HYDROGEN
Safety Panel

Safety Planning for the H-Prize Competition

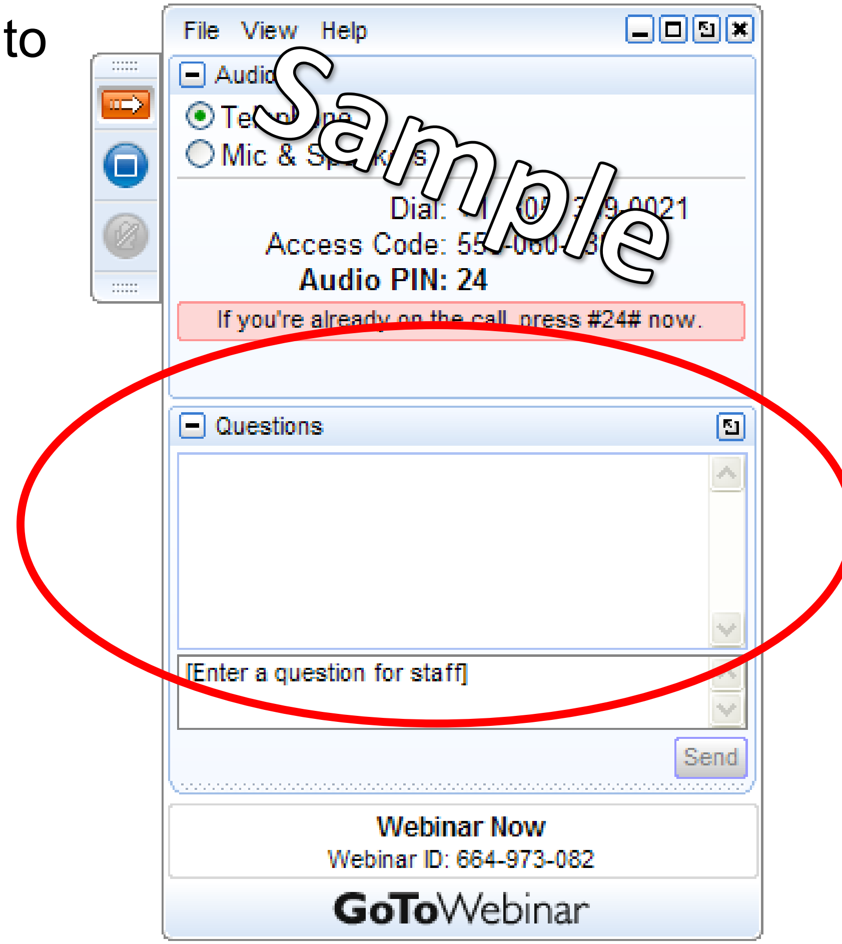
Nick Barilo and Don Frikken
Hydrogen Safety Panel

H-Prize Safety Webinar, August 6, 2015

PNNL-SA-111763

Question and Answer

- Please type your questions into



About the H-Prize

H2 Refuel is the 2014-2016 H-Prize competition. It challenges America's innovators to deploy an on-site hydrogen generation system, using electricity or natural gas, to fuel hydrogen vehicles, that can be used in homes, community centers, retail sites or similar locations. The best entry, based on technical and cost criteria, will win $1 million.

The H-Prize was established by the 2007 Energy Independence and Security Act to be a series of competitions to encourage and reward innovations and advances in hydrogen energy technologies.

The H-Prize is administered by the Hydrogen Education Foundation, and sponsored by the Department of Energy's Fuel Cell Technologies Office.

Safe practices for the production, storage, distribution and use of hydrogen are essential to establish public confidence and for reducing barriers to widespread acceptance of hydrogen technologies.

Safety Planning

- As part of the design submission for finalist selection, contestants must:
  - include a safety plan
  - a hazard analysis, and
  - have received approvals from local planning/zoning, fire and building officials before system operation (this may require some approval processes be started by the time of design submission, and that should be indicated in the submission information)

The following slides provide an overview and resources to help with safety planning.

See http://www.hydrogenprize.org/how-to-compete/safety/ for more information and resource links.

Hydrogen Safety Resources

PNNL has a core capability in hydrogen safety to meet the DOE Fuel Cell Technologies Office goals and needs. The capability is implemented through the resources below.

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 H_2 and Fuel Cell Emergency Response Training Resource

HYDROGEN Emergency Response Training Resources

Hydrogen **Safety Panel**

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
- working with design, construction, and operations personnel to ensure that safety is a priority 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

- Over 410 project 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.

Hydrogen Safety Panel Members

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

Learnings from Fuel Cell Deployments

- Project Integration
  - A thorough and integrated approach to project safety planning needs to involve all parties
- Hazard Analysis
  - Safety vulnerability analysis needs to comprehensively consider potential incident scenarios introduced by hydrogen/fuel cell deployment and equipment operations and exposures
- Requirements
  - Practices in technology development phases don't necessarily translate to safe or code compliant configurations for deployment
  - Safety issues associated with the modular design approach for refueling equipment need to be better understood by both manufacturers and code developers for safe and economical deployments
- Certification
  - The role and scope of third-party certification of hydrogen and fuel cell systems need to be clarified to facilitate their commercialization
    - What is covered and do certifications support or replace AHJ approval?

The Need for Safety planning

Safety is an essential ingredient for establishing public confidence and reducing barriers toward the goals of decreasing our dependence on oil, reducing carbon emissions and enabling clean, reliable power generation. Safe practices in the production, storage, distribution, and use of hydrogen are:

- essential to protect people from injury or death, and
- necessary to minimize damage to facilities

HYDROGEN Safety Panel

The 2014-2016 H-Prize Competition

H2refuel

U.S. Department of Energy

Primary Goals

The goals of safety planning are to:

- identify hazards,
- evaluate risks by considering the likelihood and severity/consequence of an incident associated with the hazards, and
- minimize the risks associated with a project

To achieve these goals, various hazard analysis and risk assessment techniques are used, in conjunction with safety reviews.

Safety planning should be an integral part of the design and operation of a system. Safety approvals should not be after thoughts or final hurdles to be overcome before a system can become operational.

Guidance for Effective Safety Plans

The project safety planning process is meant to:

- help identify and avoid potential hydrogen and related incidents
- generate a good safety plan that will serve as a guide for the safe conduct of all project work

A safety plan should:

- use a graded approach based on level of risk and complexity
- cover all experimental/operational work being conducted with particular emphasis on the aspects involving hydrogen, hazardous materials handling and fuel cell systems

Safety Plan Topics

- Scope of Work
- Organizational Safety Information
  - Organizational Policies & Procedures
  - Hydrogen and Fuel Cell Experience
- Project Safety
  - Identification of Safety Vulnerabilities
  - Risk Reduction Plan
  - Management of Change Procedures
  - Project Safety Documentation
- Communications Plan
  - Employee Training
  - Safety Events and Lessons Learned
  - Emergency Response


Safety Planning

for the

2014-2016 H-Prize Competition

July 2015

The 2014-2016 H-Prize Competition

H2refuel

U.S. Department of Energy

Focusing on the Hazards

Potential hazards in any work, process or system should be identified, analyzed and eliminated or mitigated as part of sound safety planning. **In general, a good safety plan identifies:**

- immediate (primary) failure modes
- secondary failure modes that may come about as a result of other failures

For effective safety planning, an attempt is made to identify all conceivable failures, from catastrophic failures to benign collateral failures. Identification and discussion of perceived benign failures may lead to the identification of more serious potential failures.

Identification of Safety Vulnerabilities

- Identification of Safety Vulnerabilities (ISV). Assessment of the potential hazards associated with work at any scale from laboratory to operations begins with the identification of an appropriate assessment technique. The ISV is the formal means by which potential safety issues associated with laboratory or process steps, materials, equipment, operations, facilities and personnel are identified. The plan should describe:
  - the ISV method that is used for this project
  - who leads and stewards the use and results of the ISV process
  - significant accident scenarios identified (e.g. higher consequence, higher frequency)
  - significant vulnerabilities (risks) identified
  - safety critical equipment

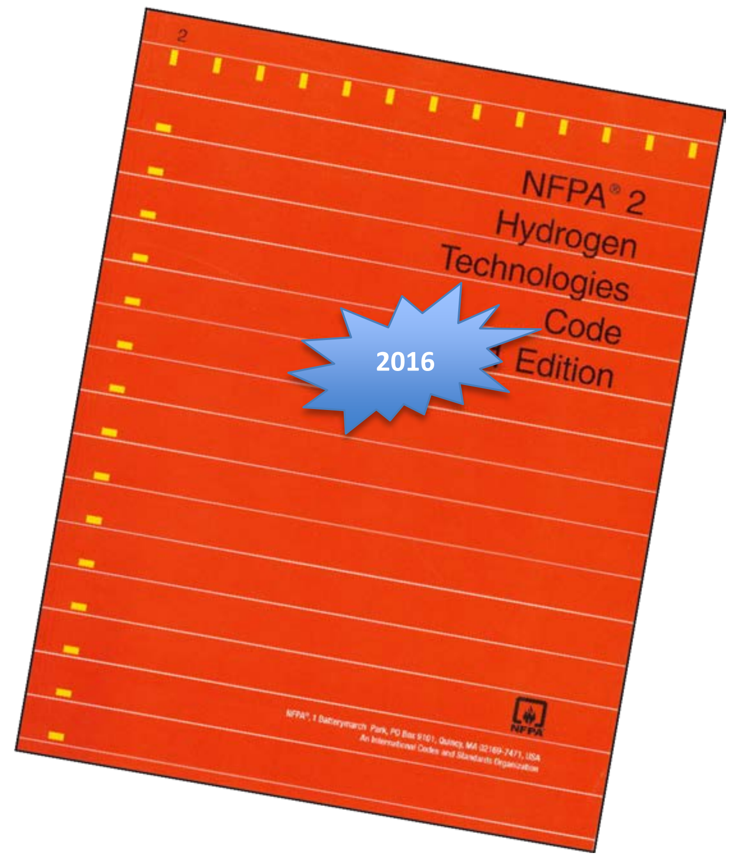
Two questions should be addressed in the ISV:

- *What hazard associated with this project is most likely to occur?*
- *What hazard associated with this project has the potential to result in the worst consequence?*

Codes and Standards

Designs must meet the relevant safety codes and standards for installation in the target location, including the applicable parts of the following:

- NFPA 2, Hydrogen Technologies Code, 2011 Edition
- NFPA 70, National Electrical Code®
- ASME B31.3, Process Piping; or B31.12, Hydrogen Piping and Pipelines
- ASME Boiler and Pressure Vessel Code (BPV)
- SAE J2719, Hydrogen Fuel Quality for Fuel Cell Vehicles



Compliance with applicable codes and standards is essential for ensuring public confidence in commercial projects, particularly for those deploying new technologies.

Codes and Standards (cont'd)

The following fueling protocols are likely to apply to some but not all potential system designs; relevant designs/submittals will be expected to be meet these codes and standards where applicable.

- SAE J2601: for automotive fueling
- SAE J2601-2: for heavy duty vehicle fueling
- ISO/IS 22734-2: Hydrogen generators using water electrolysis process, residential applications

Additional codes and standards may apply depending on the system design and installation location.

Submissions that deviate from the base codes and standards listed will need to provide detailed information on what is different and how equivalent safety is provided.

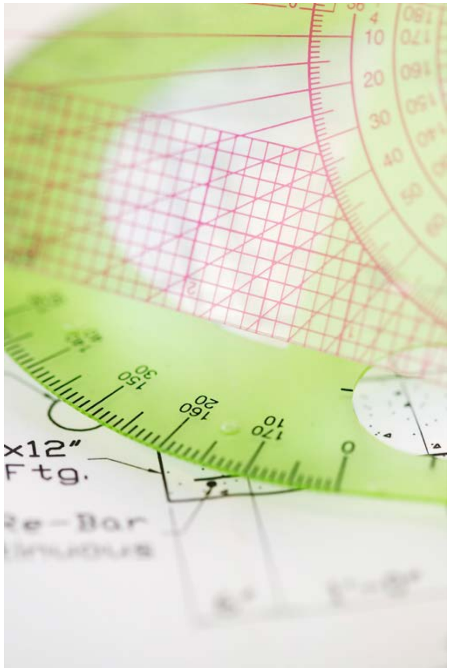
Other Relevant Questions…

- Who are the authorities having jurisdiction, and to what degree have they been involved in the design and installation of equipment for this project?
- Was there any special permitting and/or certification that was required?
- Has a third-party review or certification of any components, sub-systems, systems or products been considered and performed?

Additional Required Documentation

In addition to the safety plan, the following documents should be provided:

1. Process flow diagram, piping and instrument diagram, or both
2. Preliminary design or functional description for each component in the system
3. Codes and standards compliance discussion
4. Layout of the system in the planned installation, along with
   a. Required separation distances
   b. Hydrogen vent system considerations
   c. Electrical classification and ignition source control
   d. Ventilation requirements for any enclosed spaces



Safety Resources

Hydrogen Tools

A Transformative Step Towards Hydrogen Adoption

Now Available

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

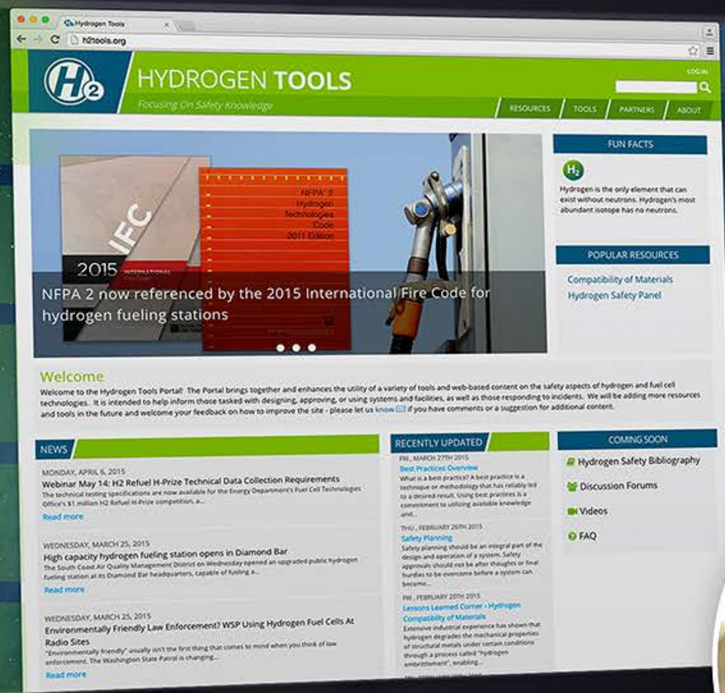
FOCUSED CONTENT tailored to the specialized needs of H_2 user groups

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



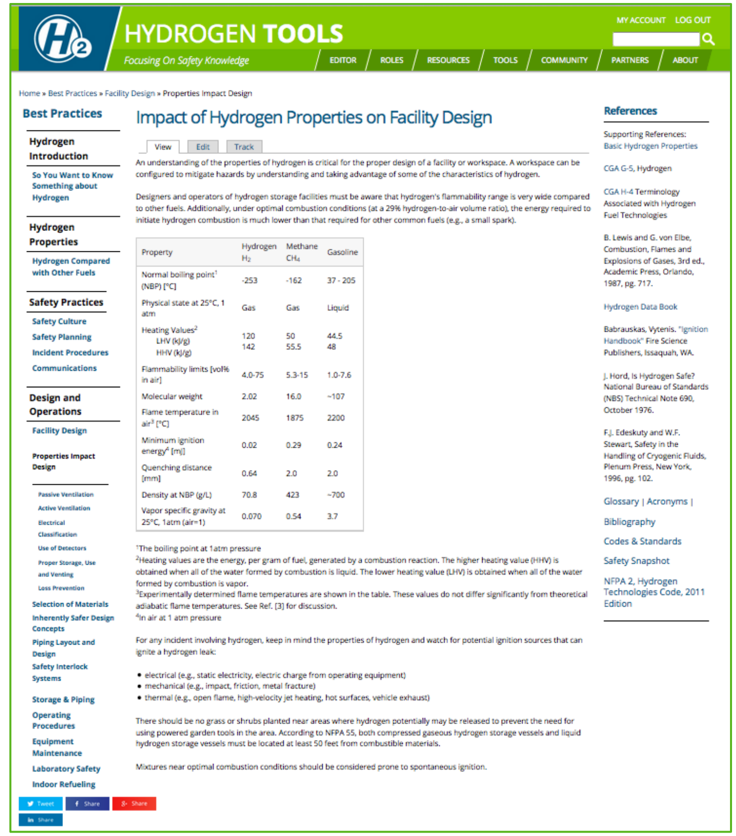
+ Mobile Friendly

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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Focusing On Safety Knowledge

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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)	120 142	50 55.5	44.5 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

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

Gaseous Hydrogen Properties

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

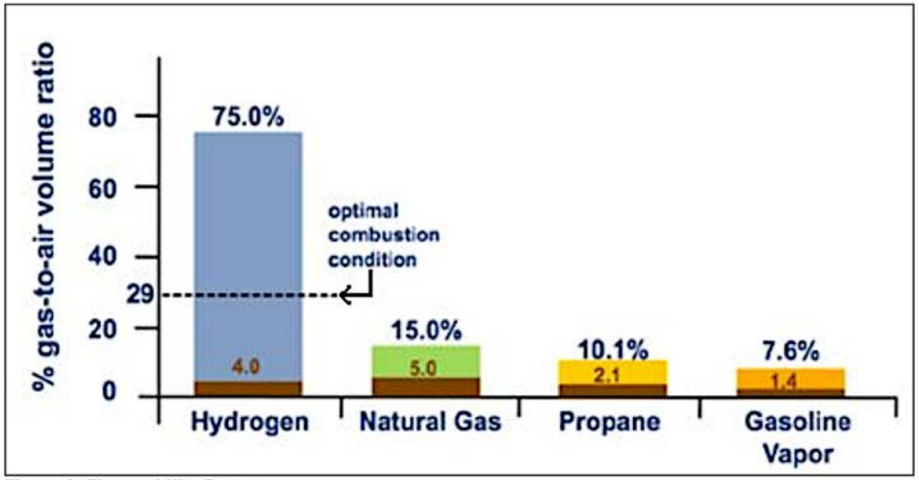


Figure 3. Flammability Range

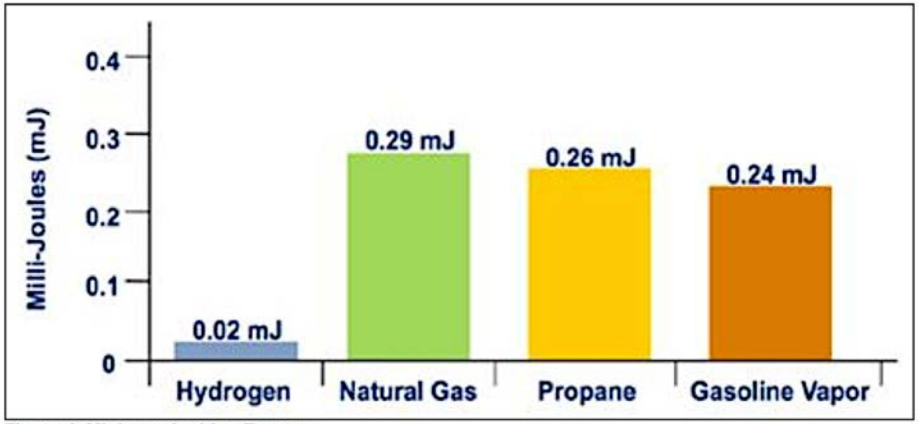


Figure 4. Minimum Ignition Energy

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

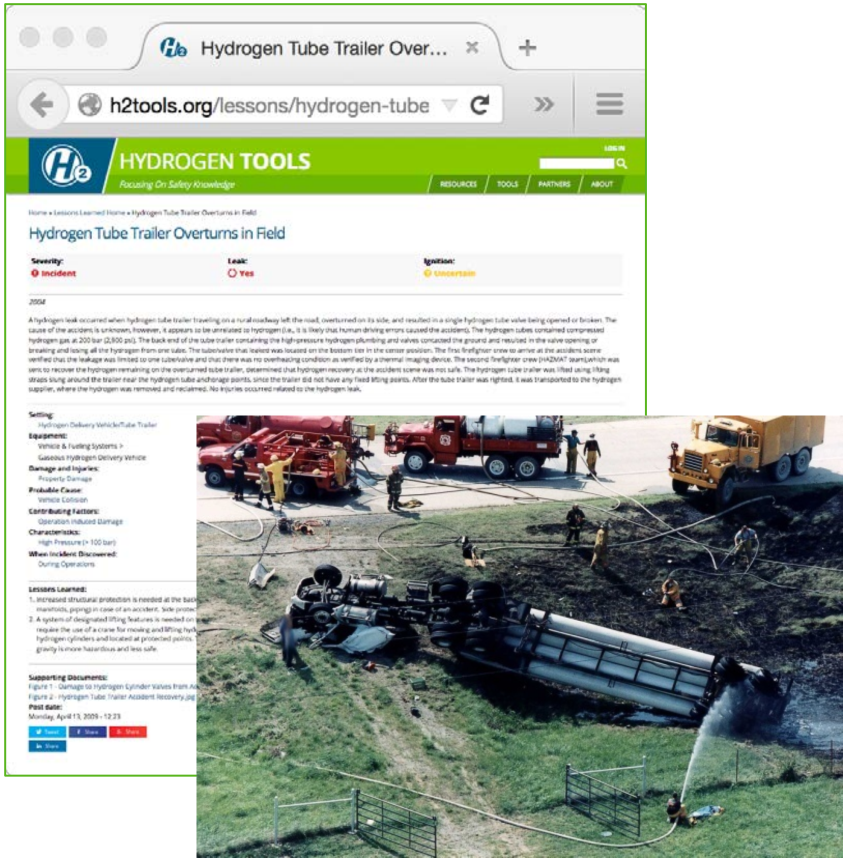
Source: California Fuel Cell Partnership

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

NOTE: *Information that may uniquely identify an incident will not be displayed in the incident reports in order to maintain anonymity for the companies and locations.*

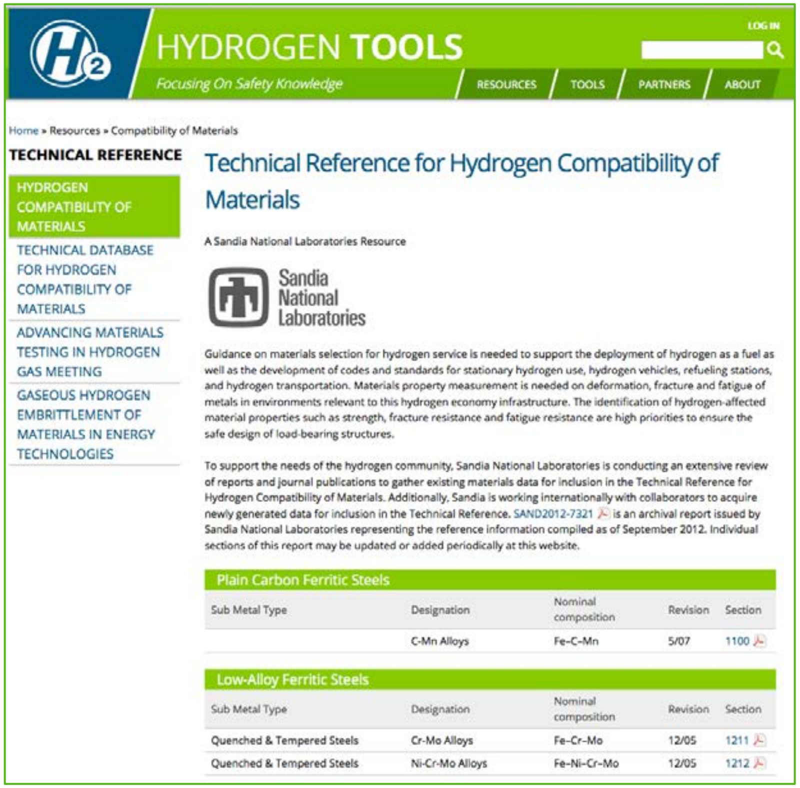


Tube Trailer Rollover

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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TECHNICAL REFERENCE

HYDROGEN COMPATIBILITY OF MATERIALS

TECHNICAL DATABASE FOR HYDROGEN COMPATIBILITY OF MATERIALS

ADVANCING MATERIALS TESTING IN HYDROGEN GAS MEETING

GASEOUS HYDROGEN EMBRITTLEMENT OF MATERIALS IN ENERGY TECHNOLOGIES

Technical Reference for Hydrogen Compatibility of Materials

A Sandia National Laboratories Resource

Sandia National Laboratories

Guidance on materials selection for hydrogen service is needed to support the deployment of hydrogen as a fuel as well as the development of codes and standards for stationary hydrogen use, hydrogen vehicles, refueling stations, and hydrogen transportation. Materials property measurement is needed on deformation, fracture and fatigue of metals in environments relevant to this hydrogen economy infrastructure. The identification of hydrogen-affected material properties such as strength, fracture resistance and fatigue resistance are high priorities to ensure the safe design of load-bearing structures.

To support the needs of the hydrogen community, Sandia National Laboratories is conducting an extensive review of reports and journal publications to gather existing materials data for inclusion in the Technical Reference for Hydrogen Compatibility of Materials. Additionally, Sandia is working internationally with collaborators to acquire newly generated data for inclusion in the Technical Reference. SAND2012-7321 is an archival report issued by Sandia National Laboratories representing the reference information compiled as of September 2012. Individual sections of this report may be updated or added periodically at this website.

Plain Carbon Ferritic Steels

Sub Metal Type	Designation	Nominal composition	Revision	Section
	C-Mn Alloys	Fe-C-Mn	5/07	1100

Low-Alloy Ferritic Steels

Sub Metal Type	Designation	Nominal composition	Revision	Section
Quenched & Tempered Steels	Cr-Mo Alloys	Fe-Cr-Mo	12/05	1211
Quenched & Tempered Steels	Ni-Cr-Mo Alloys	Fe-Ni-Cr-Mo	12/05	1212

Hydrogen Safety Training for Researchers

- **Objectives:** Provide basic hydrogen safety training through an interactive online course
- Laboratory researchers and technical personnel handling hydrogen need basic information on pressure, cryogenics, flammability, asphyxiation, and other risks and precautions for using hydrogen.
- **Six Modules** are included in the course, with a quiz at the end of each module.
  - Course introduction and overview
  - Basic handling precautions for hydrogen use as they relate to Hydrogen's physical and chemical properties
  - Safety issues related to pressure systems
  - Safety issues related to cryogenic systems
  - Overview of emergency response considerations for hydrogen incidents
  - High-Level overview of the codes and standards that apply to hydrogen applications

Sample Screenshot

Working with First Responders

Preplanning

- H-Prize participants and and facility owners should work with local first responders to assist in their 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 (see the resource lists at the end of this presentation).

Equipment

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

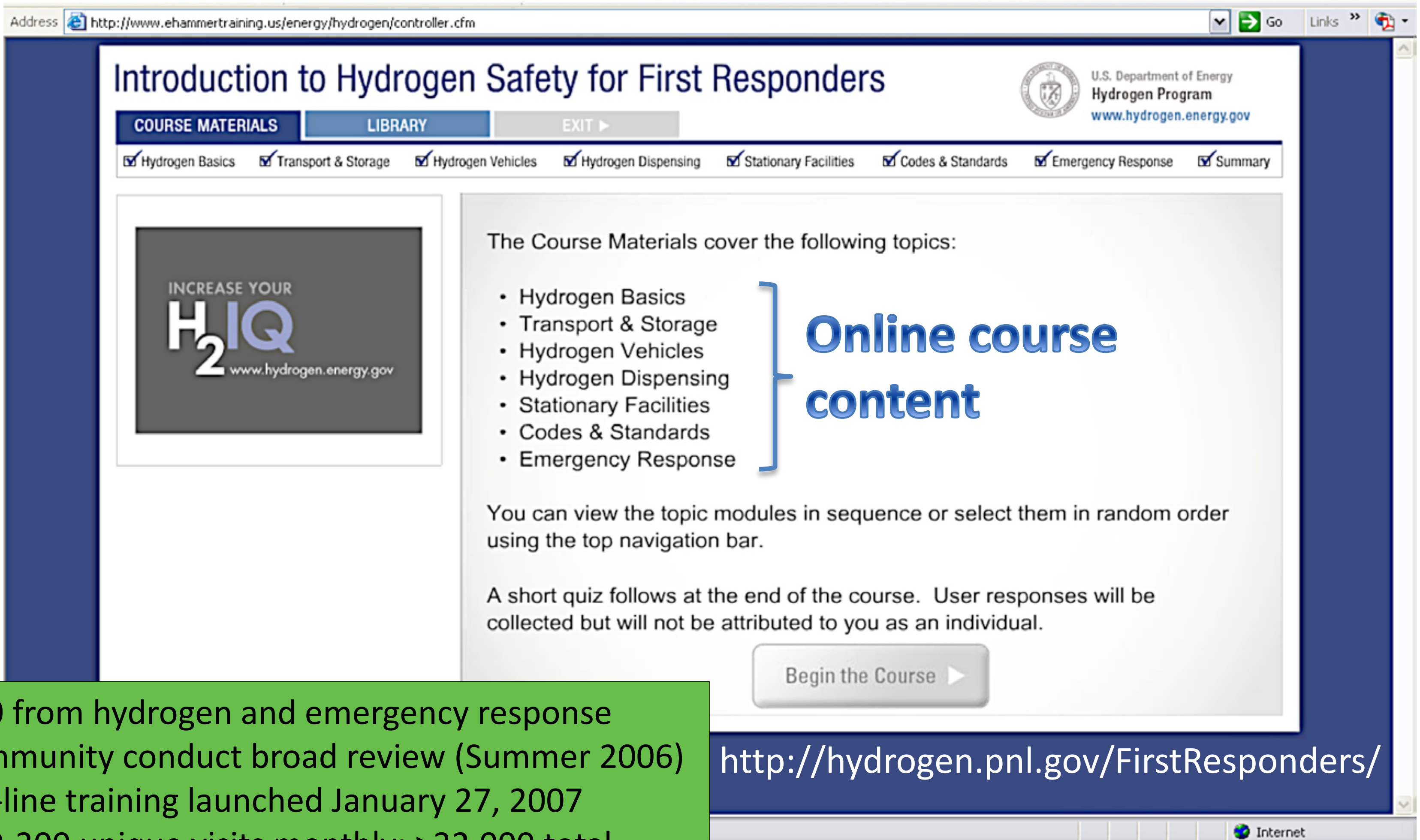
First Response Hydrogen Safety Training

- **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
  - 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.

Weblinks:
Online training – http://hydrogen.pnl.gov/FirstResponders/
National training resource - http://h2tools.org/fr/nt

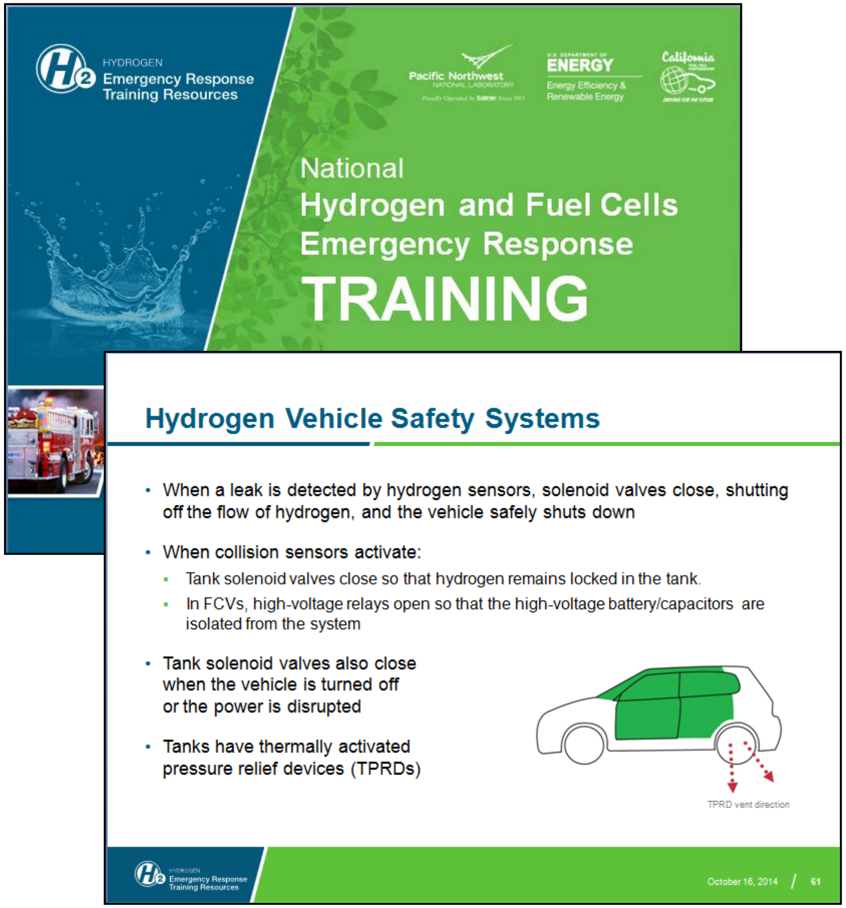
Online Awareness-level Training

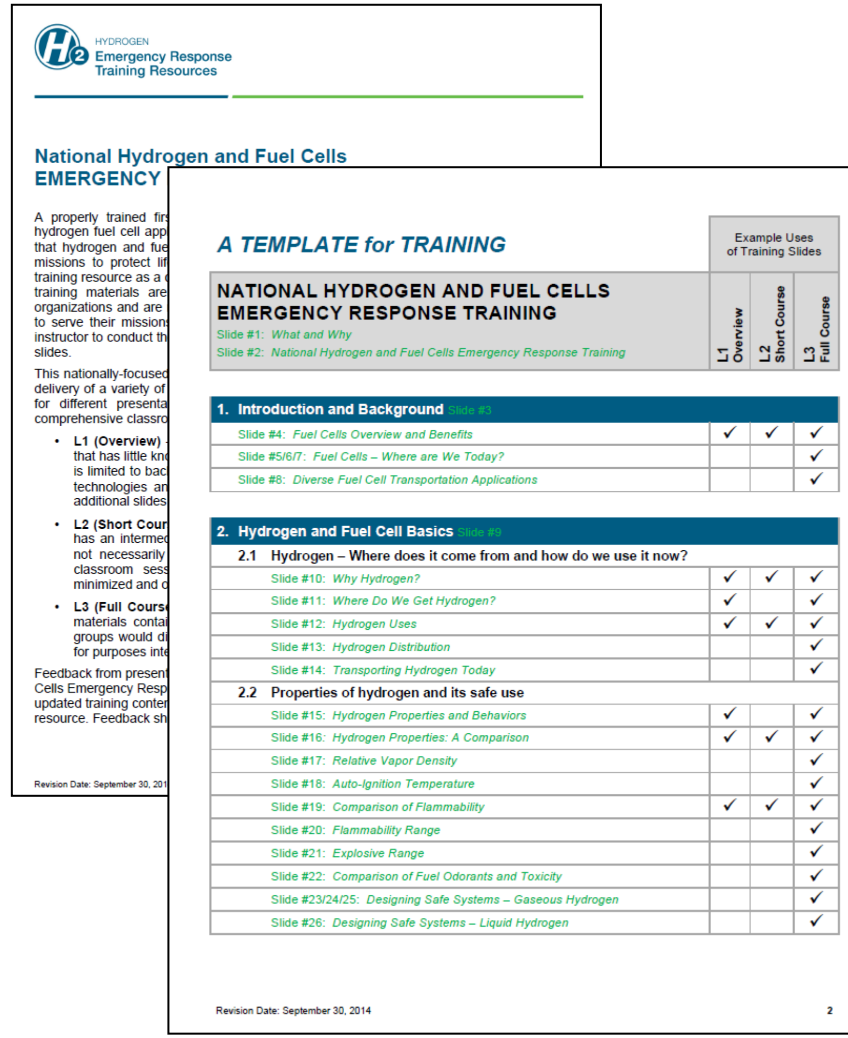


http://hydrogen.pnl.gov/FirstResponders/

- 100 from hydrogen and emergency response community conduct broad review (Summer 2006)
- On-line training launched January 27, 2007
- 200-300 unique visits monthly; >32,000 total.

National First Responder Training Resource





A TEMPLATE for TRAINING

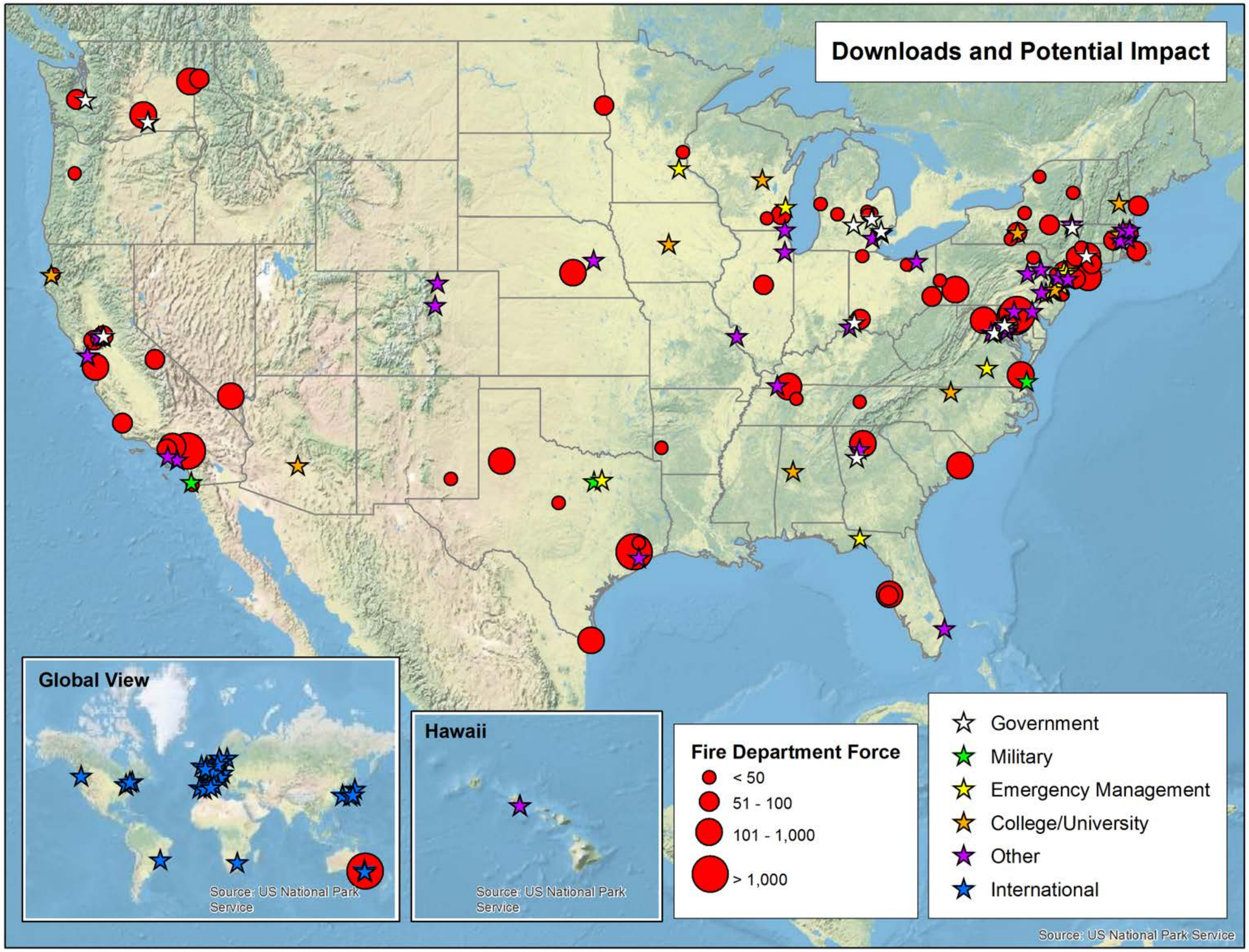
NATIONAL HYDROGEN AND FUEL CELLS EMERGENCY RESPONSE TRAINING
Slide #1: What and Why
Slide #2: National Hydrogen and Fuel Cells Emergency Response Training

Example Uses of Training Slides	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

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

Final Thoughts

- **The Safety Panel's Role**
  - The Safety Panel serves as an asset for contestant's "continuous and priority attention to safety."
  - Learnings from individual projects benefit the broader safety knowledge base for hydrogen and fuel cell technologies.

- **Lessons Learned**
  - H-Prize participants are asked to share lessons learned based on incidents, near-misses or other learnings during the conduct of this work that can be shared more broadly.

- **Questions/Comments**
  - Contestants may request assistance from or provide input to the safety review team/Hydrogen Safety Panel on any safety-related topic.

Thank You for Your Attention!

Contact Information:

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Questions and Answers