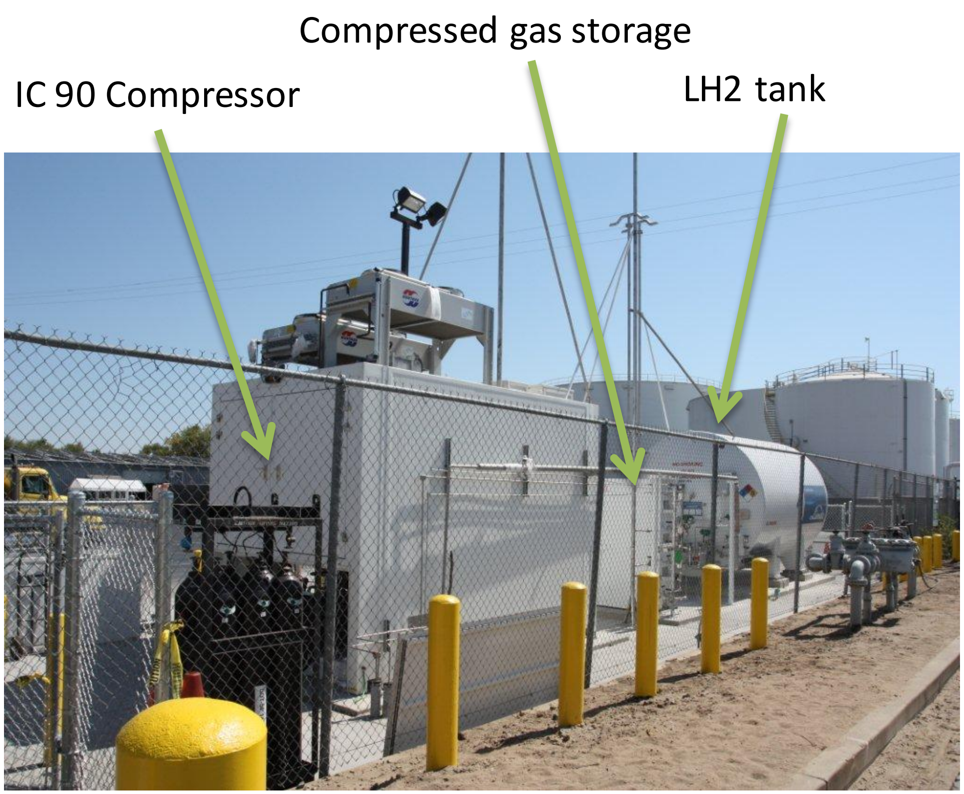


Graphic: Pacific Northwest National Laboratory

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



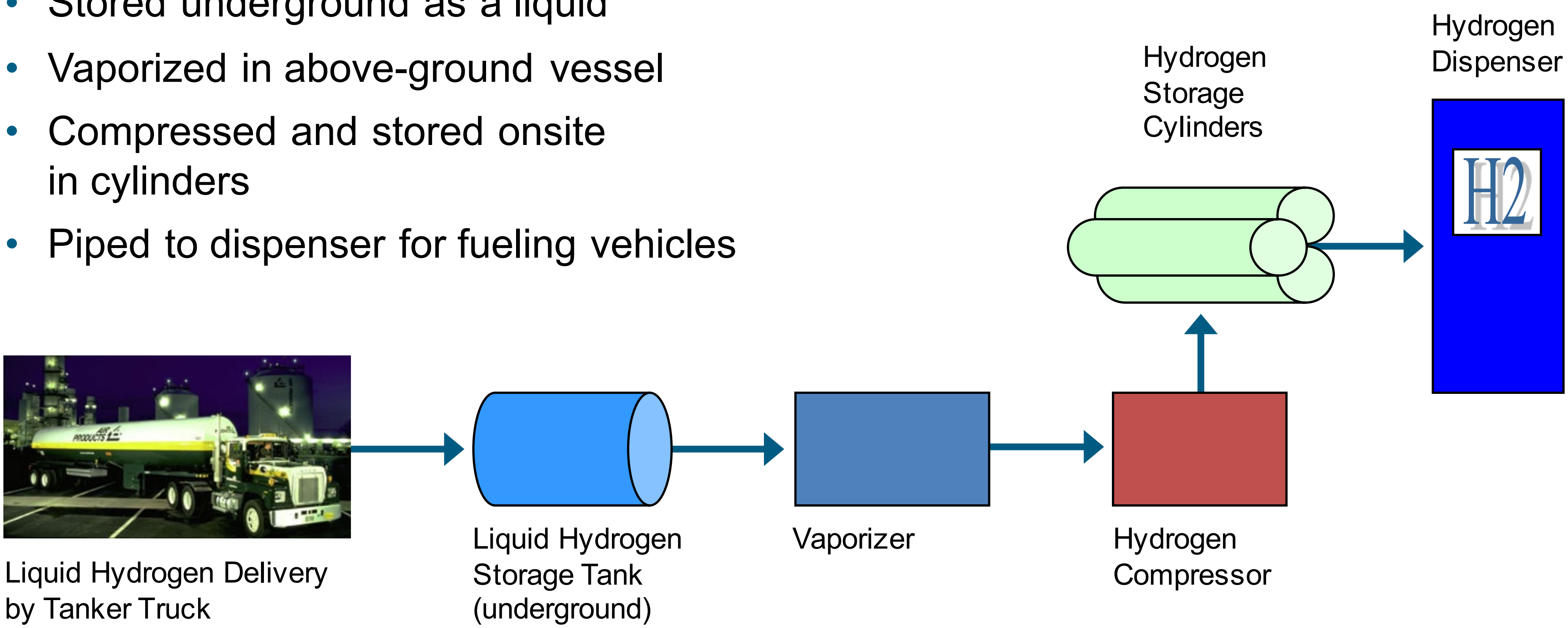
Fueling dispenser & canopy

Photos: California Fuel Cell Partnership and Linde.

Liquid Hydrogen Storage

Liquid hydrogen is:

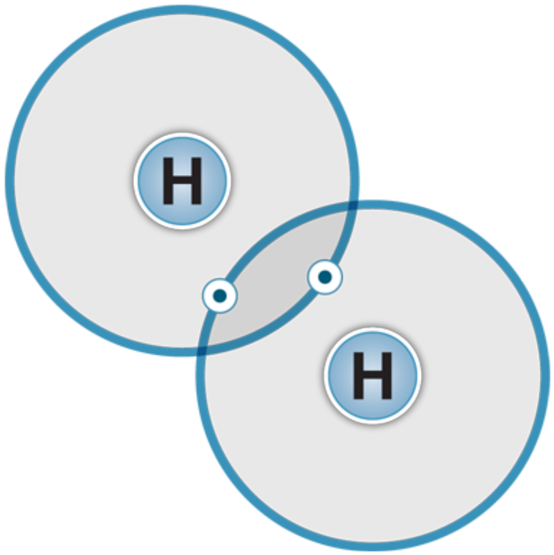
- Delivered to fueling station by tanker truck
- Stored underground as a liquid
- Vaporized in above-ground vessel
- Compressed and stored onsite in cylinders
- Piped to dispenser for fueling vehicles



Properties of 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

Codes and Standards: IFGC Chapter 7, ASME B31.12, CGA G5.5

Gaseous Hydrogen

Gaseous hydrogen:

- has a flammable range of 4-75% in air
- will typically rise and disperse rapidly (14x lighter than air)
- diffuses through materials not normally considered porous
- requires only a small amount of energy for ignition (0.02 mJ)
- burns with a pale blue, almost invisible flame
- can embrittle some metals

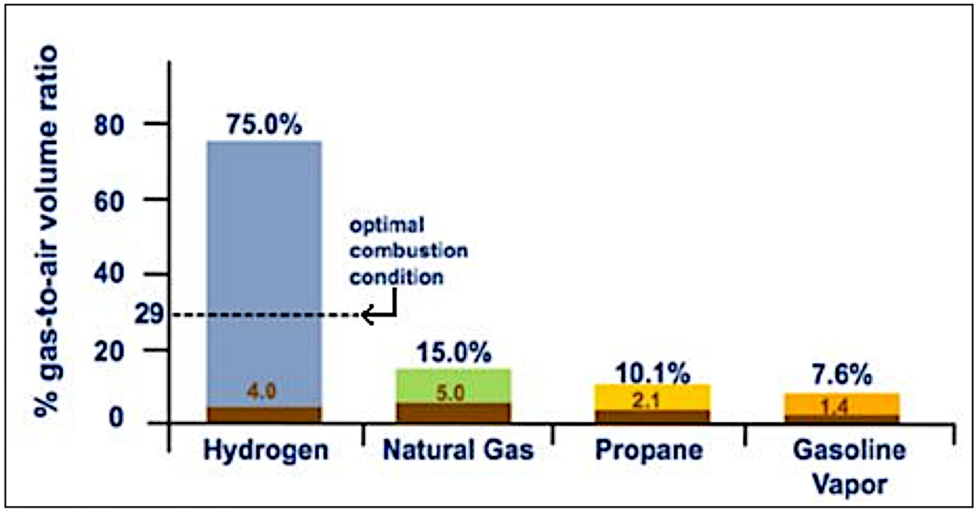


Figure 3. Flammability Range

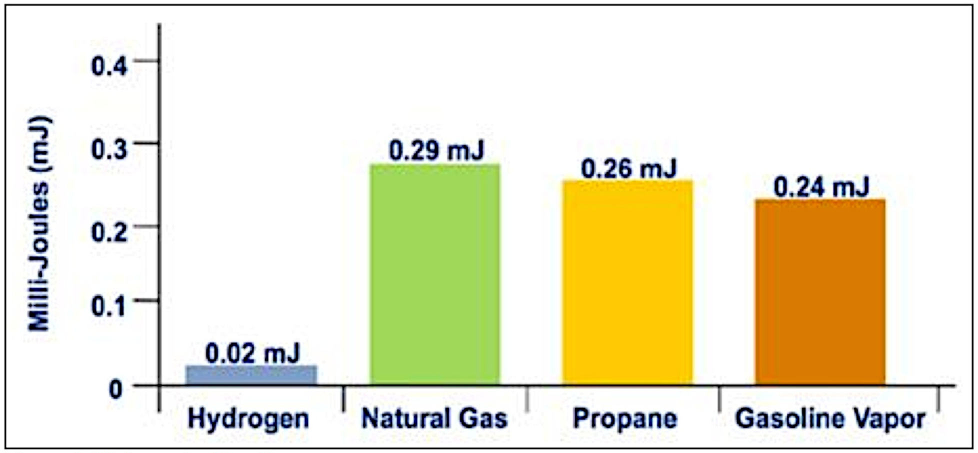


Figure 4. Minimum Ignition Energy

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

Comparing Hydrogen and Propane Flames

Primary Codes and Standards

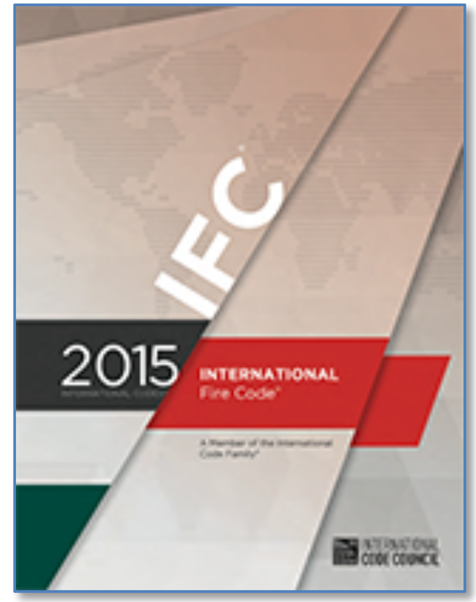
Design Consideration: Codes & Standards

There are many organizations working on codes, standards and guides. https://h2tools.org/fuelcellstandards-view is currently tracking the world-wide development of over 300 hydrogen and fuel cell standards and related documents. Let's focus on the critical infrastructure documents.

- International Fire Code (IFC) - addresses hydrogen applications
- International Building Code (IBC) - general construction requirements
- International Fuel Gas Code (IFGC)
- NFPA 2 Hydrogen Technologies Code
- NFPA 55 Compressed Gases and Cryogenic Fluids Code
- NFPA 70 National Electrical Code
- ASME B31.12 Hydrogen Pipelines and Piping Code - hydrogen piping design

Important ICC 2015 Code References

- **IFC Section 2309** – Hydrogen Motor Fuel-Dispensing and Generation Facilities
- **IFC Chapter 50** – Hazardous Materials - General Provisions
- **IFC Chapter 53** – Compressed Gases
- **IFC Chapter 58** – Flammable Gases and Flammable Cryogenic Fluids
- **International Fuel Gas Code (IFGC) Chapter 7** – Gaseous Hydrogen Systems



Significant changes in the 2015 IFC

"*Compressed hydrogen (CH2) for use as a vehicular fuel shall also comply with Chapters 23 and 58 of this code, the International Fuel Gas Code and NFPA 2.*" (IFC 5301.1)

"*Hydrogen motor fuel-dispensing stations and repair garages and their associated above-ground hydrogen storage systems shall also be designed, constructed and maintained in accordance with Chapter 23 and NFPA 2.*" (IFC 5801.1)

The Need for a National Hydrogen Code

With the increased interest in hydrogen being used as a fuel source, the National Fire Protection Association was petitioned to develop an all-encompassing document that establishes the necessary requirements for hydrogen technologies.

- Origin and development of the NFPA 2, Hydrogen Technologies Code
  - Technical committee formed in 2006
  - Focus is to address all aspects of hydrogen storage, use, and handling
  - Draws from existing NFPA codes and standards (extracts from NFPA 52, 55 and 853) (*NFPA 52 hydrogen requirements removed and transferred to NFPA 2*)
  - Identifies and fills technical gaps for a complete functional set of requirements
  - Developed for code users and enforcers
  - Structured so that it works seamlessly with building and fire codes

In the course of this presentation, any comment as to the "meaning" of any part of any NFPA code or standard is only the opinion of the presenter and is NOT to be relied upon as either accurate or official. Only the NFPA may issue a formal interpretation of its codes and standards.

NFPA 2 Scope

The code applies to the use of gaseous and liquefied hydrogen in

- **Storage**
- **Transfer**
- **Production**
- **Use**

including stationary, portable and vehicular infrastructure applications.

Fundamental requirements are provided for

- Storage
- Piping
- Installation
- Handling
- Generation

The Code does not cover

- Onboard vehicle or mobile equipment components or systems
- Mixtures of gaseous hydrogen and other gases with a hydrogen concentration <95% by volume

Contents of NFPA 2, 2016 Edition

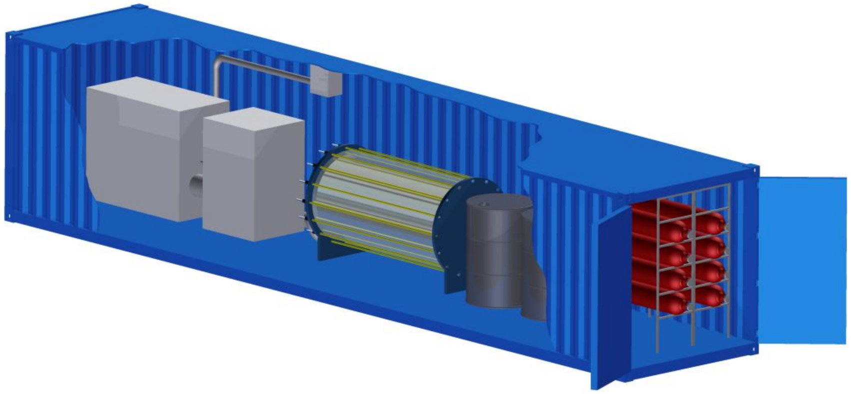
	Document Title, *Hydrogen Technologies Code*
Fundamental Chapters	**Chapter 1, *Administration***
	Chapter 2, *Referenced Publications*
	Chapter 3, *Definitions*
	Chapter 4, *General Fire Safety Requirements*
	Chapter 5, *Performance-Based Option*
	Chapter 6, *General Hydrogen Requirements*
	Chapter 7, *Gaseous Hydrogen*
	Chapter 8, *Liquefied Hydrogen*
Reserved	Chapter 9, *Explosion Protection*
Use Specific Chapters	**Chapter 10, *GH2 Vehicle Fueling Facilities***
	Chapter 11, *LH2 Fueling Facilities*
	Chapter 12, *Hydrogen Fuel Cell Power Systems*
	Chapter 13, *Hydrogen Generation Systems*
	Chapter 14, *Combustion Applications*
	Chapter 15, *Special Atmosphere Applications*
	Chapter 16, *Laboratory Operations*
	Chapter 17, *Parking Garages*
	Chapter 18, *Road Tunnels*
	Chapter 19, *Repair Garages*
	Annex A
	Annexes B-M

New Requirements for NFPA 2-2016



NFPA 2, 2016 Edition has prescriptive requirements for Hydrogen Equipment Enclosures[1], including:

- Ventilation
- Isolation (gas and fire barrier)
- Electrical requirements
- Bonding/grounding
- Explosion control
- Detection



[1] A prefabricated area confined by at least three walls and a roof, not routinely occupied or used in a laboratory, *with a total area less than 450 ft^2 designed to protect hydrogen*.

Fundamental Safety Considerations

The Basics…

Hydrogen safety, much like all flammable gas safety, relies on five key considerations:

- Recognize hazards and define mitigation measures
- Ensure system integrity
- Provide proper ventilation to prevent accumulation (manage discharges)
- Ensure that leaks are detected and isolated
- Train personnel

General Considerations

Hydrogen cylinders and storage tanks should be stored outside at a safe distance from structures, ventilation intakes, and vehicle routes. This applies even while in use. Best practices call for compressed hydrogen bottles supplying a manifold to be located outside, with welded lines to connect to indoor equipment. Safety considerations for indoor storage or use of bulk gaseous hydrogen include:

- Buildings should be constructed of noncombustible materials.
- Mechanical ventilation systems should have inlets low to the ground and exhausts at the highest point of the room in the exterior wall or roof. Consideration should be given to providing venting for both normal conditions and emergency situations.
- Hydrogen sensors should be installed at the exhaust within the enclosure.
- Automatic shutoff that activates if a leak or fire is detected in the facility that is being supplied with hydrogen.
- Ignition sources should in storage areas should be avoided.
- Classified electrical equipment should be used in close proximity to storage systems.
- Gaseous hydrogen system components should be electrically bonded and grounded.

Code and Standards: IFC, IBC, IFGC, NFPA 2, NFPA 70

Ventilation

- Proper ventilation can reduce the likelihood of a flammable mixture of hydrogen forming in an enclosure following a release or leak.
  - At a minimum, ventilation rates should be sufficient to dilute a potential hydrogen leak to 25% of the lower flammability limit (LFL) for all operations and credible accident scenarios.
- Passive ventilation features such as roof or eave vents can prevent the buildup of hydrogen in the event of a leak or discharge, but passive ventilation works best for outdoor installations.
  - In designing passive ventilation, ceiling and roof configurations should be thoroughly evaluated to ensure that a hydrogen leak will be able to dissipate safely. Inlet openings should be located at floor level in exterior walls, and outlet openings should be located at the highest point of the room in exterior walls or the roof.

Is there a problem here?

Code and Standards: IFC 2311.7.1/5808.3.1, IFGC 703.1.1, NFPA 2-6.17

Active Ventilation

- If passive ventilation is insufficient, active (mechanical, forced) ventilation can be used to prevent the accumulation of flammable mixtures.
  - ✓ Equipment used in active ventilation systems (e.g., fan motors, actuators for vents and valves) should have the applicable electrical classification and be approved for hydrogen use.
  - ✓ If active ventilation systems are relied upon to mitigate gas accumulation hazards, procedures and operational practices should ensure that the system is operational at all times when hydrogen is present or could be accidentally released.
  - ✓ Hydrogen equipment and systems should be shut down if there is an outage or loss of the ventilation system if LFL quantities of hydrogen could accumulate due to the loss of ventilation. If the hazard is substantial, an automatic shutdown feature may be appropriate.
- Ventilation (passive or active) should be at a rate not less than1 scf/min/ft^2 (0.3048 $Nm^3/min/m^2$) of floor area over the area of storage or use.

Be aware that no practical indoor ventilation features can quickly disperse hydrogen from a massive release by a pressurized vessel, pipe rupture, or blowdown.

Code and Standards: IFC 2311.7.1/5808.3.1, IFGC 703.1.2, NFPA 2-6.17

Leak Detection

Hydrogen leak detection systems may be required by the AHJ or may be installed as a means for enhancing safety of the operation. Leak detection can be achieved by:

- **Providing hydrogen (or flammable gas) detectors in a room or enclosure, or**
- **By monitoring the internal piping pressures and/or flow rates for changes that would suggest a leak is present in the system.**
- **Other methods include providing detectors in close proximity to the exterior piping or locating hydrogen piping within another pipe and monitoring the annulus for leaks**.

Regardless of the method used, leak detection systems should, at a minimum, incorporate automatic shutoff of the hydrogen source (and startup of a properly-configured active ventilation system, if present) when hydrogen is detected. For systems designed to monitor hydrogen concentrations in rooms or areas, the leak detection system should also warn personnel with visual and audible warnings when the environment is becoming unsafe. Remote notification should also be considered.

Code and Standards: IFC 5003.2.2, NFPA 2-7.1.22

Leak Detection Design and Performance

Goals for an area hydrogen leak detection system include:

- Provide for automatic shut-off and isolation of hydrogen sources
- Shut down process equipment to a safe mode
- Control active ventilation
- Activate audible and visual alarms

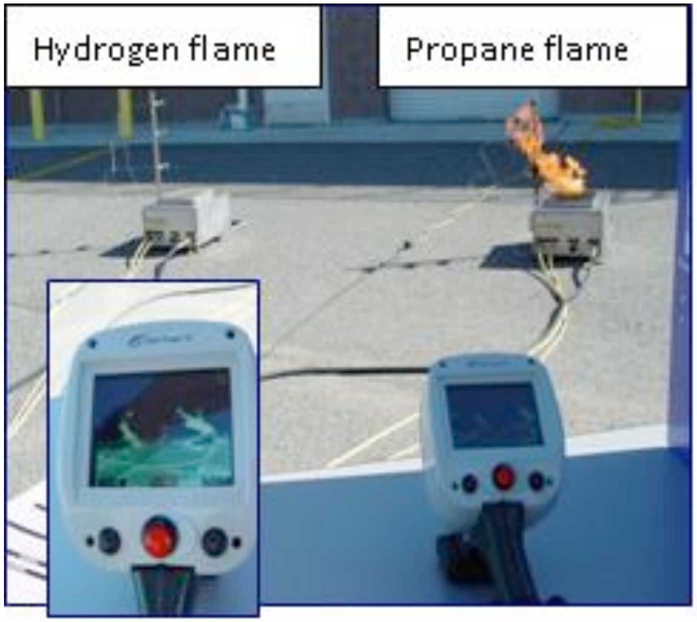
Specific performance considerations:

- Detection sensitivity of +/-0.25% by volume of hydrogen in air
- Response time of 1 second at a concentration of 1% by volume
- The design of a leak detection system must ensure that any leaking hydrogen would pass by the detector.
- The sensitivity of the detector to other gases and vapors should be considered in the selection of the detector and should be explained to personnel.
- A good practice is to set the detectors to alarm at 1% hydrogen by volume in air, which is 25% of the lower flammability limit (LFL). If automatic shutdown is incorporated into the system, manual reset should be required to restart the system.
- Portable gas detectors are valuable for local leak detection. Portable detectors should be used for entry or re-entry into rooms in which an alarm has occurred to ensure that the hydrogen has dissipated.
- Maintenance and recalibration of leak detectors should be performed every 3-6 months and recorded in facility records or manufacturer's instructions.

Checking for Leaks

Hydrogen burns with a pale blue flame that is nearly invisible in daylight. Hydrogen flames also emit low radiant heat, so a person may not feel heat until they are very close to the flame. Best practices include the following:

- A portable flame detector (e.g., thermal imaging camera) should be used if possible.
- Otherwise, listen for venting hydrogen and watch for thermal waves that signal the presence of a flame.
- Use a combustible probe (e.g., broom)
- Always allow enough time for troubleshooting/debugging a monitoring system before it's used.
- Where multiple gases are co-located, always respond in a manner to investigate/ mitigate the most hazardous gas.



Hydrogen and Propane Flames in Daylight (Photo courtesy of HAMMER)

A Lesson Learned on Hydrogen Leaks

Hydrogen Explosion and Iron Dust Flash Fires in Powdered Metals Plant

- Operators in a powdered metals production facility heard a hissing noise near one of the plant furnaces and determined that it was a gas leak in the trench below the furnaces. The trench carried hydrogen, nitrogen, and cooling water runoff pipes as well as a vent pipe for the furnaces.
- ***Maintenance personnel presumed that the leak was nonflammable nitrogen because there had recently been a nitrogen piping leak elsewhere in the plant***. Using the plant's overhead crane, they removed some of the heavy trench covers. They determined that the leak was in an area that the crane could not reach, so they brought in a forklift with a chain to remove the trench covers in that area.
- Eyewitnesses stated that as the first trench cover was wrenched from its position by the forklift, friction created sparks followed immediately by a powerful explosion. Several days after the explosion, Chemical Safety Board (CSB) investigators observed a large hole (~3x7 inches) in a corroded section of hydrogen vent piping inside the trench.
- As the hydrogen-air mixture in the partially open trench exploded, the resulting overpressure dispersed large quantities of iron dust from the rafters and other surfaces in the plant, and some of this dust subsequently ignited. Eyewitnesses reported that embers were raining down and igniting iron dust flash fires in the area. Visibility was so poor due to dust and smoke that even with a flashlight, it was impossible to see more than 3 or 4 feet. Three plant employees eventually died from burn injuries despite wearing supposedly flash-fire-resistant garments. Two others suffered smoke-inhalation injuries. Due to the extensive nature of the injuries, and the abundance of both hydrogen and combustible dust present at the time of the incident, it is difficult to specifically determine which fuel, if not both, caused the fatal injuries to the victims.

source: http://www.h2tools.org/lessons

Flame Detection

Hydrogen flames are almost invisible to humans, so thermal and optical sensors are used to detect burning hydrogen.

- To cover a large area or volume, many thermal detectors are needed and should be located at or near the site of a potential fire.
- Optical sensors for detecting hydrogen flames can operate in the ultraviolet or infrared spectral region.

Flame detectors should be installed in certain applications (e.g., NFPA 2 requires them near hydrogen dispensers in hydrogen fueling stations). Detectors should provide a rapid and reliable indication of the existence of a hydrogen flame. The system should also:

- Provide for automatic shut-off and isolation of hydrogen sources
- Shut down the system to a safe mode
- Control active ventilation
- Activate audible and visual alarms
- Control access to areas with high concentrations of hydrogen or active fires

Photo courtesy of HAMMER

Code and Standards: NFPA 2-10.3.1./11.3.3

Electrical Equipment

Specific considerations:

- Fans for active ventilation systems should be provided with a rotating element of nonferrous or spark-resistant construction.
- Equipment or devices should be designed for use in hydrogen service.
- The gaseous hydrogen system should be electrically bonded and grounded.
- Equipment not conforming to NEC requirements must be located outside the area classified as hazardous.

Electrical Equipment Requirements for Bulk Systems

Location	**Classification***	**Distance**
Area containing gaseous hydrogen storage, compression or ancillary equipment	Class 1, Division 2	Up to 15 ft from storage/equipment
Area containing liquefied hydrogen storage	Class 1, Division 2 Class 1, Division 1	Up to 25 ft from the storage equipment, excluding the piping system, downstream of the source valve Within 3 ft from points where connections are regularly made and disconnected
Interior of dispensing equipment	Class 1, Division 2	Up to the support mechanism (anchoring the dispenser) or connection to the ground level
Exterior of outdoor dispensing equipment	Class 1, Division 2	Up to 5 ft from dispenser
Exterior of indoor dispensing equipment	Class 1, Division 2	Up to 15 ft from the point of transfer from floor to ceiling
Outdoor discharge from relief vents	Class 1, Division 1 Class 1, Division 2	Up to 5 ft from the source 5-15 ft from the source
Discharge from relief vents within 15 degrees of the line of discharge	Class 1, Division 1	Within 15 ft from source

* All equipment shall be rated for Group B applications (NFPA 70-500.6).

Code and Standards: IFC 2309.2.3, NFPA 2-10.3.1.16

The Certification Challenge

The scarcity of listed hydrogen equipment places an extraordinary burden on code officials to ensure (approve) that products include the appropriate inherent or automatic safety measures.

Certification presents significant challenges.

- Few systems or equipment that are listed, labeled or certified
- Significant costs since the technology and products are still rapidly changing and each new iteration would require recertification

Development of a Certification Guide
The Hydrogen Safety Panel is developing a guide to assist code officials, designers, owners, evaluators and others with the application of requirements pertinent to the design and/or installation of hydrogen equipment as regulated by the model codes. The scope of the Guideline will be limited to those requirements where the terms *approved*, *certified*, *listed* and/or *labeled* are used.

ISO 9001:2008 CERTIFICATION
Intertek
NRTL/C

Code and Standards: IFC 2309.2.2, NFPA 2-7.1.3

Outdoor Separation Distances

- Hydrogen cylinders and storage tanks should be stored outside at a safe distance from structures, ventilation intakes, and vehicle routes.
- A ***bulk hydrogen compressed gas system*** is an assembly of equipment that consists of, but is not limited to, storage containers, pressure regulators, pressure relief devices, compressors, manifolds, and piping, with a storage capacity of more than 5,000 scf (141.6 Nm3) of compressed hydrogen gas and that terminates at the source valve.

Photo: h2tools.org

Code and Standards: NFPA 2-7.3.2.3

Outdoor Separation Distances for Bulk Hydrogen Systems

Pressure (psig) Pipe Internal Diameter (in.)	> 15 to ≤ 250 2.07	> 250 to ≤ 3000 0.75	> 3000 to ≤ 7500 0.29	> 7500 to ≤ 15000 0.28
Exposure Group 1 a) Lot lines b) Air intakes (HVAC, compressors, Other) c) Operable openings in buildings and Structures d) Ignition sources such as open flames and welding	40 ft	46 ft	29 ft	34 ft
Exposure Group 2 a) Exposed persons other than those servicing the system b) parked cars	20 ft	24 ft	13 ft	16 ft
Exposure Group 3 a) Buildings of non-combustible non-fire-rated construction b) Buildings of combustible construction c) Flammable gas storage systems above or below ground d) Hazardous materials storage systems above or below ground e) Heavy timber, coal, or other slow-burning combustible solids f) Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, or combustible waste and vegetation other than that found in maintained landscaped areas g) Unopenable openings in building and structures h) Utilities overhead including electric power, building services or hazardous materials piping systems	17 ft	19 ft	12 ft	14 ft

Source: NFPA 55, 2013 Edition

Calculations for Outdoor Bulk Hydrogen System Separation Distances

Pressure (psig)	> 15 to ≤ 250	> 250 to ≤ 3000	> 3000 to ≤ 7500	> 7500 to ≤ 15000
Exposure Group 1 a) Lot lines b) Air intakes (HVAC, compressors, Other) c) Operable openings in buildings and Structures d) Ignition sources such as open flames and welding	0.231d	0.738d	1.105d	1.448d
Exposure Group 2 a) Exposed persons other than those servicing the system b) parked cars	0.12584d –0.47126	0.43616d–0.91791	0.68311d–1.3123	0.92909d–1.6813
Exposure Group 3 a) Buildings of non-combustible non-fire-rated construction b) Buildings of combustible construction c) Flammable gas storage systems above or below ground d) Hazardous materials storage systems above or below ground e) Heavy timber, coal, or other slow-burning combustible solids f) Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, or combustible waste and vegetation other than that found in maintained landscaped areas g) Unopenable openings in building and structures h) Utilities overhead including electric power, building services or hazardous materials piping systems	0.096d	0.307d	0.459d	0.602d

(D) Distance (m)
(d) Diameter (mm)

Source: NFPA 55, 2013 Edition

Code and Standards: NFPA 55-10.3.2

Selection of Materials

- Materials of construction, including materials used in piping, valves and seals, must be carefully selected to account for their deterioration when exposed to hydrogen at the intended operating conditions.
- The mechanical properties of metals, including steels, aluminum and aluminum alloys, titanium and titanium alloys, and nickel and nickel alloys are detrimentally affected by hydrogen.
- **Exposure of metals to hydrogen can lead to embrittlement, cracking and/or significant losses in tensile strength, ductility, and fracture toughness. This can result in premature failure in load-carrying components.**
- Additionally, hydrogen diffuses through many materials, particularly nonmetals, due to its small molecular size.

Preferred

- Generally acceptable materials include austenitic stainless steels, aluminum alloys, copper, and copper alloys.

Avoid

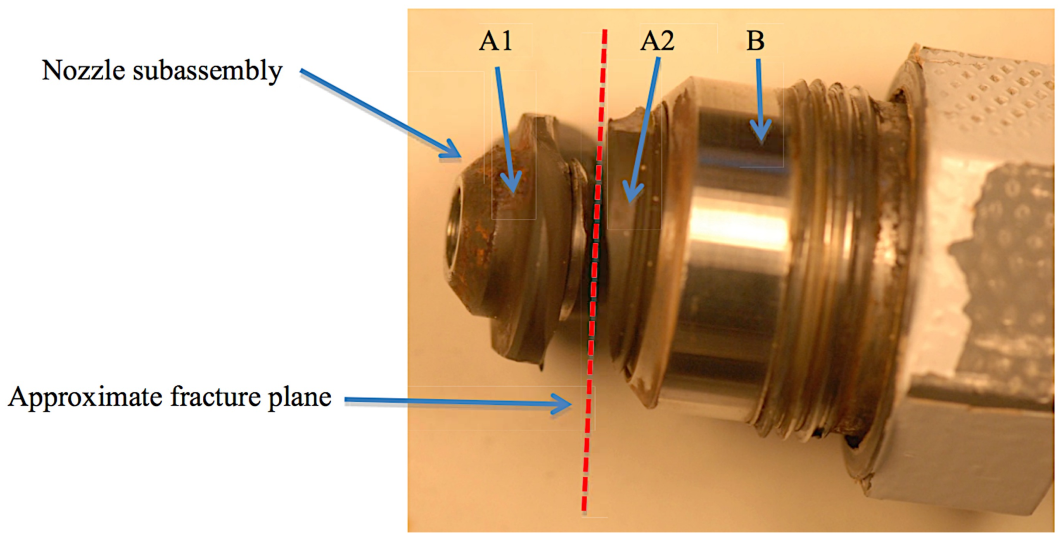
- Nickel and most nickel alloys should not be used since they are subject to severe hydrogen embrittlement.
- Gray, ductile, and malleable cast irons should generally not be used for hydrogen service.

See http://www.h2tools.org/tech-ref/technical-reference-for-hydrogen-compatibility-of-materials for additional guidance.

Codes and Standards: IFGC 5003.2.2.1, IFGC 704.1.2.3, NFPA 2-10.3.1.3

A Lesson Learned on Material Selection

A pressure relief device (PRD) valve failed on a high-pressure storage tube at a hydrogen fueling station, causing the release of approximately 300 kilograms of hydrogen gas. The gas ignited at the exit of the vent pipe and burned for 2-1/2 hours until technicians were permitted by the local fire department to enter the station and stop the flow of gas.



- The root cause of the incident was a failed pressure relief valve…
- An extensive metallurgical analysis of the failed valve concluded that **improper material selection and deviations from valve production processes led to the valve failure**.

The good news… There were no injuries and very little property damage. The corrugated roof on an adjacent canopy over a fueling dispenser was slightly singed by the escaping hydrogen flame, causing less than $300 in damage.

Source: http://www.h2tools.org/lessons

Piping Layout and Design

Hydrogen piping systems should be designed in accordance with the applicable codes and standards and to:

- Minimize leaks through the use of welded joints where possible
- Piping should not be concealed and arranged to ensure that personnel will be able to easily reach joints and fittings (to check for leaks).
- Prevent or reduce the chance of personal injury (i.e., contact with cold surfaces, head impact, tripping hazards, etc.)
- Minimize stresses (structural and thermal) in piping components and connected equipment
- Provide proper sizes and settings of pressure relief devices
- Include properly labeled shutoff valves at safe locations

Flow restrictors, such as orifice meters, in the supply line are an effective means of limiting the supply flow rate and controlling leakage rate.

Piping should be labeled to indicate content, flow direction, and design and test pressures.

Vent Lines

Vent lines for hydrogen (including pressure relief lines and boil-off from cryogenic systems) should be vented to a safe outside location. The vent should be designed to prevent moisture or ice from accumulating in the line. The vent system should:

- be leak tight
- avoid air intrusion or be designed to handle the possibility of an explosion inside the piping
- be unobstructed and protected from the weather
- safely release the unused hydrogen above the facility roof or at a remote location
- be designed to carry the excess flow of the venting gas or liquid

Codes and Standards: IFGC 704.1.2.3, ASME B31.12, CGA G5.5

Working with First Responders

Preplanning

- Facility owners and first responders should work together to perform preplanning activities. This should include a tour of the hydrogen facilities with focused attention on safety features and emergency shutoffs.

Training

- Training of emergency response personnel should be a high priority to ensure that these personnel understand how to properly respond to a hydrogen incident.
- A variety of resources are available to assist with this training (and discussed in later slides).

Equipment

- A hydrogen fire is often difficult to detect without a thermal imaging camera or flame detector. First responders have one available for their use.

Photo: Volpentest HAMMER Federal Training Center

Code and Standards: IFC 5003.9.1

Safety Considerations for Liquid Hydrogen

This presentation was primarily focused gaseous hydrogen systems and equipment. Cryogenic liquid hydrogen storage and supply systems offer additional hazards. General safety considerations for the use of cryogenic liquid are listed below.

- Due to its extremely low boiling point, liquid hydrogen can cause serious frostbite and hypothermia.
- Ice formation on vents and valves could cause them to malfunction.
- Condensed air could result in oxygen enrichment and explosive conditions near a liquid hydrogen storage system.
- Accidental air leakage into a liquid hydrogen storage vessel (e.g., from inadequate purging) will result in the introduction of moisture. The water will form ice, which may plug lines or cause instruments to malfunction.
- Continuous evaporation generates gaseous hydrogen and an increase in pressure inside a liquid hydrogen storage vessel if not properly released.

A liquid hydrogen release will look similar to this liquid nitrogen release.
(Photo courtesy of Scott Stookey)

- If a liquid hydrogen leak or spill occurs, a hydrogen cloud could flow horizontally for some distance or even downward, depending on the terrain and weather conditions.

Hydrogen Safety Resources

Overview of the Hydrogen Safety Panel (HSP)

Objectives

- Provide expertise and recommendations and assist with identifying safety-related technical data gaps, best practices and lessons learned.
- Help integrate safety planning into funded projects to ensure that all projects address and incorporate hydrogen and related safety practices.

Activities

- Review safety plans for H_2 facilities and projects
- Participate in H_2 project design reviews
- Engage project teams through onsite safety reviews
- Identify safety knowledge gaps
- Support fact-finding from incidents and events

Accomplishments

- 270 projects reviewed covering vehicle fueling stations, auxiliary power, backup power, combined heat and power, industrial truck fueling, portable power and R&D activities.
- White papers with recommendations recently include:
  - Secondary Protection for 70MPa Fueling
  - Safety of Hydrogen Systems Installed in Outdoor Enclosures
- Supported development/updating of safety knowledge tools: “h2tools/lessons/”, “h2bestpractices.org” and Hydrogen Tools, an iPhone/iPad app.
- Conducted 21 Hydrogen Safety Panel meetings since 2003. Panel meetings currently engage a broad cross-section of the hydrogen and fuel cell community.

Name	Affiliation
Nick Barilo, Manager	Pacific Northwest National Laboratory
Richard Kallman, Chair	City of Santa Fe Springs, CA
David Farese	Air Products and Chemicals
Larry Fluer	Fluer, Inc.
Bill Fort	Consultant
Donald Frikken	Becht Engineering
Aaron Harris	Air Liquide
Chris LaFleur	Sandia National Laboratories
Miguel Maes	NASA-JSC White Sands Test Facility
Steve Mathison	Honda Motor Company
Larry Moulthrop	Proton OnSite
Glenn Scheffler	GWS Solutions of Tolland
Steven Weiner	Excelsior Design, Inc.
Robert Zalosh	Firexplo

HSP Facts

- Formed in 2003 to support U.S. DOE Hydrogen and Fuel Cells Program
- 400+ years of experience, representing many hydrogen sectors and technical areas of expertise
- Includes committee members from NFPA 2 and 55, and technical committees of ASME, SAE and ISO
- Contributes to peer-reviewed literature on hydrogen safety
- Presents at national and international forums

Supporting State Efforts

The Panel is a unique resource and can be a valuable asset for supporting the safe commercial rollout of fuel cell vehicles, stationary applications and the supporting infrastructure.

Can provide support to:

- Other federal agencies
- State agencies, code officials and permitting authorities
- Private industry and commercial installers

Types of Activities:

- Design and document reviews
- Participation in or review of risk assessments
- Site reviews

Safety is paramount - its the first question we get asked in California when we go into local communities. If anything, we need to figure out how to expand the Safety Panel's reach. The reviews from the Panel have already shown benefit to the state - its a crucial, trusted 3rd party resource. – 2015 DOE AMR Reviewer Comment

Hydrogen Tools

A Transformative Step Towards Hydrogen Adoption

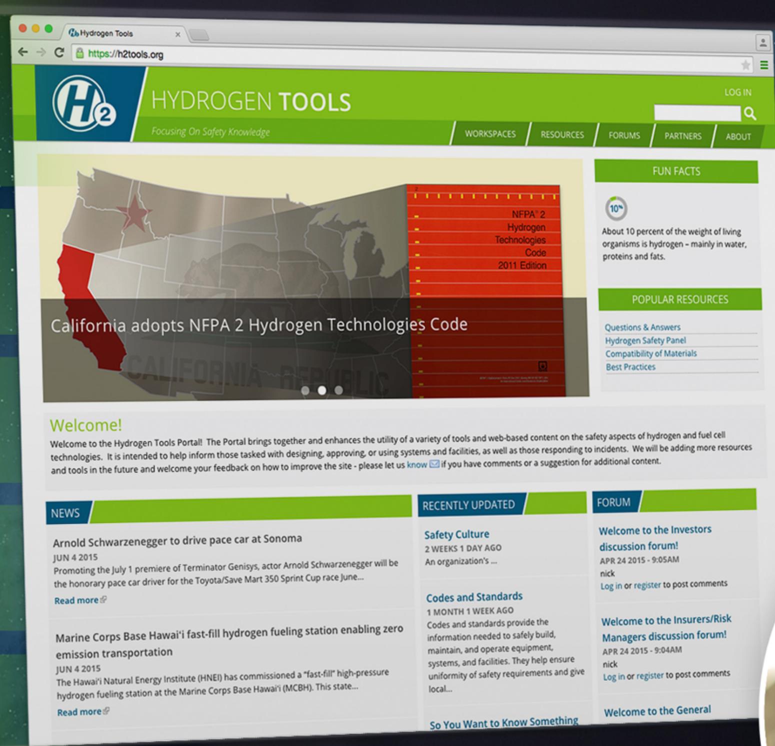
CENTRALIZED LOCATION organizes current H_2 resources in one robust location—including many proven tools, with plans for adding future content

FOCUSED CONTENT tailored to the specialized needs of H_2 user groups

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



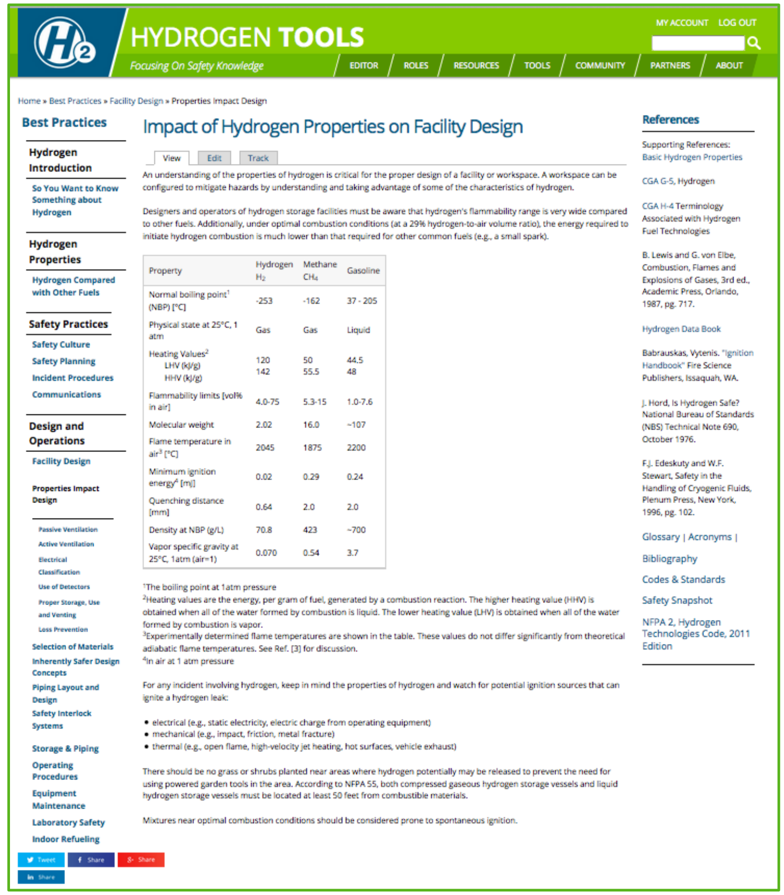
http://h2tools.org

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

H2tools.org/bestpractices
…sharing experience, applying best practices

- Introduction to Hydrogen
  - So you want to know something about hydrogen?
- Hydrogen Properties
  - Hydrogen compared with other fuels
- Safety Practices
  - Safety culture
  - Safety planning
  - Incident procedures
  - Communications
- Design and Operations
  - Facility design considerations
  - Storage and piping
  - Operating procedures
  - Equipment maintenance
  - Laboratory safety
  - Indoor refueling of forklifts

http://h2tools.org/bestpractices



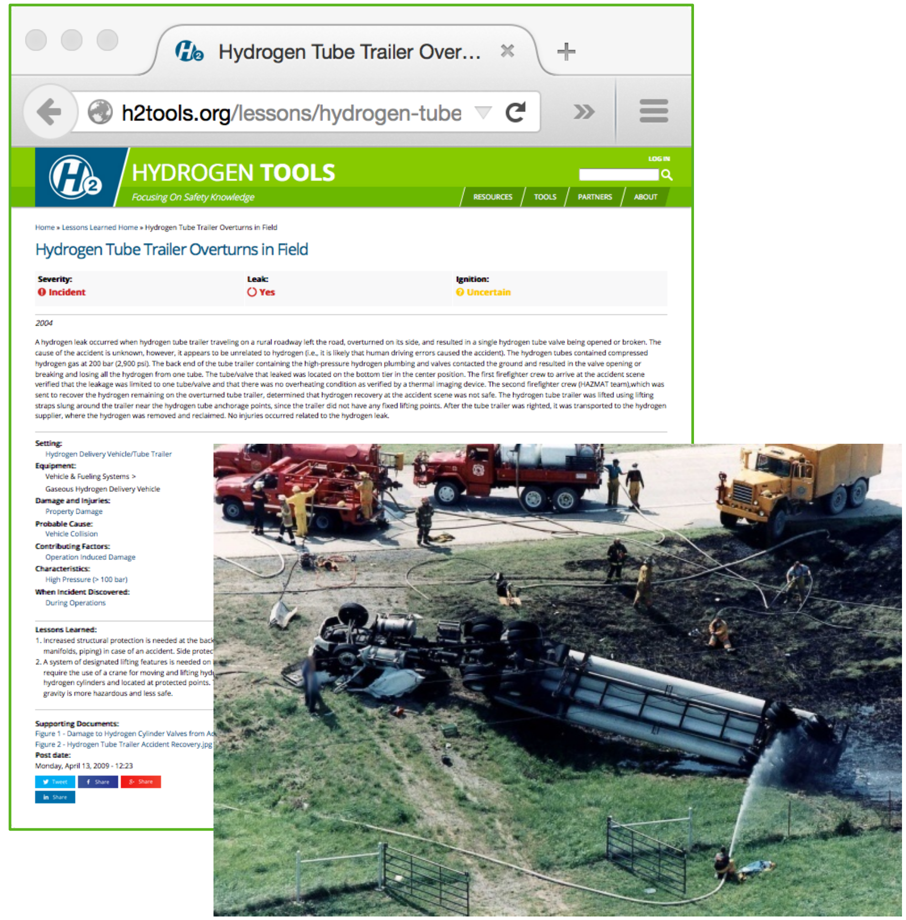
Safety events from “H2incidents.org” illustrate what can go wrong if best practices are not followed.

H2tools.org/lessons
…capturing the event, focusing on lessons learned

Each safety event record contains

- Description
- Severity (Was hydrogen released? Was there ignition?)
- Setting
- Equipment
- Characteristics (High pressure? Low temperature?)
- Damage and Injuries
- Probable Cause(s)
- Contributing Factors
- Lessons Learned/Suggestions for Avoidance/Mitigation Steps Taken

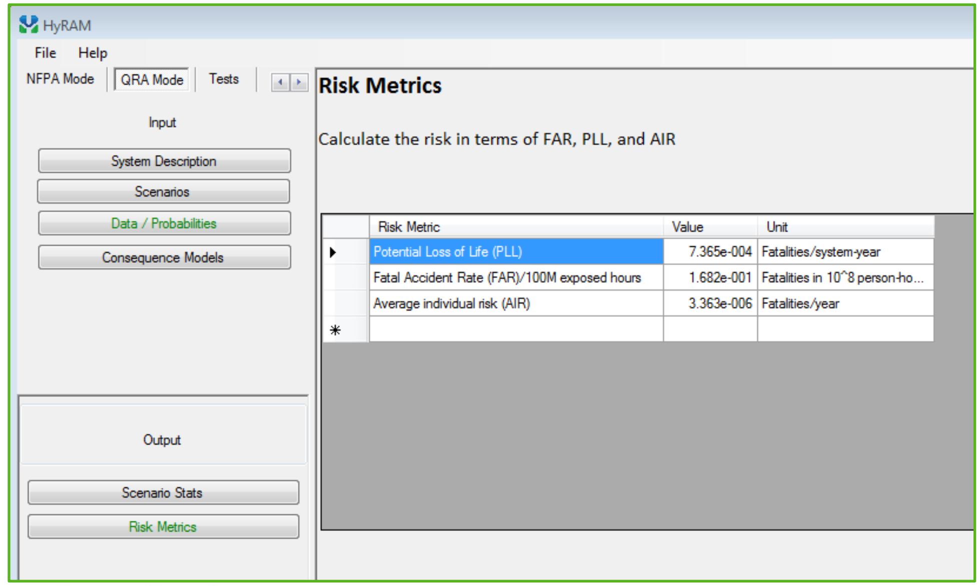
http://h2tools.org/lessons



Tube Trailer Rollover

Quantitative Risk Assessment

- Developed toolkit to enable integrated probabilistic and deterministic modeling
  - Relevant H2 hazards (thermal, mechanical)
  - Probabilistic models (traditional QRA models) & H2-specific component data
  - H_2 phenomena (gas release, heat flux, overpressure)
- Variable Users
  - High level, generic insights (e.g., for C&S developers, regulators)
  - Detailed, site-specific insights (e.g., for AHJs, station designers)
- Currently, two interfaces (views):
  - **“QRA mode”** and **“Physics mode”**
  - Planned “performance-based design” mode for targeted analyses



HyRAM
HYDROGEN RISK ASSESSMENT MODELS

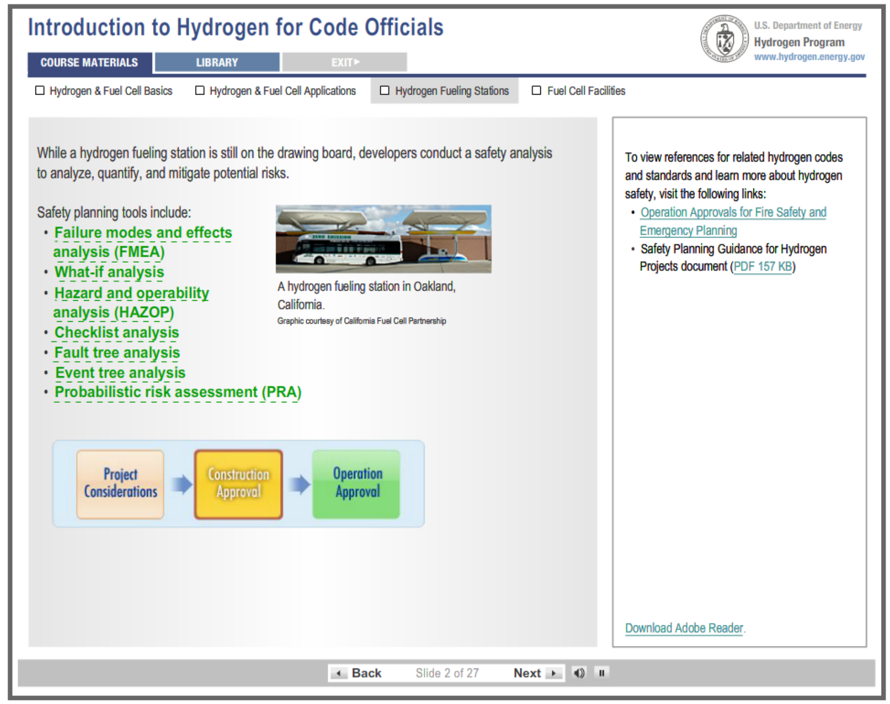
First-of-its-kind software tool for integrating H2 consequence models w/ QRA models
Includes behavior models & data developed through FY12

Introduction to Hydrogen for Code Officials

Provides an overview of hydrogen and fuel cell technologies, discusses how these technologies are used in real-world applications and discusses the codes and standards required for permitting them.

- Hydrogen and fuel cell basics
- Hydrogen and fuel cell applications
- Hydrogen fueling stations
- Fuel cell facilities

Developed by the National Renewable Energy Laboratory

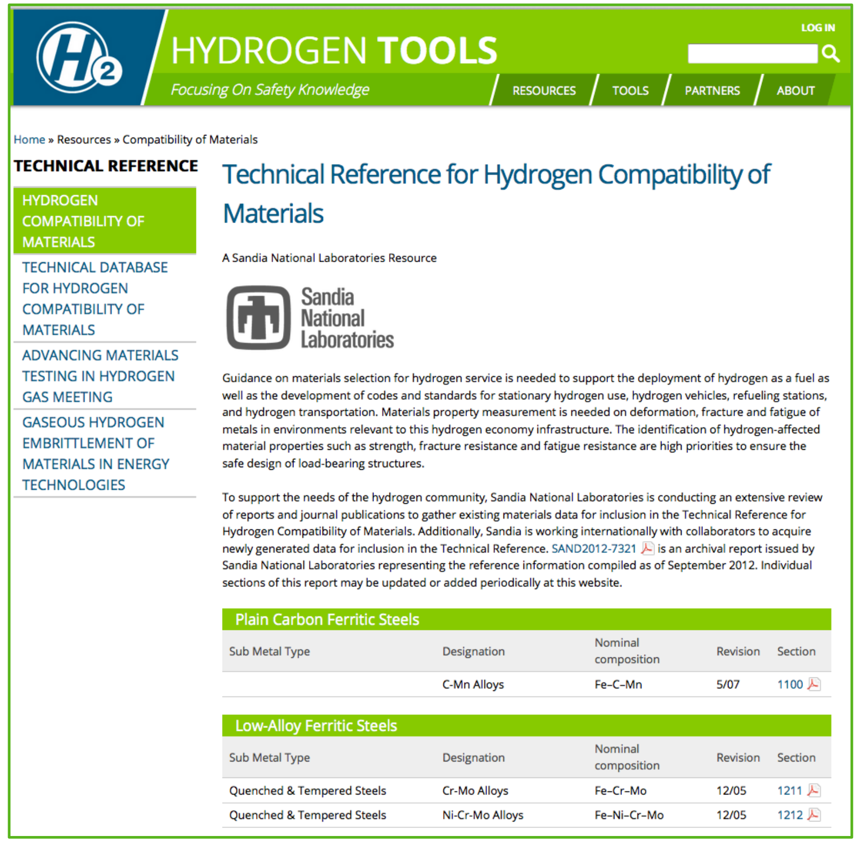


http://h2tools.org/content/training-materials

Technical Reference for Hydrogen Compatibility of Materials

Consists of material specific chapters (as individual PDF files) summarizing mechanical-property data from journal publications and technical reports

- Plain Carbon Ferritic Steels
- Low-Alloy Ferritic Steels
- High-Alloy Ferritic Steels
- Austenitic Steels
- Aluminum Alloys
- Copper Alloys
- Nickel Alloys
- Nonmetals



http://h2tools.org/tech-ref/technical-reference-for-hydrogen-compatibility-of-materials

H2USA Public-Private Partnership to address H2 Infrastructure Challenges

H2USA

http://h2usa.org

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.

*Representative sample of member logos

First Responder Hydrogen 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 (http://hydrogen.pnl.gov/FirstResponders/)
  - Classroom and hands-on operations-level training
  - National training resource (enabling trainers) (http://h2tools.org/fr/nt)

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.

Concluding thoughts

- Safe practices in the production, storage, distribution and use of hydrogen are essential for deployment of hydrogen and fuel cell technologies. ***A significant incident involving a hydrogen project could negatively impact the public's perception of hydrogen systems as viable, safe, and clean alternatives to conventional energy systems.***
- Hydrogen CAN be used safely. However, because hydrogen's use as a fuel is still a relatively new endeavor, the proper methods of handling, storage, transport and use are often not well understood across the various communities either participating in or impacted by its demonstration and deployment. Those working with hydrogen and fuel cell technologies should utilize the online resources discussed in this presentation to become familiar with the technology.
- The IFC, IFCG and NFPA 2 provide fundamental requirements for the use of hydrogen and fuel cell technologies. Online resources are available to help code officials and project proponents better understand and apply the necessary safe practices for the successful deployment of this technology.

Thank You for Your Attention!

The author wishes to thank the U.S. Department of Energy's Fuel Cell Technologies Office (Sunita Satyapal, Director and Charles James, Safety, Codes and Standards Lead), Dave Conover from the Pacific Northwest National Laboratory and the California Fuel Cell Partnership for their support of this work.

My Contact Information:

Nick Barilo, P.E.
Hydrogen Safety Program Manager
Pacific Northwest National Laboratory
P.O. Box 999, MSIN K7-76
Richland, WA 99352 USA
Tel: 509-371-7894
nick.barilo@pnnl.gov

Time for Our Tour!

We'll now take a bus to Torrance, CA to see stationary fuel cell application and a hydrogen vehicle fuel station.