HYDROGEN
Safety Resources

Overview of the DOE Hydrogen Safety, Codes and Standards Program Part 2

Hydrogen and Fuel Cells - Emphasizing Safety to Enable Commercialization

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Why is Safety Important

- 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.***

Hydrogen Safety Resources

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

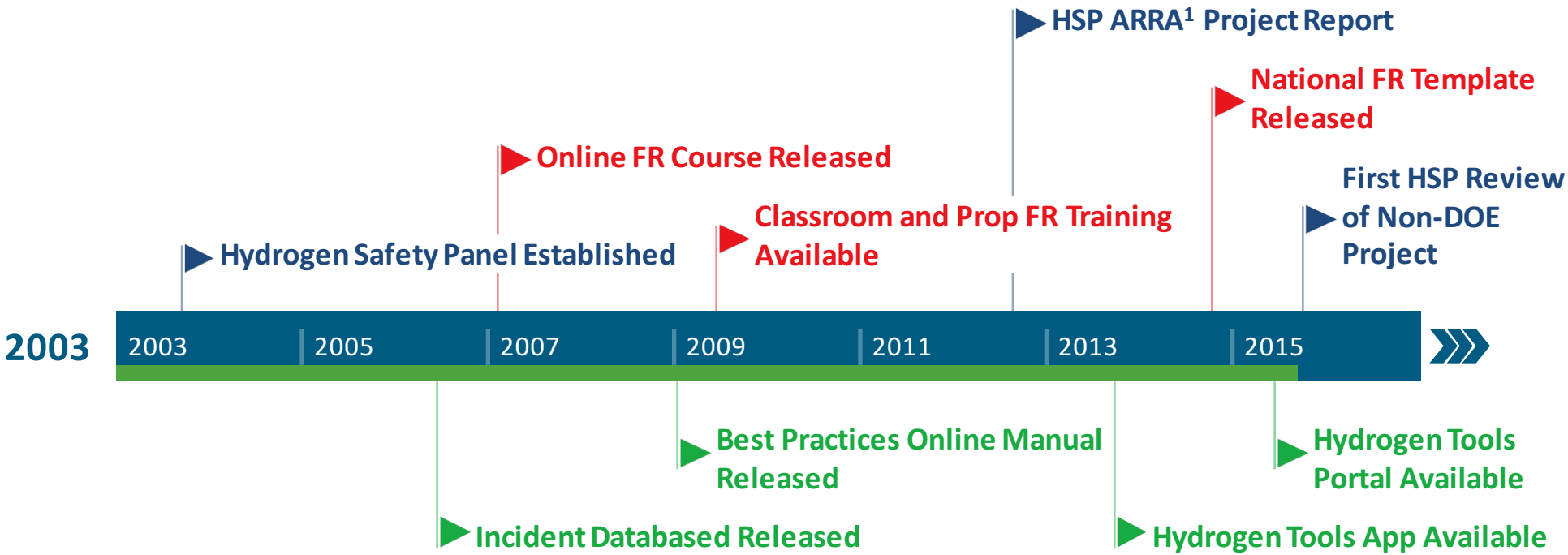
HYDROGEN Tools

- 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

Hydrogen Safety Program Timeline



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

[1]ARRA - American Recovery and Reinvestment Act of 2009

Hydrogen Safety Panel

Hydrogen Safety Panel Mission

The Hydrogen Safety Panel (HSP) 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 Contributes in Many Ways

The Hydrogen Safety Panel contributes to its objective by:

- providing safety planning guidance
- participating in safety reviews
- reviewing project designs and safety plans
- sharing safety knowledge and best practices
- 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 Membership

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

Formed in 2003 to support U.S. DOE Hydrogen and Fuel Cells Program, the Hydrogen Safety Panel:

- has a combined 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

Hydrogen Safety Panel Accomplishments

- Reviewed 272 projects (418 reviews) covering vehicle fueling stations, auxiliary power, backup power, combined heat and power, industrial truck fueling, portable power and R&D activities.
- Recent white papers with recommendations include:
  - Safety of Hydrogen Systems Installed in Outdoor Enclosures
  - Secondary Protection for 70MPa Fueling
- Supports development/updating of safety knowledge tools on the Hydrogen Tools Portal (h2tools.org): Lessons Learned and Best Safety Practices
- Conducted 21 Hydrogen Safety Panel meetings since 2003. Panel meetings currently engage a broad cross-section of the hydrogen and fuel cell community.

Example of Learnings from Demonstration Projects

Safety vulnerability analysis needs to comprehensively consider all potential incident scenarios introduced by hydrogen/fuel cell deployment and equipment operations and exposures.

- A thorough hazards analysis is critical for ensuring safety deployment of hydrogen and fuel cell technologies
- Many projects did not comprehensively address the potential safety vulnerabilities of all operations regardless of the fuel cell application
- Hazard analysis was the most frequently cited recommendation but also had the most "no actions"

Recommendations and actions from Panel safety review (development and deployment projects)

Category	Recommendations Implemented	In Progress	No Action	Total Recommendations
Safety Vulnerability/ Mitigation Analysis	23	4	13	40
System/Facility Design Modifications	11	5	1	17
Equipment/Hardware Installation and O&M	18	7	2	27
Safety Documentation	16	7	0	23
Training	3	3	0	6
Housekeeping	14	6	1	21
Emergency Response	9	3	3	15
Total	94	35	20	149

A New Review Approach for Demonstration Projects

Demonstration projects require a new review approach…

Timing for HSP involvement affects the benefit

When HSP review and site visits were provided after the equipment was operational:

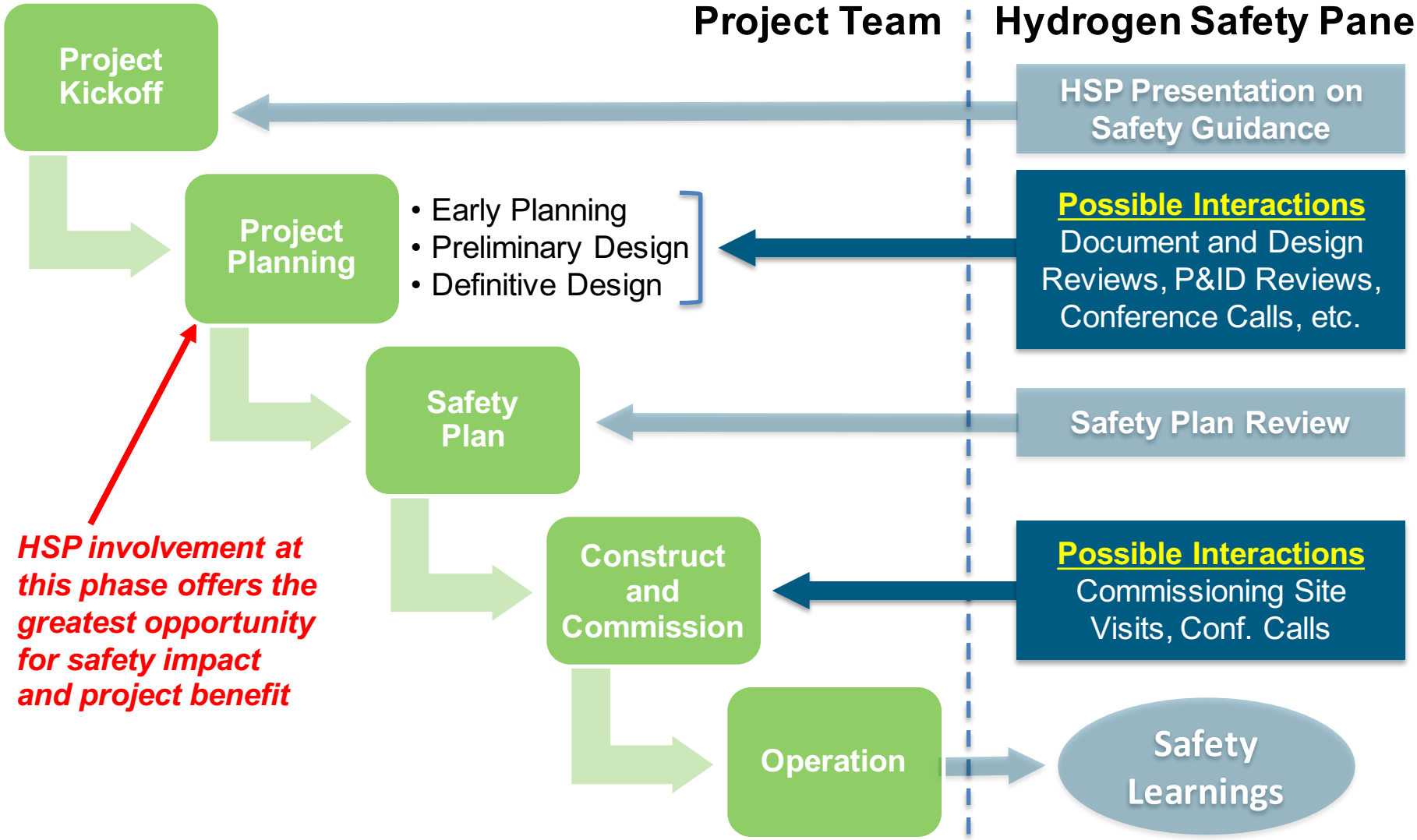
- It is difficult and costly to implement recommendations affecting equipment and configuration
- Projects resist input when it occurs after the completion of design or construction activities

Benefits of early HSP involvement realized in four Hawaii projects:

- Helped the projects understand and evaluate the safety issues and code requirements
- Significant design changes were made based on input from the HSP
- Project management and stakeholders had greater confidence in approving the final configuration

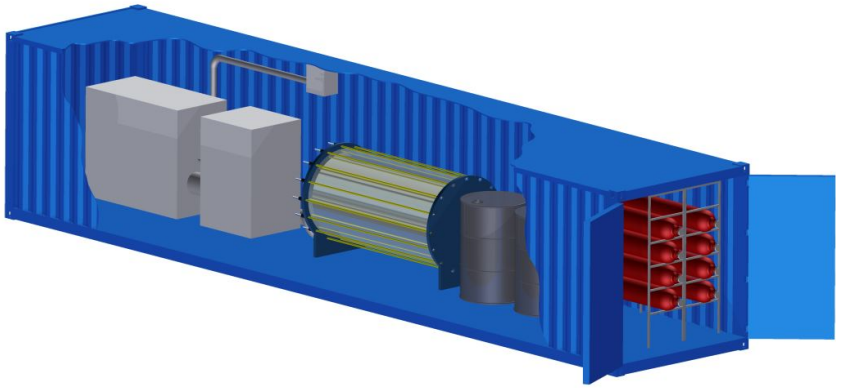
"I believe getting the HSP involved early in the project contributes to a much safer outcome by putting many sets of highly qualified eyes on the project. In fact it would have been useful to get the HSP involved even earlier in the design process - perhaps at the preliminary design review." **Mitch Ewan, HNEI**

Maximizing Impact of Panel Review Activities



HSP's Impact on Codes and Standards

- The Panel's white paper, "Safety of Hydrogen Systems Installed in Outdoor Enclosures," and risk evaluation of enclosures 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?

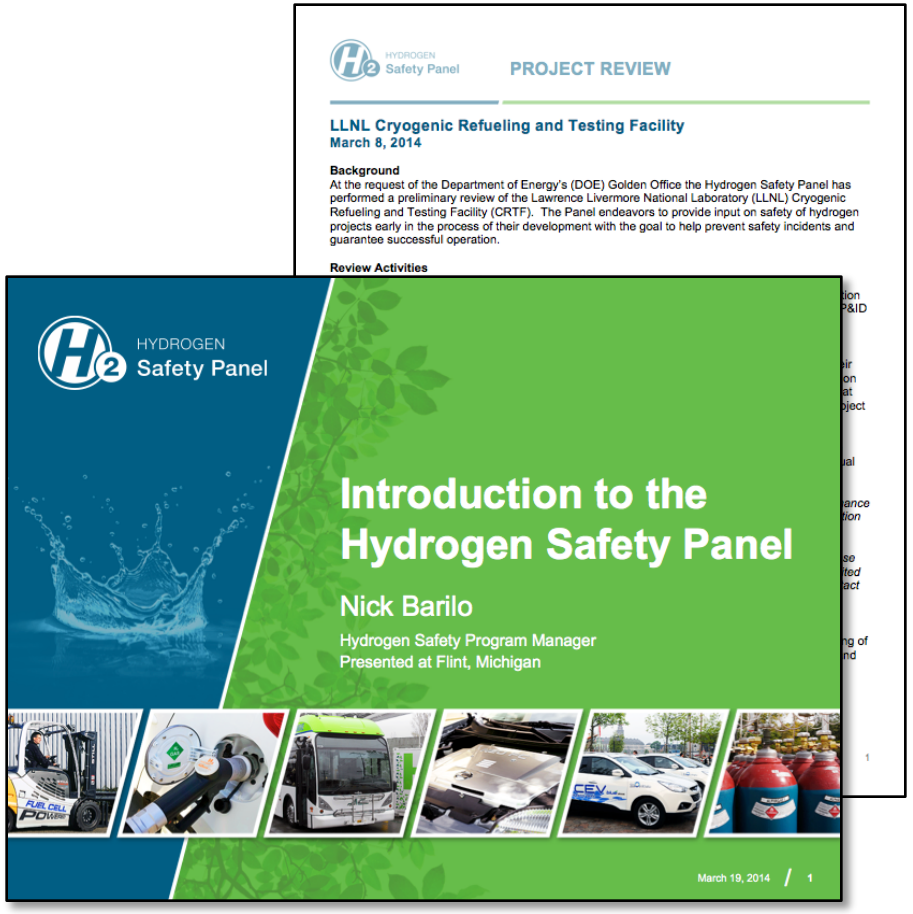
- The HSP is developing a guide to assist code officials, designers, owners, evaluators and others with the application of requirements pertinent to the design and/or installation of hydrogen equipment as regulated by the model codes

Highlighting the HSP as a Safety Resource

HYDROGEN
Safety Panel

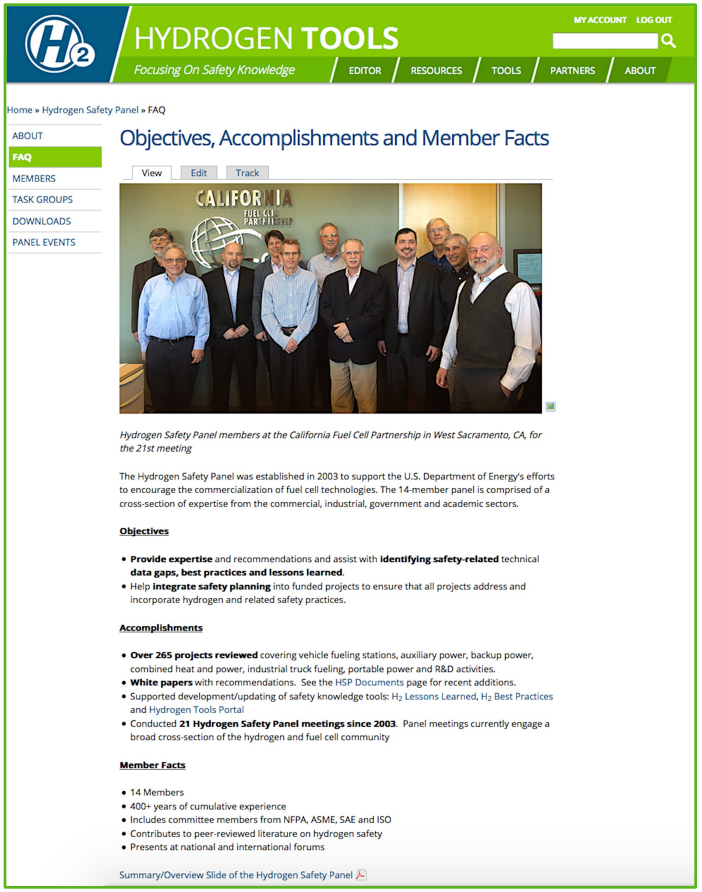
To enhance the Hydrogen Safety Panel's role as a safety resource for enabling the widespread acceptance of hydrogen, ***product branding*** *is now used:*

- 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 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

By contributing to:

- Design and document reviews
- Participation in and/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

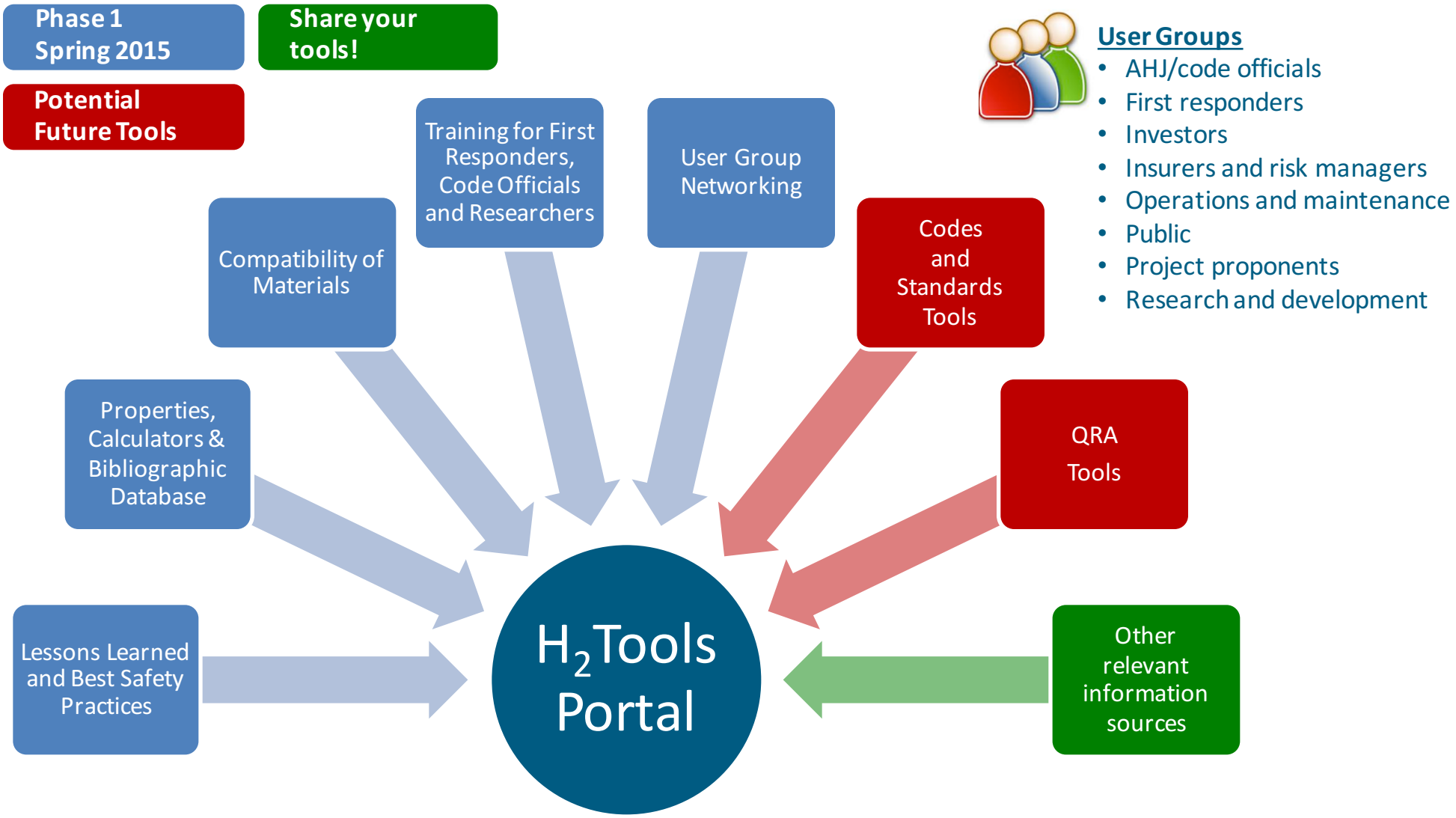
TRUSTED COMMUNITIES fostered through social networking around H_2 subject matter expertise

EXPANDABLE FORMAT built with frequently requested future feature sets in mind

http://h2tools.org

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

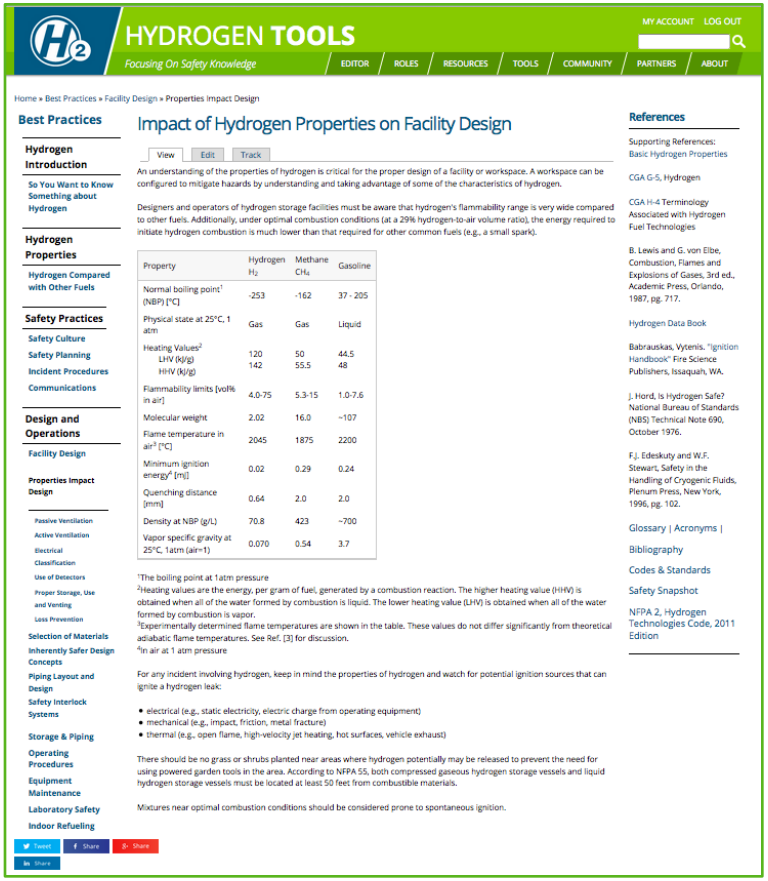
Consolidating Safety Information and Knowledge



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



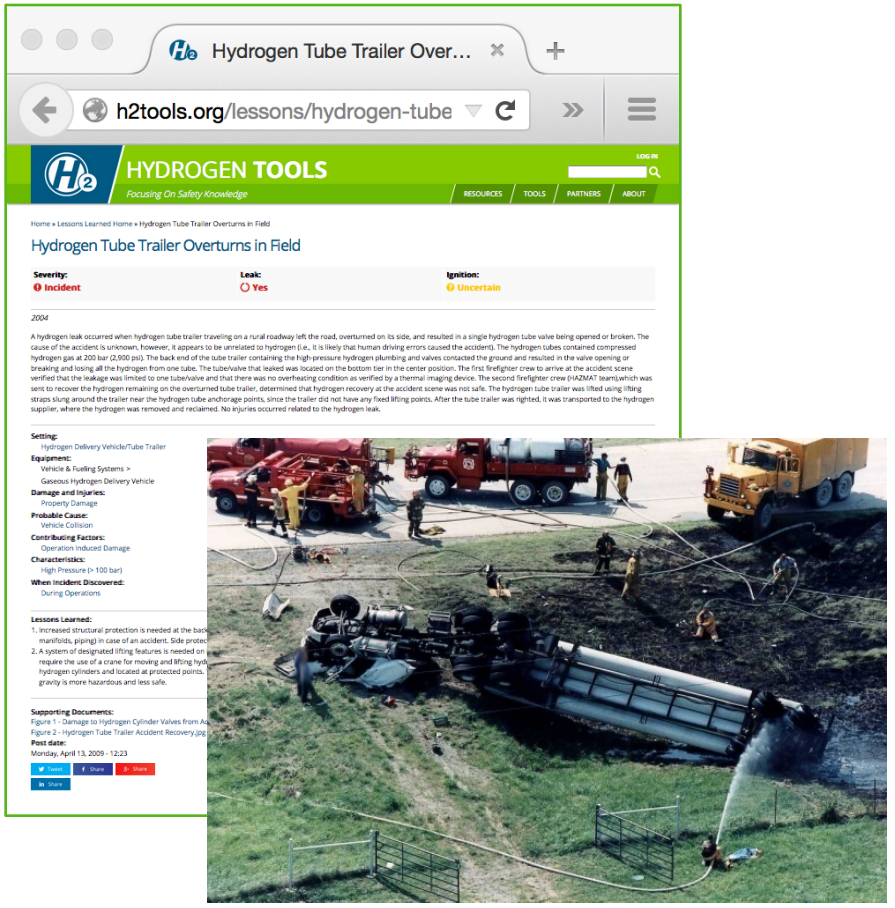
Safety events from "H2incidents.org" illustrate what can go wrong if best practices are not followed.

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



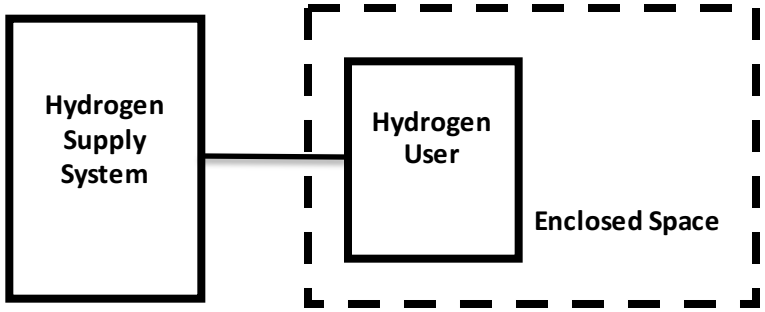
Tube Trailer Rollover

Hydrogen Safety Checklist
…Outdoor Storage, Indoor Dispensing and Use

Hydrogen safety, much like all flammable gas safety, relies on 5 key considerations:

1. Recognize hazards and define mitigation measures **[PLAN]**
2. Ensure system integrity **[KEEP H2 IN THE SYSTEM]**
3. Provide proper ventilation to prevent accumulation **[MANAGE DISCHARGES]**
4. Ensure that leaks are detected and isolated **[DETECT AND MITIGATE]**
5. Train personnel and ensure that hazards and mitigations are understood and that established work instructions are followed **[MANAGE OPERATIONS]**

http://h2tools.org/hsp/safety-resources



Hydrogen Safety Considerations Checklist

	Approach	Examples of Actions
Plan the Work	Recognize hazards and define mitigation measures	☐ Identify risks such as flammability, toxicity, asphyxiates, reactive materials, etc. ☐ Identify potential hazards from adjacent facilities and nearby activities ☐ Address common failures of components such as fitting leaks, valve failure positions (open, closed, or last), valves leakage (through seat or external), instrumentation drifts or failures, control hardware and software failures, and power outages. ☐ Consider uncommon failures such as a check valve that does not check, relief valve stuck open, block valve stuck open or closed, and piping or equipment rupture. ☐ Consider excess flow valves/chokes to size of hydrogen leaks ☐ Define countermeasures to protect people and property. ☐ Follow applicable codes and standards.
	Isolate hazards	☐ Store hydrogen outdoors as the preferred approach; store only small quantities indoors in well ventilated areas. ☐ Provide horizontal separation to prevent spreading hazards to/from other systems (especially safety systems that may be disabled), structures, and combustible materials. ☐ Avoid hazards caused be overhead trees, piping, power and control wiring, etc.
	Provide adequate access and lighting	Provide adequate access for activities including: ☐ Operation, including deliveries ☐ Maintenance ☐ Emergency exit and response
	Approach	**Examples of Actions**
Keep the Hydrogen in the System	Design systems to withstand worst-case conditions	☐ Determine maximum credible pressure considering abnormal operation, mistakes made by operators, etc., then design the system to contain or relieve the pressure. ☐ Contain: Design or select equipment, piping and instrumentation that are capable of maximum credible pressure using materials compatible with hydrogen service. ☐ Relieve: Provide relief devices that safely vent the hydrogen to prevent damaging overpressure conditions. ☐ Perform system pressure tests to verify integrity after initial construction, after maintenance, after bottle replacements, and before deliveries through transfer connections.
	Protect systems	☐ Design systems to safely contain maximum expected pressure or provide pressure relief devices to protect against burst. ☐ Mount vessels and bottled gas cylinders securely. ☐ Consider that systems must operate and be maintained in severe weather and may experience earthquakes and flood water exposures. ☐ De-mobilize vehicles and carts before delivery transfers or operation. ☐ Protect against vehicle or accidental impact and vandalism. ☐ Post warning signs.
	Size the storage appropriately for the service	☐ Avoid excess number of deliveries/change-outs if too small. ☐ Avoid unnecessary risk of a large release from an oversized system.

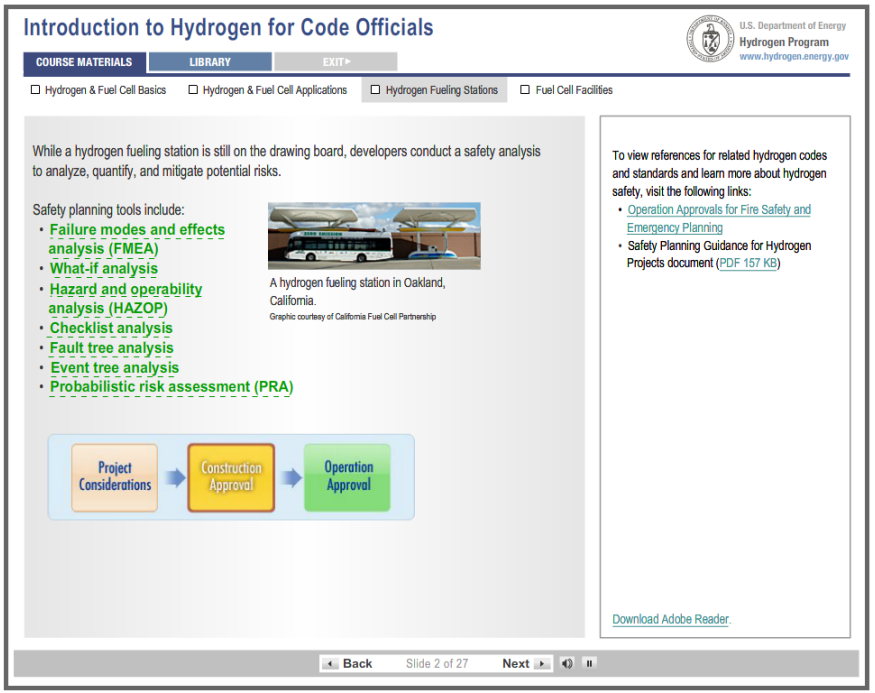
Introduction to Hydrogen for Code Officials

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 and maintained by:

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

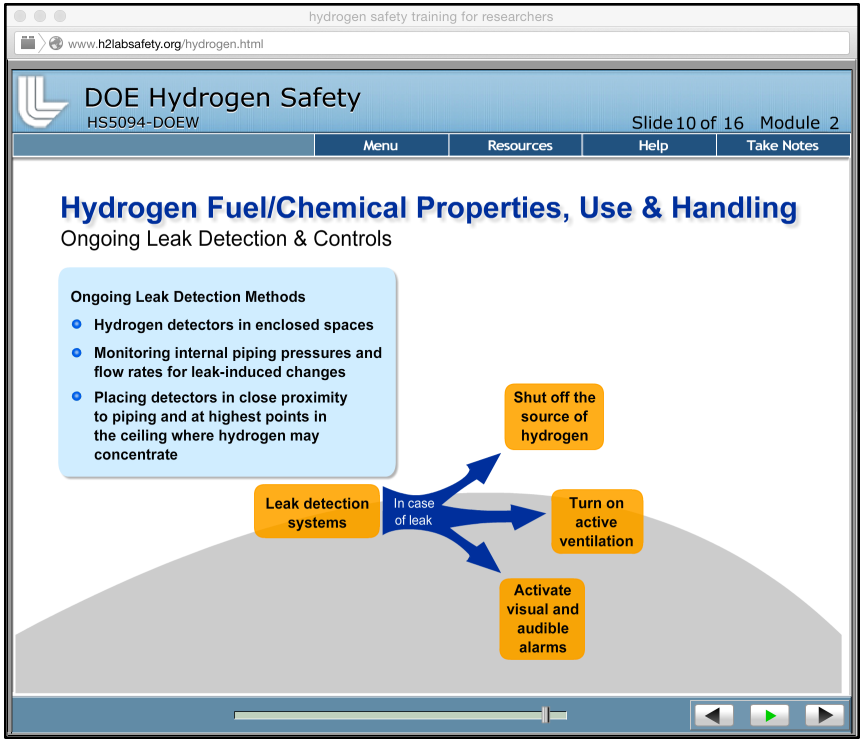


http://h2tools.org/content/training-materials

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
  - 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

Developed and maintained by: Lawrence Livermore National Laboratory



Sample Screenshot

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.

What Others Are Saying About These Safety Resources

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."

Thank You for Your Attention!

The authors also wish 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…

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for more Hydrogen Safety related news and the latest resources