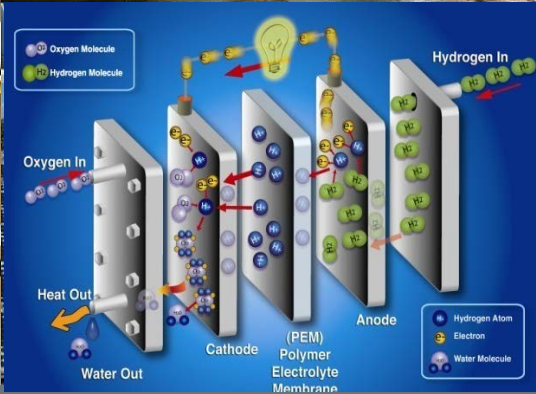
# Fuel Cell Technologies Office: Safety, Codes and Standards Overview and Status

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






**Hydrogen Technical Advisory Committee Meeting**

Holiday Inn Capitol
Washington, DC

October 27, 2015

**Will James**
Project Manager
Safety, Codes and Standards Program
Fuel Cell Technologies Office
U.S. Department of Energy

# Outline



- Safety, Codes and Standards: Will James
  - Safety, Codes and Standards Program Overview
  - History of Hydrogen Codes and Standards
  - Current Gaps and Challenges in Codes and Standards
- Status of the Hydrogen Safety Program: Nick Barilo (PNNL)
  - Hydrogen Safety Panel
  - Sharing Safety Knowledge
  - First Responder Training Resources

# SCS Program Goal and Objectives



## Codes & Standards Objectives:

- Conduct R&D to provide critical data and information needed to define requirements in developing codes and standards.
- Support and facilitate development and promulgation of essential codes and standards to enable widespread deployment of hydrogen and fuel cell technologies

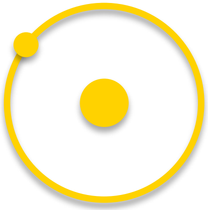
## Hydrogen Safety Objectives:

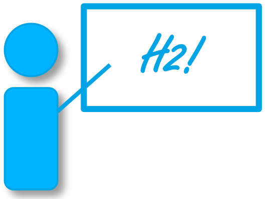
- Ensure that best safety practices underlie R&D and market deployment activities supported through DOE-funded projects.
- Develop and enable widespread sharing of safety-related information resources and lessons learned with first responders, authorities having jurisdiction (AHJs), and other key stakeholders.


***Enable the widespread commercialization of hydrogen and fuel cell technologies through the timely development of codes and standards and dissemination of safety information***

# Safety, Codes & Standards Program Strategy








## Research & Development

- Hydrogen Behavior
- Hydrogen Risk Assessment
- Materials Compatibility
- Fuel Quality
- Component Testing
- Sensors (both Safety and Contaminant Detection)

## Codes & Standards Support and Implementation

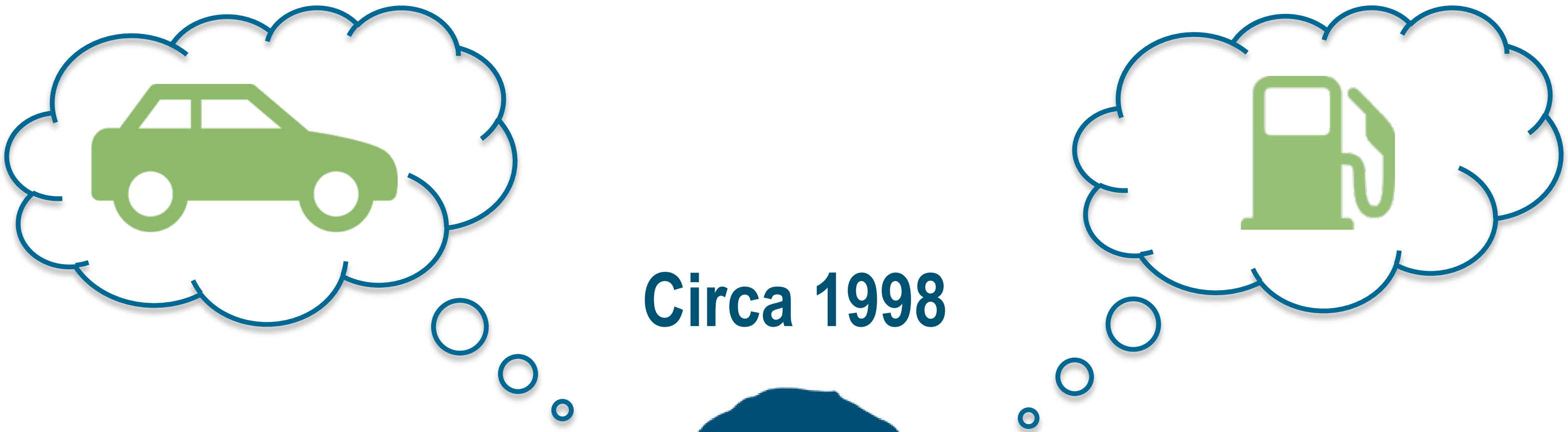
- Domestic and International CDO and SDO participation and support
- Hydrogen Risk Assessment Models (HyRAM)
- Alternative Code Compliance Methods
- Continuous Codes and Standards Improvement
- Sensor Validation (industry engagement)

## Outreach

- Hydrogen Safety Panel
- Codes Official Training
- First Responders Training
- State Engagement and Support (e.g. – California and 8 State MOU)
- International Collaboration (e.g. – IPHE RCSWG, IA-HySAFE)
- Resource Development and Dissemination (training prop, H2Tools.org)

***An integrated approach to safety, codes and standards: research and development informs codes and standards implementation efforts, which support outreach efforts***

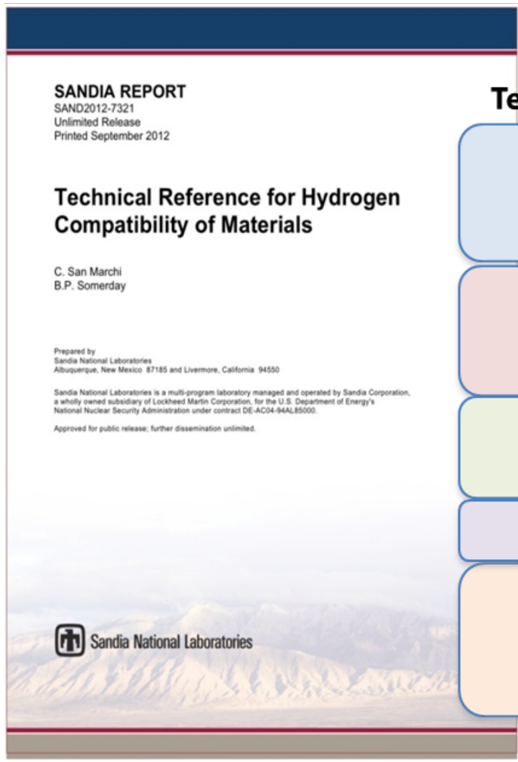
# Thinking Back……



Circa 1998

**Where are the FCEV and hydrogen infrastructure codes and standards?**

# SNL Technical Reference helps Launch SCS


SANDIA REPORT
SAND2012-7321
Unlimited Release
Printed September 2012

Technical Reference for Hydrogen Compatibility of Materials

C. San Marchi
B.P. Somerday

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Approved for public release; further dissemination unlimited.

Sandia National Laboratories

| Technical Reference | Technical Database |
|---|---|
| 1100 Carbon steels<br>└ 1100: C-Mn alloys | 1100 Carbon steels<br>├ CIA85: tension, fracture, fatigue<br>├ SAN10: fracture, fatigue<br>└ SAN11: fracture fatigue |
| 1200 Low-alloy steels<br>├ 1211: Cr-Mo alloys<br>└ 1222: Ni-Cr-Mo alloys | 1200 Low-alloy steels<br>└ NIB10: fracture, fatigue |
| 1400-1800 High-alloy steels<br>└ 1401: 9Ni-4Co | 1400-1800 High-alloy steels |
| 2000 Austenitic steels | 2000 Austenitic steels |
| 3000 Aluminum alloys<br>├ 3101: Pure aluminum<br>├ 3210: 2xxx-series alloys<br>└ 3230: 7xxx-series alloys | 3000 Aluminum alloys<br>└ SAN11: fracture, fatigue |

**These information resources now available on OpenEI website (http://en.openei.org/wiki/Gateway:Hydrogen):**

1. **Updated full public report: Technical Reference for Hydrogen Compatibility of Materials *(SAND2002-7321), 292 pages***
2. **Datasets for fatigue crack growth of materials in gaseous hydrogen**

***Established close to 1998 with the development of the Technical Reference at Sandia National Laboratories***

# R&D Support for RCS Development

**Multi-year Program Plan**
**R&D Roadmap**

### Hydrogen Behavior

*Release behavior modeling and validation*

### Test Methods, Component/System Performance

*Critical materials, components, systems validation*

### Data, Analysis, Implementation

*Resources, risk assessment and mitigation*

### RCS Development and Harmonization

*Support completion of essential codes and standards*

### Education Outreach, Training

*Hydrogen Safety Panel, training for first responders*

**Science and Technology Foundation:**

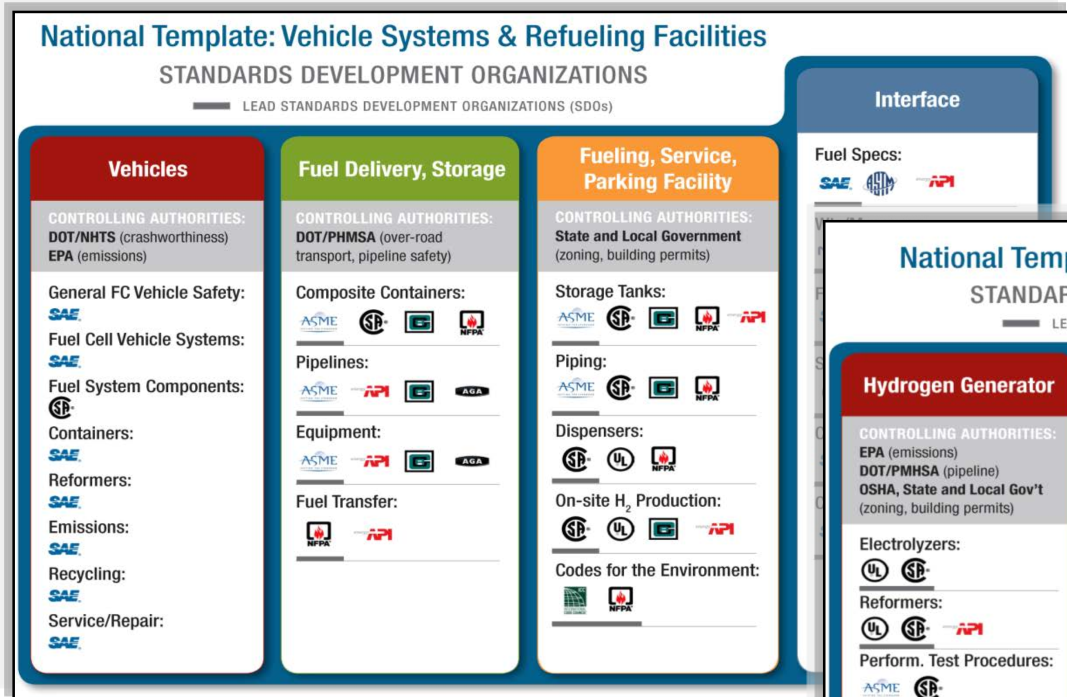
***Regulations, codes and standards (RCS) based on data and scientific understanding.***

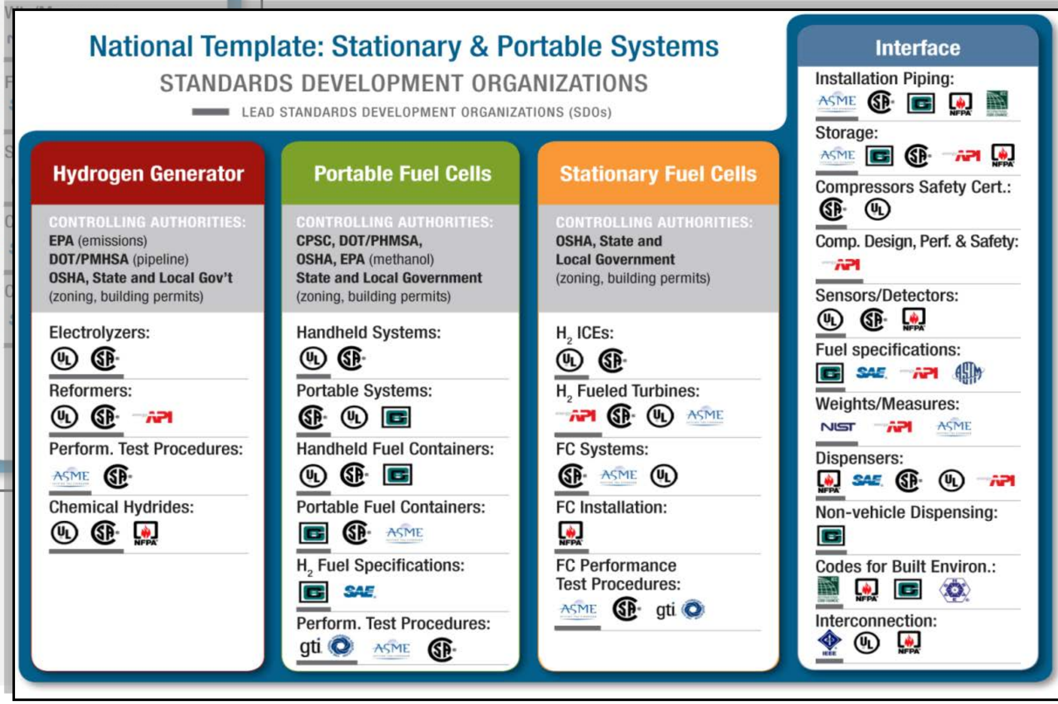
### Commercialization Decision

***Enabling early market growth by establishing essential regulations, codes and standards (RCS) validated by R&D and developed through stakeholder consensus.***

***Establish regulations, codes and standards needed to enable full market deployment of hydrogen and fuel cell technologies***

## National Codes and Standards Template




Latest version available online at:
*http://energy.gov/eere/fuelcells/downloads/national-template-hydrogen-vehicle-and-infrastructure-codes-and-standards*

***National template developed in 2002 to delineate and coordinate critical roles of standards and model code development organizations***

# Building the Hierarchy of Regulations, Codes & Standards



**Primary Building and Fire Codes**

**Hydrogen-specific codes and standards that the IBC and IFC reference such as NFPA 55 and NFPA 853**

**Component standards and design codes that are referenced in NFPA 2/55 such as:**

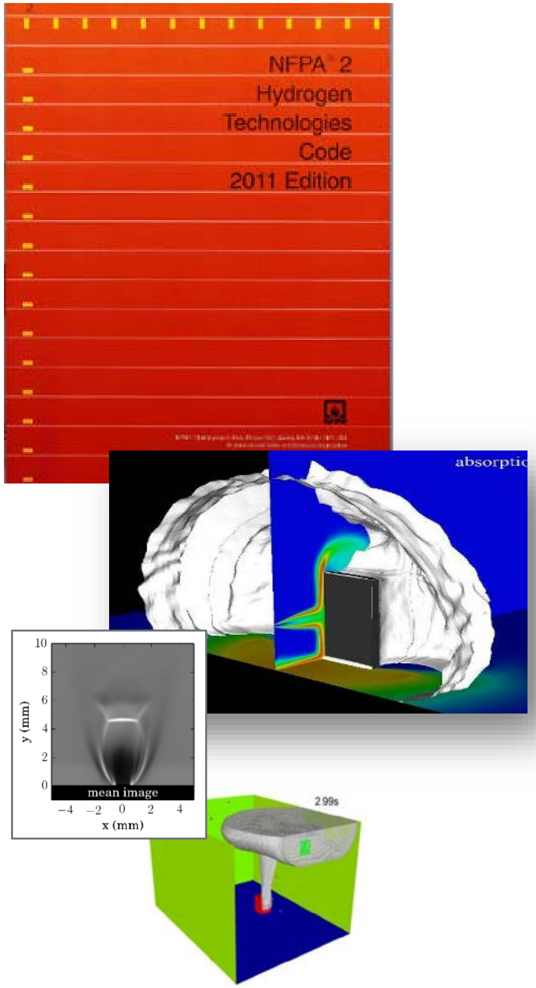
1) CSA FC1 Stationary Fuel Cell Power Systems

2) CGA P1 Safe Handling of Compressed Gases in Containers

3) ASME B31.3 and ASME BPVC

# Development of NFPA 2 Hydrogen Technologies Code






| Separation Distances | NFPA 55 (2005) | NFPA 2 (2011) |
|---|---|---|
| | *GH2 - ft (m)* | *GH2 - ft (m)* |
| Lot lines | 0 (0) | **24 (7.3)** |
| Building openings or air intakes | **50 (15)** | **24 (7.3)** |
| Ignition sources | 0 (0) | 24 (7.3) |
| Places of public assembly | **50 (15)** | nd |
| Parked cars | 15 (4.6) | 13 (4.0) |
| Public sidewalks and parked cars | 15 (4.6) | nd |
| Overhead utilities | nd | 10 (3.0) |
| Required area for separation distance based on table alone | **3780 $ft^2$ (351 $m^2$)** | **5304 $ft^2$ (493 $m^2$)** |
| Required area for sample installations* | **12480 $ft^2$ (1159 $m^2$)** | **5304 $ft^2$ (493 $m^2$)** |

*Data from report: http://energy.sandia.gov/wp-content/gallery/uploads/SAND_2014-3416-SCS-Metrics-Development_distribution.pdf
*nd = not defined*

**Applies to the production, storage, transfer, and use of hydrogen in both gaseous and liquid forms.**

***NFPA 2 Hydrogen Technologies Code was published in 2011, which utilized a science-based approach***

# Harmonization of Fuel Quality

| Table C.1: Hydrogen Fuel Quality Specification | | | | |
|---|---|---|---|---|
| Constituent | Chemical Formula | Limits [e] | Laboratory Test Methods to Consider and Under Development [f] | Minimum Analytical Detection Limit |
| Hydrogen fuel index | $H_2$ | >99.97% | | |
| Total allowable non-hydrogen, non-helium, non-particulate constituent | | 100 µmol/mol | | |
| Acceptable limit of each individual constituent | | | | |
| Water[a] | $H_20$ | 5 µmol/mol | ASTM D7653-10, ASTM D7649-10 | 0.12 µmol/mol |
| Total hydrocarbons[b] ($C_1$ basis) | | 2 µmol/mol | ASTM D7675-11 | 0.1 µmol/mol |
| Oxygen | $O_2$ | 5 µmol/mol | ASTM D7649-10 | 1 µmol/mol |
| Helium | He | 300 µmol/mol | ASTM D1945-03 | 100 µmol/mol |
| Nitrogen, Argon | $N_2$, Ar | 100 µmol/mol | ASTM D7649-10 | 5 µmol/mol |
| Carbon dioxide | $CO_2$ | 2 µmol/mol | ASTM D7649-10, ASTM D7653-10 | 0.1 µmol/mol |
| Carbon monoxide | CO | 0.2 µmol/mol | ASTM D7653-10 | 0.01 µmol/mol |
| Total sulfur[c] | | 0.004 µmol/mol | ASTM D7652-11 | 0.00002 µmol/mol |
| Formaldehyde | HCHO | 0.01 µmol/mol | ASTM D7653-10 | 0.01 µmol/mol |
| Formic acid | HCOOH | 0.2 µmol/mol | ASTM D7550-09 , ASTM D7653-10 | 0.02 µmol/mol |
| Ammonia | $NH_3$ | 0.1 µmol/mol | ASTM D7653-10 | 0.02 µmol/mol |
| Total halogenates[d] | | 0.05 µmol/mol | ASTM WK23815, WK34574 | 0.01 µmol/mol |
| Particulate Concentration | | 1 mg/kg | ASTM D7650-10, ASTM D7651-10 | 0.005 mg/kg |


- Fuel quality specification references at the nozzle (interface between vehicle and station)
- Harmonization of SAE 2719 (Sept 2011) and ISO 14687-2 (Dec 2012)
  - Committee participation included OEMs, IGCs, Oil Companies, States, FC integrators, etc.
  - Testing only occurs in the event of a dispute

***Harmonization of the Fuel Quality Specification between SAE and ISO, which was completed in Dec 2012, allows for consistency in the fuel delivered to the fuel cell.***

# Global Technical Regulation

## Objective

Develop performance-based and harmonized international regulations, codes and standards (RCS) critical to fair and open competition in worldwide markets for hydrogen and fuel cell vehicles.

## Benefits and Challenges

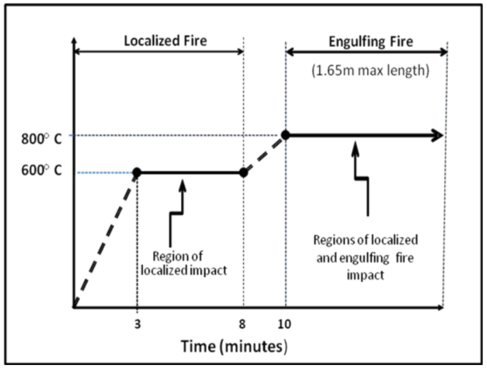
- Fair and open competition in worldwide markets for hydrogen and fuel cell vehicles.
- Ensure that U.S. (North American) interests and concerns are considered in the development of global RCS.

## Approach

- Team with the Department of Transportation.
- Consistent high-level technical representation.
- Technical proposals and scientific data from the automobile industry incorporated into GTR.

Localized Fire Test Example

Preliminary Temperature Profile




## Accomplishments

- Significant portions of SAE J2579 Technical Information Report for Fuel Systems in Fuel Cell and other Hydrogen Vehicles have been incorporated into the GTR.
- Technical experts provided extensive input to the GTR.

***Final Approval of GTR occurred in June 2013. United States is currently leveraging the GTR to inform the Federal Motor Vehicle Safety Standard (FMVSS)***

# Example: Impact of SCS R&D on Codes and Standards



| Regulation, Code or Standard | DOE Support | Status | Time Saved (resulting from DOE Support) |
|---|---|---|---|
| **Global Technical Regulation (GTR)** for fuel cell vehicles | Tank testing data; SAE standard, which provided basis for document; expert technical support from Dr. Sloane and Glenn Scheffler | Approved by UN GRSP WP 29 | **5 years** |
| **NFPA 2** Hydrogen Technologies Code and Integration into International Fire Code (IFC) | Extensive technical analysis to develop risk informed requirements for siting hydrogen storage systems; extensive logistical support including committee chair and consultant producing draft code document | Final document promulgated 2011; integrated into IFC 2013 | **3 years** |
| **SAE J2601** Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles | Performed validation testing for fueling algorithm in standard; provided logistical support for SAE Fuel Cell Technical Committee | Published 2014 | **3 years** |
| **SAE J2719** Development of a Hydrogen Quality Guideline for Fuel Cell Vehicles/ISO 14687 Hydrogen fuel – product specification – part 2: proton exchange membrane (PEM) fuel cell applications for road vehicles | Extensive test data, logistical support, and coordination of ISO/SAE standard development activities | Published 2012 | **5 years** |

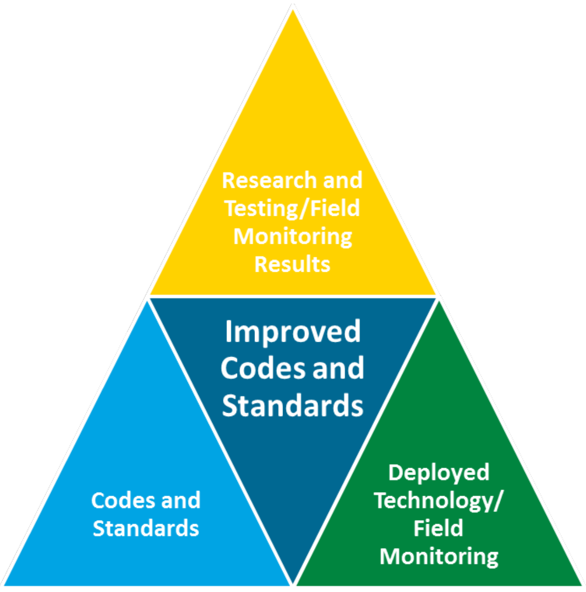
# Thinking Forward……

## What's Next for SCS?

# Continuous Codes and Standards Improvement (CCSI)



| Barrier | Action |
|---|---|
| 1. Increase HRS performance and reliability to level required for deployment | Continue testing and support RCS development by engaging with component manufacturers, system designers and CDOs/SDOs. |
| 2. Simplify RCS to the level to support deployment | Use field data through CCSI to streamline the RCS process |
| 3. Provide SCS information that is accessible and useable to the infrequent user | Provide easily accessible information that would quickly provide the necessary requirements to the user |




**Examples of Utilizing CCSI:**

- Hydrogen Code Improvement (HCI) Team (thru FCHEA Transportation Working Group)
- Joint NFPA 2/55 Task Group to address separation distances for gaseous and liquid hydrogen storage

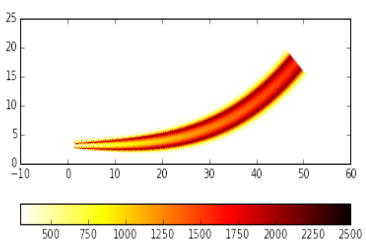
***CCSI encourages the safe and rapid growth of hydrogen fueling infrastructure***

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

# Supporting Deployment Through R&D: $H_2$ Behavior and Risk Assessment

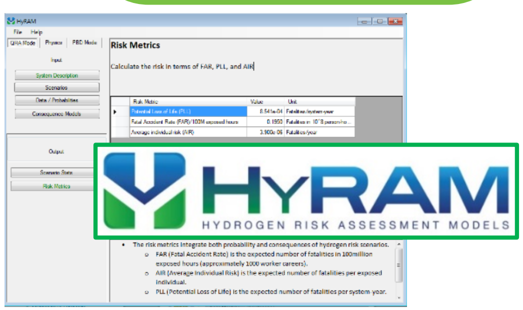
## Cold Hydrogen Release Laboratory

Validate liquid $H_2$ ($LH_2$)models enable risk assessment tools. New cryo-temperature laboratory will bring a science-based approach to LH2 at the code committees.



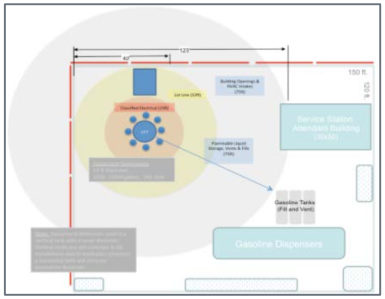

## Hydrogen Risk Assessment Models (HyRAM)

Quantitative risk assessment (QRA) utilizes engineering models to produce risk metrics which enable performance-based design.




## Alternative Compliance Methods

Performance-based design is a risk-enabled (via QRA), NFPA 2 - compliant option for station design.

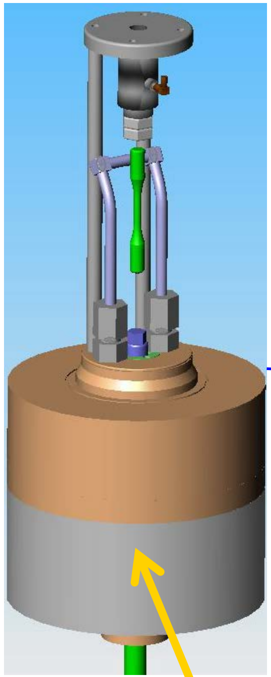


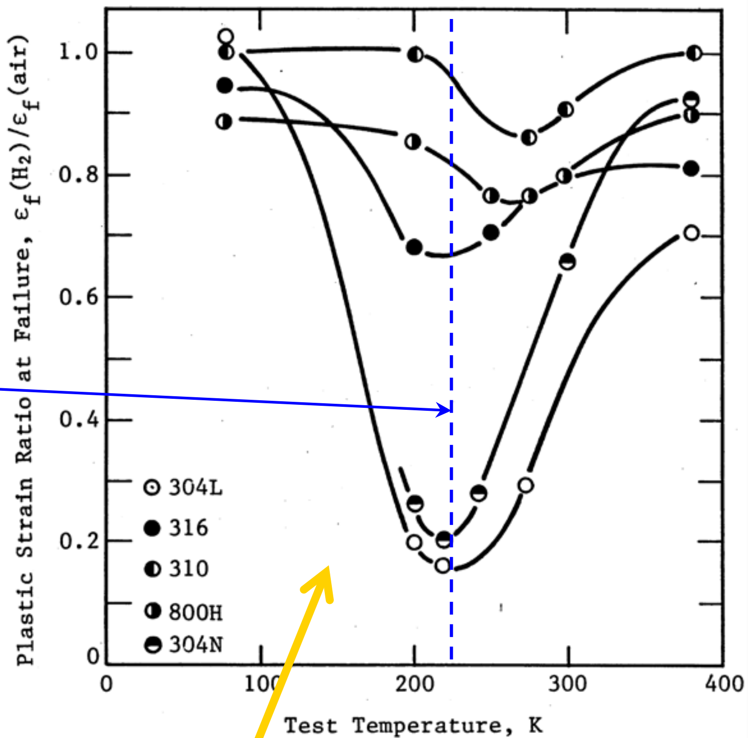

## Station Deployment

*At SNL, validation of $LH_2$ models are incorporated into QRA tools, enabling alternative compliance methods and ultimately accelerating infrastructure deployment*

# Supporting Deployment Through R&D: $H_2$ Materials

## *Low-Temperature Testing of Materials in Hydrogen Atmosphere (SNL)*






Low-temperature pressure vessel internal structure

Ductility of stainless steels in H2 gas normalized by ductility in air

## *Compatibility of Polymeric Materials used in Hydrogen Infrastructure (PNNL, SNL, ORNL)*

- **Objective:** generate a foundational understanding of the unique effects associated with the ***combination of high pressure and H2*** on the integrity of polymer materials and generate the knowledge will be used to develop ***standardized test methods*** to enable science-based selection of materials for H2 service.
  - Results will be published in existing platforms (H2Tools.org and the Technical Reference for H2 Compatibility of Materials)

***Developing a knowledge base of the behavior of materials in hydrogen to support a robust hydrogen refueling infrastructure***

# SCS International Collaboration Examples



European Union

- HyCoRa – LANL/ANL, VTT, SINTEF
- MATHRYCE – SNL, VTT, Air Liquide, JRC
- HyResponse – PNNL, ENSOSP, AREVA

Japan

- I2CNER – SNL, Kyushu University
- Materials Compatibility – SNL, AIST-Tsukuba
- FQ Test Method Development – LANL, JARI, CEA

- Active international collaborations with national and foreign labs, universities, private organizations, and energy companies
- Bilateral and multilateral efforts focus on safety training, materials compatibility for high-pressure hydrogen applications, fuel quality, and sensor testing and validation

***Leveraging international collaboration allows for the development and promulgation of essential codes and standards to enable widespread deployment***

## International Partnership for Hydrogen and Fuel Cells in the Economy

**IPHE International Safety and Reliability Data Sharing Initiative**

- IPHE initiative with two member countries currently participating (Japan and the United States).
- The purpose to gather information with a **focus on safety and incident data as well as on station maintenance and reliability.**
- The data being gathered follows an agreed-upon template based on the work currently being performed at the U.S. DOE's National Renewable Laboratory (NREL).
  - Data is collected and anonymized by NREL's National Fuel Cell Technology Evaluation Center (NFCTEC).
  - Similar, though less comprehensive databases already exist in the U.S. and other IPHE member countries.

***A multi-lateral data sharing initiative is vital to support safe, near-term deployment of this emerging technology.***

# Thank You

**Will James - Team Lead**
**202-287-6223**
**charles.james@ee.doe.gov**

**hydrogenandfuelcells.energy.gov**

# Status of the Hydrogen Safety Program

HYDROGEN
Safety Resources


Nick Barilo, PNNL Hydrogen Safety Program


DOE Hydrogen and Fuel Cell Technical Advisory Committee Meeting

Washington, DC
October 27, 2015

# Agenda

## 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

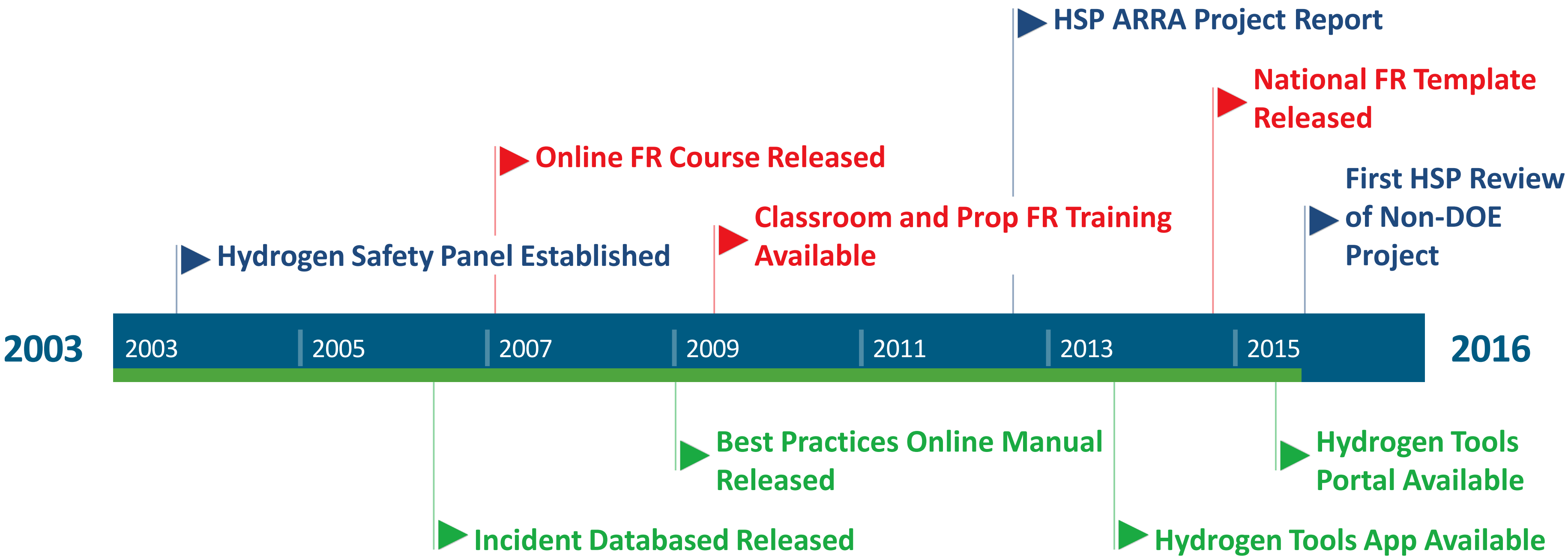
## HYDROGEN Tools

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

## HYDROGEN Emergency Response Training Resources

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

# PNNL Hydrogen Safety Program Timeline




- Hydrogen Safety Panel
- Safety Knowledge Tools
- First Responder Training

# Hydrogen Safety Panel

# Hydrogen Safety Panel Mission

*The Hydrogen Safety Panel is a team of highly experienced individuals created to address concerns about hydrogen as a safe and sustainable energy carrier.*

**Principal Objective:** Promote the safe operation, handling, and use of hydrogen and hydrogen systems across all installations and applications by:

- identifying and addressing safety-related technical data gaps
- making design, construction, and operations personnel aware of relevant issues and best practices that affect safe operation and handling of hydrogen and related systems
- convincing design, construction, and operations personnel to give sufficient priority to safety in their daily, ongoing work

# Hydrogen Safety Panel Activities

**The Hydrogen Safety Panel contributes to its objective by:**

- participating in safety reviews
- providing safety planning guidance
- reviewing project designs and safety plans
- sharing safety knowledge and best practices
- presenting and recognizing safety as a priority
- participating in incident investigations.


*Hydrogen Safety Panel members at the California Fuel Cell Partnership in West Sacramento, CA, for the 21st meeting*

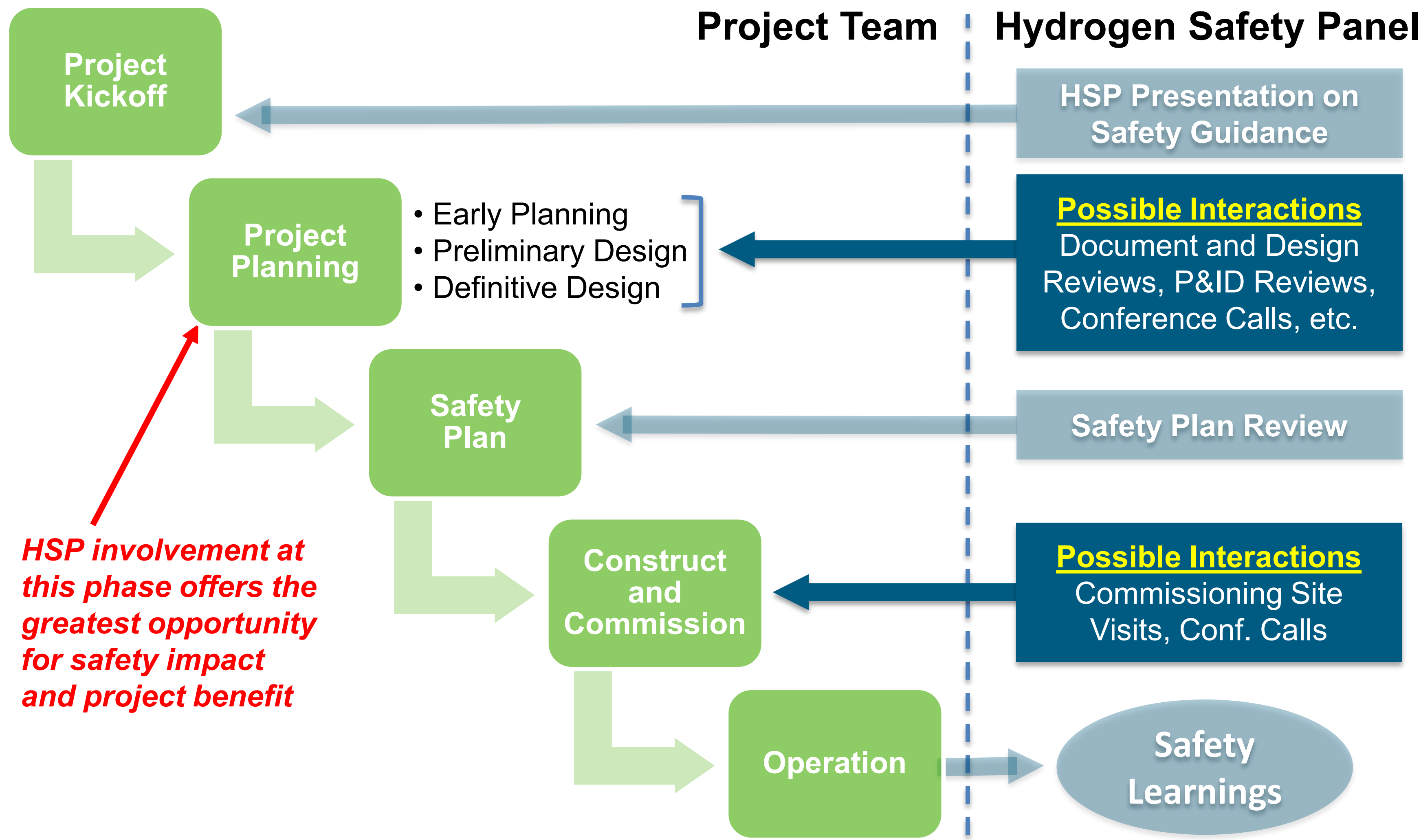
# Hydrogen Safety Panel Accomplishments

- Reviewed over 270 projects (415 reviews) 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: Lessons Learned and Best Safety Practices on the Hydrogen Tools Portal (h2tools.org).
- Conducted 21 Hydrogen Safety Panel meetings since 2003. Panel meetings currently engage a broad cross-section of the hydrogen and fuel cell community.

**Current Hydrogen Safety Panel Members**

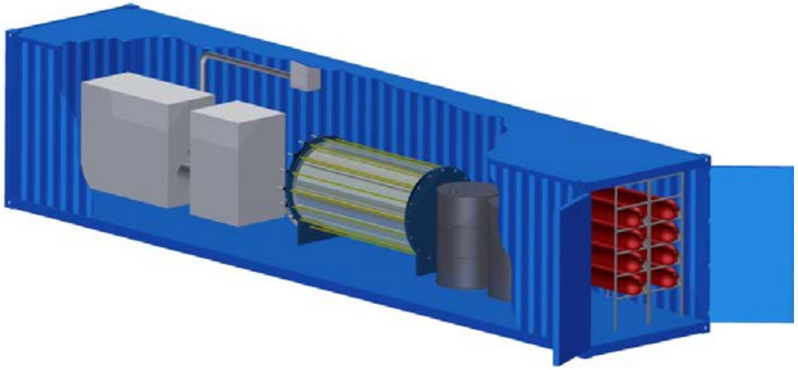
| Name | Affiliation |
|---|---|
| Nick Barilo, Manager | Pacific Northwest National Laboratory |
| Richard Kallman, Chair | City of Santa Fe Springs, CA |
| David Farese | Air Products and Chemicals |
| Larry Fluer | Fluer, Inc. |
| Bill Fort | Consultant |
| Donald Frikken | Becht Engineering |
| Aaron 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 |

# Overview of HSP & DOE Project Activities



# HSP Support Input for Codes and Standards

- The Panel's white paper, "Safety of Hydrogen Systems Installed in Outdoor Enclosures," and risk evaluation activities supported changes for the 2016 version of NFPA 2.
- NFPA 2, 2016 now 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 ft² designed to protect hydrogen*.

* Final balloting approved in December 2014

# 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
- When equipment is not listed, the code official must "approve" it before installation

***So what criteria do code officials use to approve the equipment?***

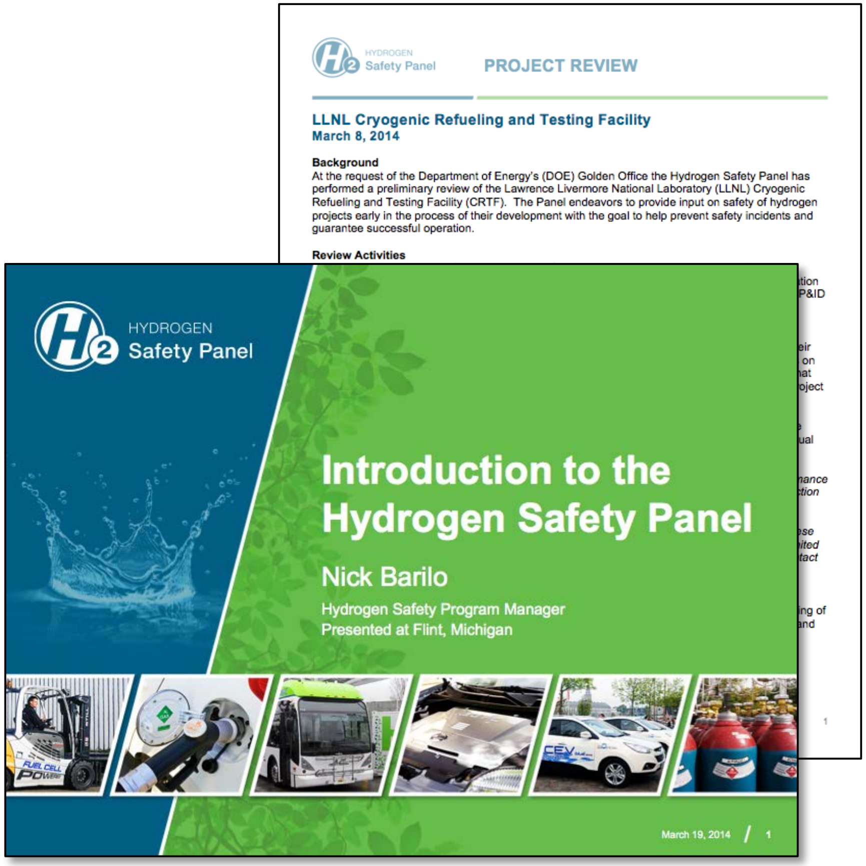
- The HSP is developing a guide to assist code officials, designers, owners, evaluators and others with the application of requirements pertinent to the design and/or installation of hydrogen equipment as regulated by the model codes

# Highlighting the HSP as a Safety Resource

HYDROGEN
Safety Panel

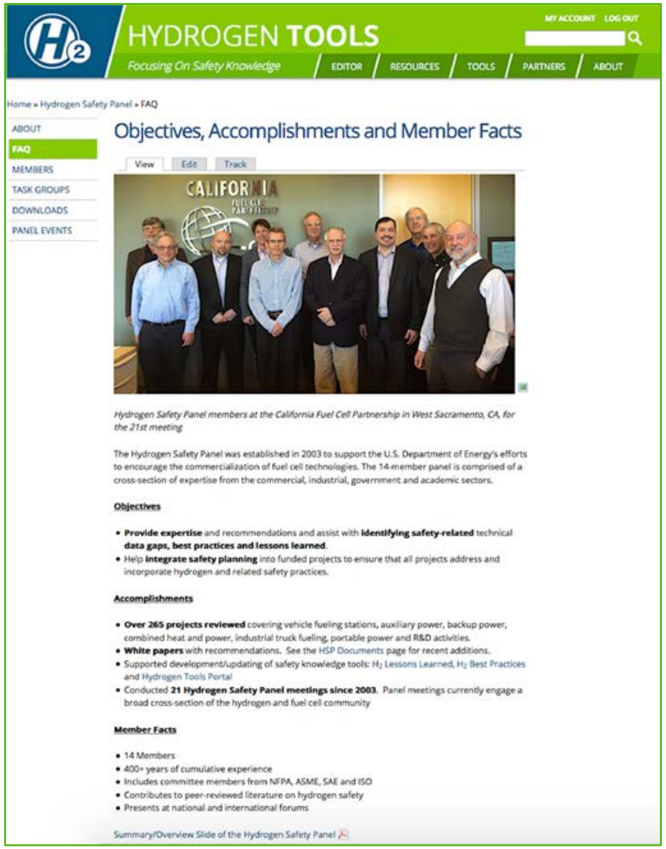
*To enhance the Hydrogen Safety Panel's role as a safety resource for enabling the widespread acceptance of hydrogen, **product branding** is now used:*

- The consistent and appropriate use of branding will strengthen recognition of the HSP and its reputation as a safety resource
- Branding will also validate that information is coming from a reliable and trustworthy source



# HSP Support for State Deployment of Infrastructure

- Assisting the H2USA market acceleration working group through focused SCS outreach activities
- Supporting the California Governor's Office and CA Green Team
  - Included in the CA Hydrogen Station Permitting Guidebook - "this panel can be consulted to review innovative projects and provide feedback and insights to both station developers and AHJs."
- Drafted safety sections for the Hawaii implementation plan
  - Includes reference to the HSP as a safety resource
- Working with code officials in Massachusetts to discuss safety issues and assist with infrastructure rollout
- Completed a safety review of a mobile fuel cell power unit for the California Air Resources Board




Establishing public visibility… Hydrogen Safety Panel **website** online March 2015

# Maximizing the Impact of the HSP

***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

# Sharing Safety Knowledge

# 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

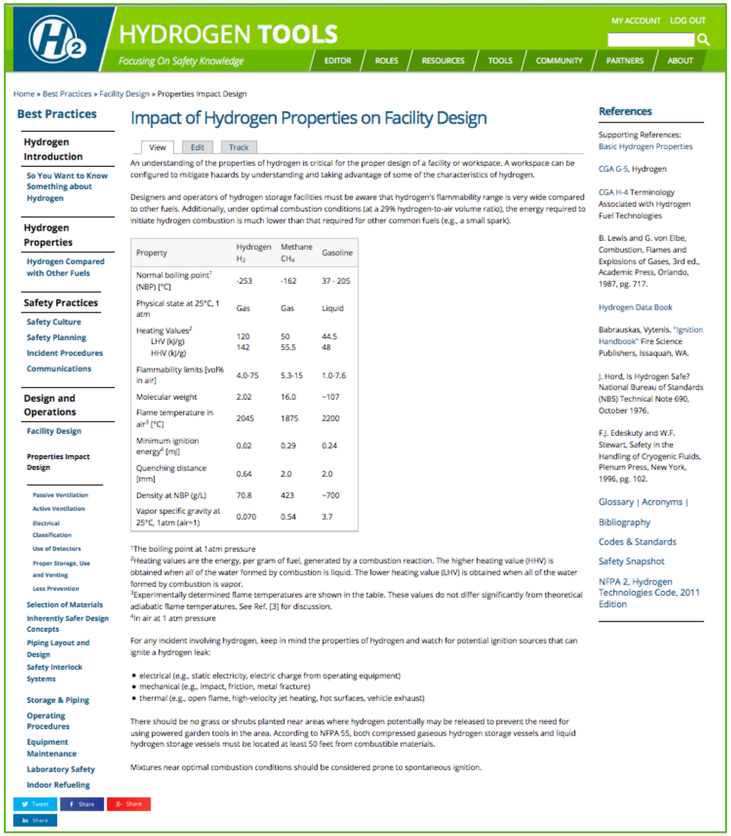

http://**h2tools**.org

› **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


HYDROGEN TOOLS
Focusing On Safety Knowledge
MY ACCOUNT LOG OUT
EDITOR ROLES RESOURCES TOOLS COMMUNITY PARTNERS ABOUT

Home » Best Practices » Facility Design » Properties Impact Design

**Best Practices**

Hydrogen Introduction
- 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
- Properties Impact Design
  - Passive Ventilation
  - Active Ventilation
  - Electrical Classification
  - Use of Detectors
  - Proper Storage, Use and Venting
  - Loss Prevention
- Selection of Materials
- Inherently Safer Design Concepts
- Piping Layout and Design
- Safety Interlock Systems
- Storage & Piping
- Operating Procedures
- Equipment Maintenance
- Laboratory Safety
- Indoor Refueling

## Impact of Hydrogen Properties on Facility Design

View | Edit | Track

An understanding of the properties of hydrogen is critical for the proper design of a facility or workspace. A workspace can be configured to mitigate hazards by understanding and taking advantage of some of the characteristics of hydrogen.

Designers and operators of hydrogen storage facilities must be aware that hydrogen's flammability range is very wide compared to other fuels. Additionally, under optimal combustion conditions (at a 29% hydrogen-to-air volume ratio), the energy required to initiate hydrogen combustion is much lower than that required for other common fuels (e.g., a small spark).

| Property | Hydrogen $H_2$ | Methane $CH_4$ | Gasoline |
|---|---|---|---|
| Normal boiling point[1] (NBP) [°C] | -253 | -162 | 37 - 205 |
| Physical state at 25°C, 1 atm | Gas | Gas | Liquid |
| Heating Values[2] LHV (kJ/g) HHV (kJ/g) | 120<br>142 | 50<br>55.5 | 44.5<br>48 |
| Flammability limits [vol% in air] | 4.0-75 | 5.3-15 | 1.0-7.6 |
| Molecular weight | 2.02 | 16.0 | ~107 |
| Flame temperature in air[3] [°C] | 2045 | 1875 | 2200 |
| Minimum ignition energy[4] [mJ] | 0.02 | 0.29 | 0.24 |
| Quenching distance [mm] | 0.64 | 2.0 | 2.0 |
| Density at NBP (g/L) | 70.8 | 423 | ~700 |
| Vapor specific gravity at 25°C, 1atm (air=1) | 0.070 | 0.54 | 3.7 |

[1]The boiling point at 1atm pressure
[2]Heating values are the energy, per gram of fuel, generated by a combustion reaction. The higher heating value (HHV) is obtained when all of the water formed by combustion is liquid. The lower heating value (LHV) is obtained when all of the water formed by combustion is vapor.
[3]Experimentally determined flame temperatures are shown in the table. These values do not differ significantly from theoretical adiabatic flame temperatures. See Ref. [3] for discussion.
[4]In air at 1 atm pressure

For any incident involving hydrogen, keep in mind the properties of hydrogen and watch for potential ignition sources that can ignite a hydrogen leak:

- electrical (e.g., static electricity, electric charge from operating equipment)
- mechanical (e.g., impact, friction, metal fracture)
- thermal (e.g., open flame, high-velocity jet heating, hot surfaces, vehicle exhaust)

There should be no grass or shrubs planted near areas where hydrogen potentially may be released to prevent the need for using powered garden tools in the area. According to NFPA 55, both compressed gaseous hydrogen storage vessels and liquid hydrogen storage vessels must be located at least 50 feet from combustible materials.

Mixtures near optimal combustion conditions should be considered prone to spontaneous ignition.

**References**

Supporting References: Basic Hydrogen Properties

CGA G-5, Hydrogen

CGA H-4 Terminology Associated with Hydrogen Fuel Technologies

B. Lewis and G. von Elbe, Combustion, Flames and Explosions of Gases, 3rd ed., Academic Press, Orlando, 1987, pg. 717.

Hydrogen Data Book

Babrauskas, Vytenis. "Ignition Handbook" Fire Science Publishers, Issaquah, WA.

J. Hord, Is Hydrogen Safe? National Bureau of Standards (NBS) Technical Note 690, October 1976.

F.J. Edeskuty and W.F. Stewart, Safety in the Handling of Cryogenic Fluids, Plenum Press, New York, 1996, pg. 102.

Glossary | Acronyms | Bibliography

Codes & Standards

Safety Snapshot

NFPA 2, Hydrogen Technologies Code, 2011 Edition

Tweet Share Share Share

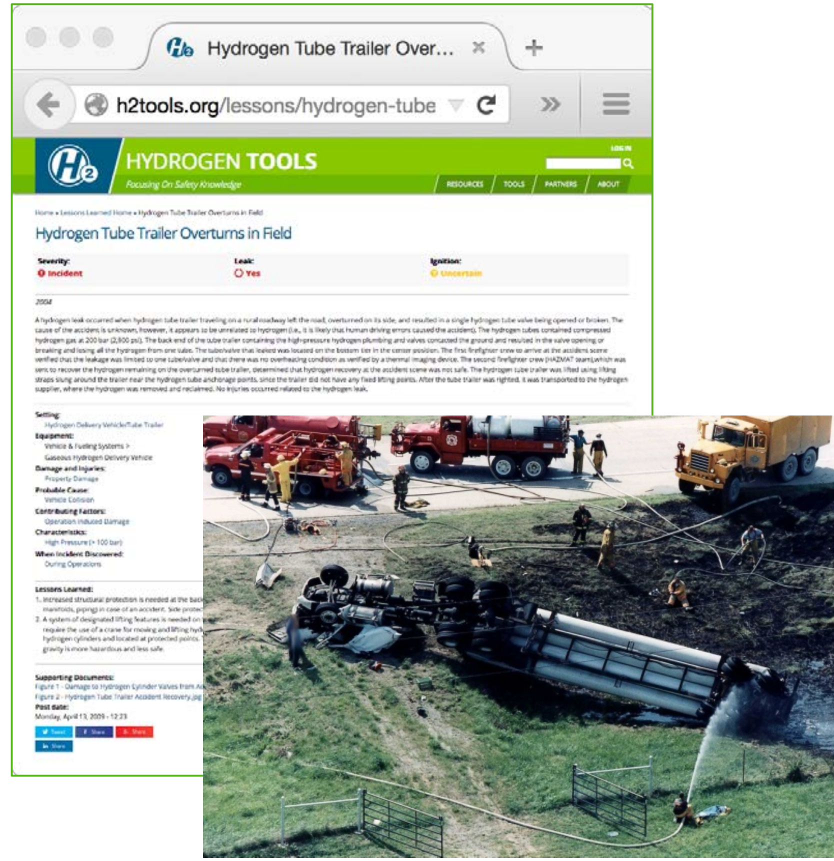
*Safety events from "H2incidents.org" illustrate what can go wrong if best practices are not followed.*

# 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**

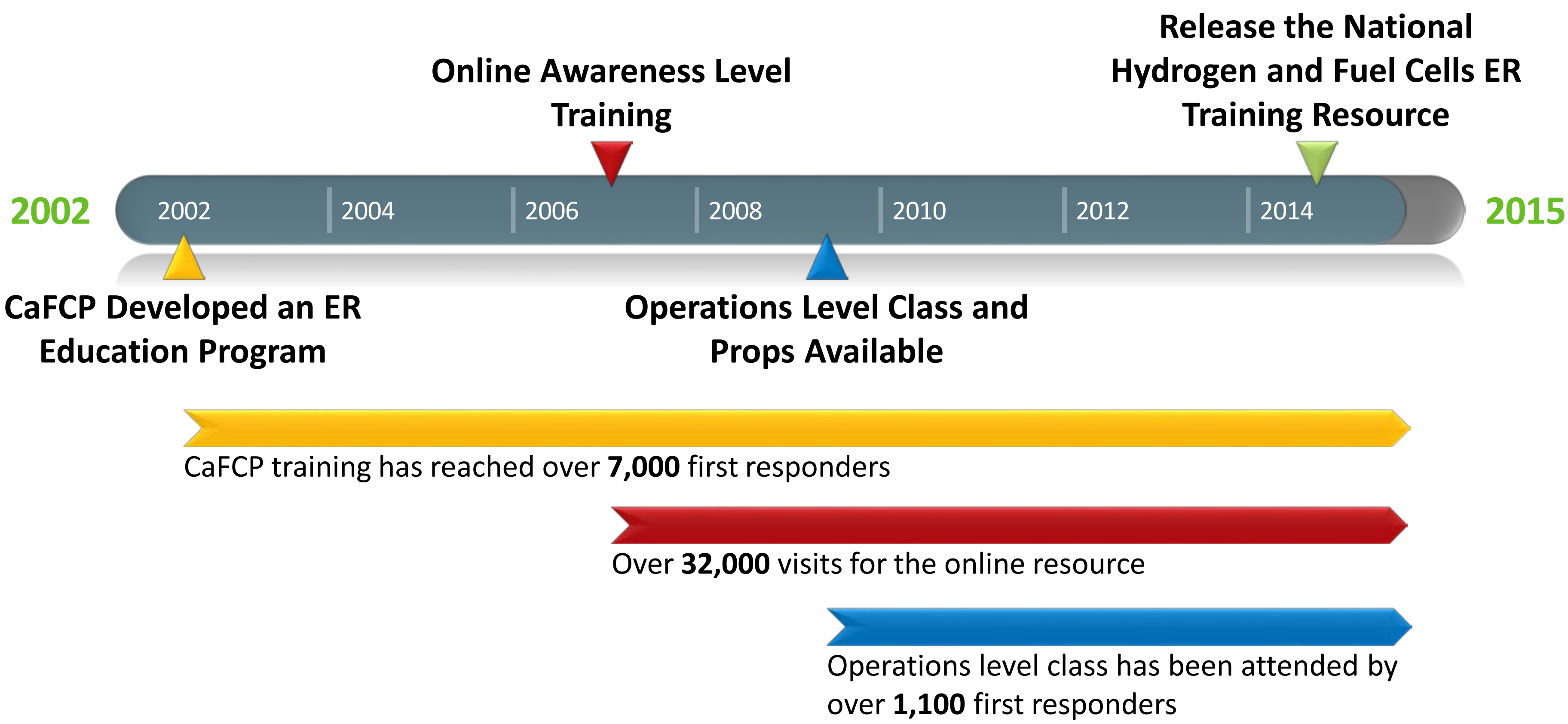
# First Responder Training Resources

# 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)

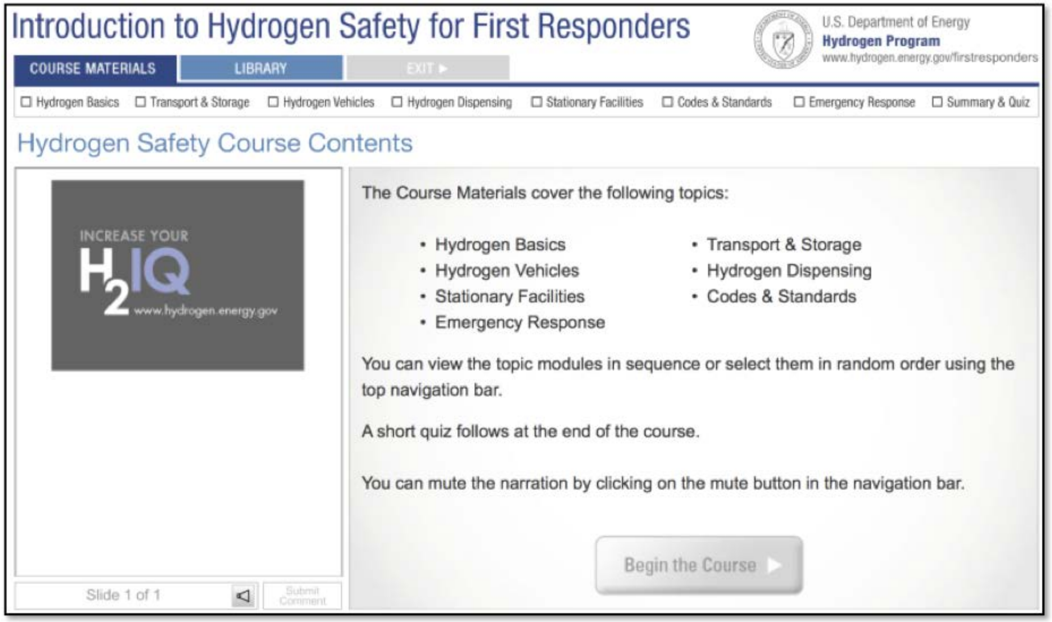
***A properly trained first responder community is critical to the successful introduction of hydrogen fuel cell applications and their transformation in how we use energy.***

# Training Resources - Timeline and Accomplishments



# Expanding the Reach of First Responder Training

- PNNL has begun discussions with the National Fire Academy to transfer the online awareness training to them. This will:
  - allow a broader distribution of the materials,
  - better crediting of course completion/CEUs, and
  - Provide a good long-term landing spot for the training.
- PNNL/CaFCP will continue to provide subject matter expertise on the technical content.



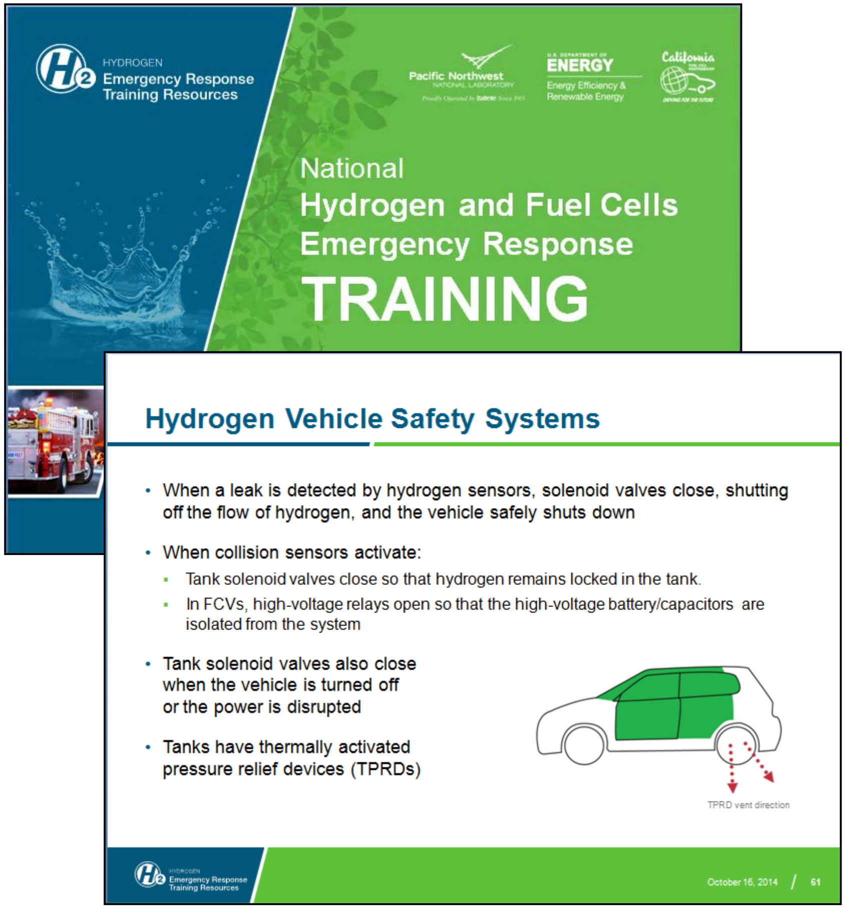
# Classroom and Hands-on Training

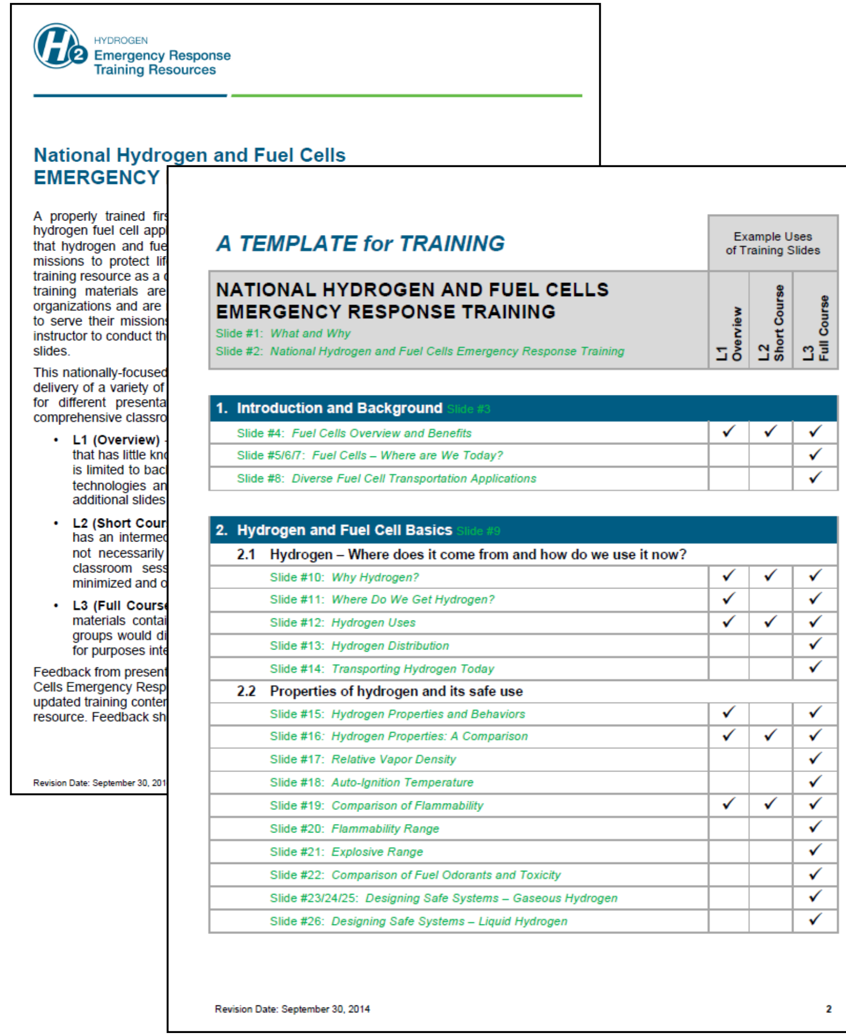
- **Classroom Content**
  - Hydrogen and Fuel Cell Basics
  - Hydrogen Vehicles
  - Stationary Facilities
  - Emergency Response
  - Incident Scenarios
- **Demonstrations/Hands-on Exercise with FCEV Prop**
  - Demonstration of Hydrogen Flame Characteristics
  - Student Participation in Rescue Evolutions

*Multiple instructors for classroom training*

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

# National First Responder Training Resource



HYDROGEN
Emergency Response
Training Resources

National Hydrogen and Fuel Cells
EMERGENCY

Revision Date: September 30, 201

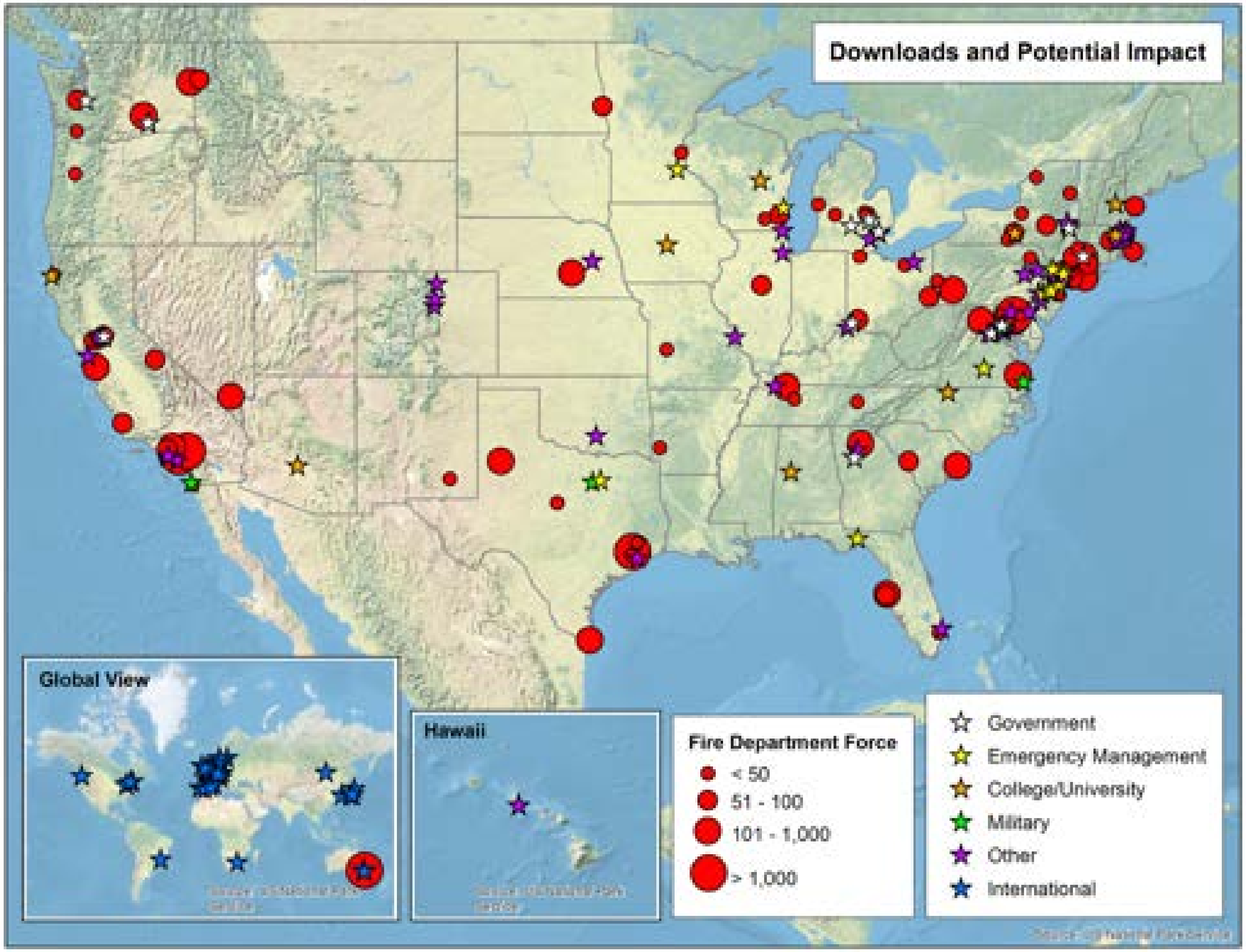
A TEMPLATE for TRAINING

| NATIONAL HYDROGEN AND FUEL CELLS EMERGENCY RESPONSE TRAINING<br>Slide #1: *What and Why*<br>Slide #2: *National Hydrogen and Fuel Cells Emergency Response Training* | Example Uses of Training Slides<br>L1 Overview | L2 Short Course | L3 Full Course |
|---|---|---|---|
| **1. Introduction and Background** Slide #3 | | | |
| Slide #4: *Fuel Cells Overview and Benefits* | ✓ | ✓ | ✓ |
| Slide #5/6/7: *Fuel Cells – Where are We Today?* | | | ✓ |
| Slide #8: *Diverse Fuel Cell Transportation Applications* | | | ✓ |
| **2. Hydrogen and Fuel Cell Basics** Slide #9 | | | |
| **2.1 Hydrogen – Where does it come from and how do we use it now?** | | | |
| Slide #10: *Why Hydrogen?* | ✓ | ✓ | ✓ |
| Slide #11: *Where Do We Get Hydrogen?* | ✓ | | ✓ |
| Slide #12: *Hydrogen Uses* | ✓ | ✓ | ✓ |
| Slide #13: *Hydrogen Distribution* | | | ✓ |
| Slide #14: *Transporting Hydrogen Today* | | | ✓ |
| **2.2 Properties of hydrogen and its safe use** | | | |
| Slide #15: *Hydrogen Properties and Behaviors* | ✓ | | ✓ |
| Slide #16: *Hydrogen Properties: A Comparison* | ✓ | ✓ | ✓ |
| Slide #17: *Relative Vapor Density* | | | ✓ |
| Slide #18: *Auto-Ignition Temperature* | | | ✓ |
| Slide #19: *Comparison of Flammability* | ✓ | ✓ | ✓ |
| Slide #20: *Flammability Range* | | | ✓ |
| Slide #21: *Explosive Range* | | | ✓ |
| Slide #22: *Comparison of Fuel Odorants and Toxicity* | | | ✓ |
| Slide #23/24/25: *Designing Safe Systems – Gaseous Hydrogen* | | | ✓ |
| Slide #26: *Designing Safe Systems – Liquid Hydrogen* | | | ✓ |

Revision Date: September 30, 2014 2

Can be downloaded at http://h2tools.org/fr/nt

# National Training Resource Downloads




**Since October 2014**

- **>300 downloads**
- **in 6 Continents**
- **and 35 of 50 states**
- **translated into Japanese in support of Japan fuel cell activities**

# 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. ***The resources described in this presentation will continue to play a critical role to help identify issues and inform those tasked with designing, approving, or using systems and facilities, as well as those responding to incidents.***

# What Others Are Saying About These Safety Activities

## Feedback from the 2015 DOE Annual Merit Review

- "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."
- "HSP – excellent – still **need to get this talent used more broadly**"
- "**Component listing is** critical as well - the plan to level the playing field by showing AHJs and Station Developers how they can establish comfort that station systems will perform is **incredibly timely and important. It's a big, unanswered question** in California."
- "Listed equipment – **Development of a guide** to assist AHJ's to "approve" installations which are not "listed" **will be a great asset in the early stages of development** until the community gets hardware listed."
- "The new H2tools website is an example of successful communication effort, is well structured and of utility for users with different goals and level of competences."
- "Given the funding level this project has achieved a lot of very high quality work on all three aspects of this work. Having the notion of safety planning in the FOA is a great idea. It sets the posture for a safety culture and allows the HSP to engage early in the project."

# Thank You for Your Attention!

The author also 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), and the California Fuel Cell Partnership for their support of this work.

# For additional information…

CONTACT:

**Nick Barilo, P.E.**
Hydrogen Safety Program Manager
Pacific Northwest National Laboratory
(509) 371-7894
nick.barilo@pnnl.gov

OR VISIT:

**http://h2tools.org**

for more Hydrogen Safety related news and the latest resources

# Thank You

**Will James - Team Lead**
**202-287-6223**
**charles.james@ee.doe.gov**

Nick Barilo - Hydrogen Safety Program Manager
Pacific Northwest National Laboratory
(509) 371-7894 – nick.barilo@pnnl.gov

**hydrogenandfuelcells.energy.gov**