HYDROGEN
Safety Panel

# Safety Planning for Hydrogen and Fuel Cell Projects


Nick Barilo

Hydrogen Safety Manager, Pacific Northwest National Laboratory


California GFO-19-602 Webinar, January 15, 2020


PNNL-SA-150422

# Webinar Outline

## Part 1 Safety Planning

- Introduction to PNNL and GFO-19-602 Safety Activities
- Background on the Hydrogen Safety Panel
- Safety Planning
- Learnings from California HSP Reviews and Activities
- Hydrogen Safety Resources
- Center for Hydrogen Safety
- Q&A

## Part 2 Hydrogen Safety Considerations

- Properties of Hydrogen
- Primary Codes and Standards
- Fundamental Safety Considerations
- Q&A

# Hydrogen Safety Resources

## Hydrogen Safety Panel (HSP)

- Identify Safety-Related Technical Data Gaps
- Review Safety Plans and Project Designs
- Perform Safety Evaluation Site Visits

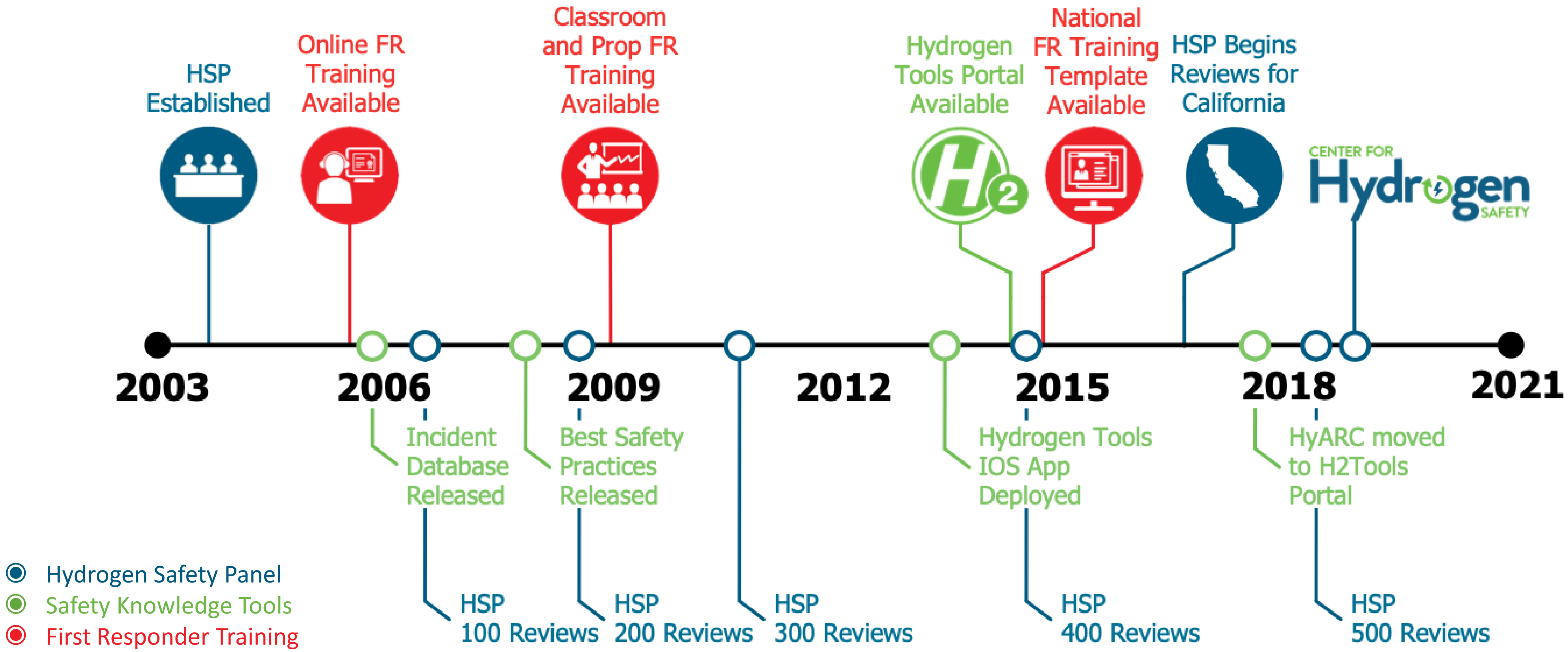
## Hydrogen Tools *Web Portal* (*http://h2tools.org*)

- Hydrogen Lessons Learned and Best Safety Practices
- Hydrogen Codes and Standards, Training and HyARC Tools

## Emergency Response Training Resources

- Online Awareness Training
- Operations-Level Classroom/Hands-On Training for First Responders (FR)
- National Hydrogen and Fuel Cell Emergency Response Training Resource

# Timeline of Hydrogen Safety Resources



# Safety – The Awardees of CEC GFO-19-602 Are Required to…

- **A telephone or web-based meeting with a representative of the PNNL HSP to establish a common understanding of the Hydrogen Safety Plan and station design review process**
- Submit a preliminary and final hydrogen safety plan **(after award)**
  - The awardee will prepare a safety plan after award and provide it to the HSP for review
  - The HSP will evaluate the safety plan and provide feedback to the CEC and awardee
  - **The awardee incorporates comments into a final safety plan**
- **Include an HSP review of the project's early design**
  - **Prior to plan submission to the authority having jurisdiction**
  - **Most beneficial at approximately the 30% design phase**
  - **Can include design reviews, review of hazard assessments, etc.**
- Include the HSP in safety related incident fact-finding
- Participate in three annual safety evaluations with the HSP
  - Just before or shortly after the station becomes operational
  - One evaluation may be in person

* Bolded items represent changes from safety activities in GFO-15-605

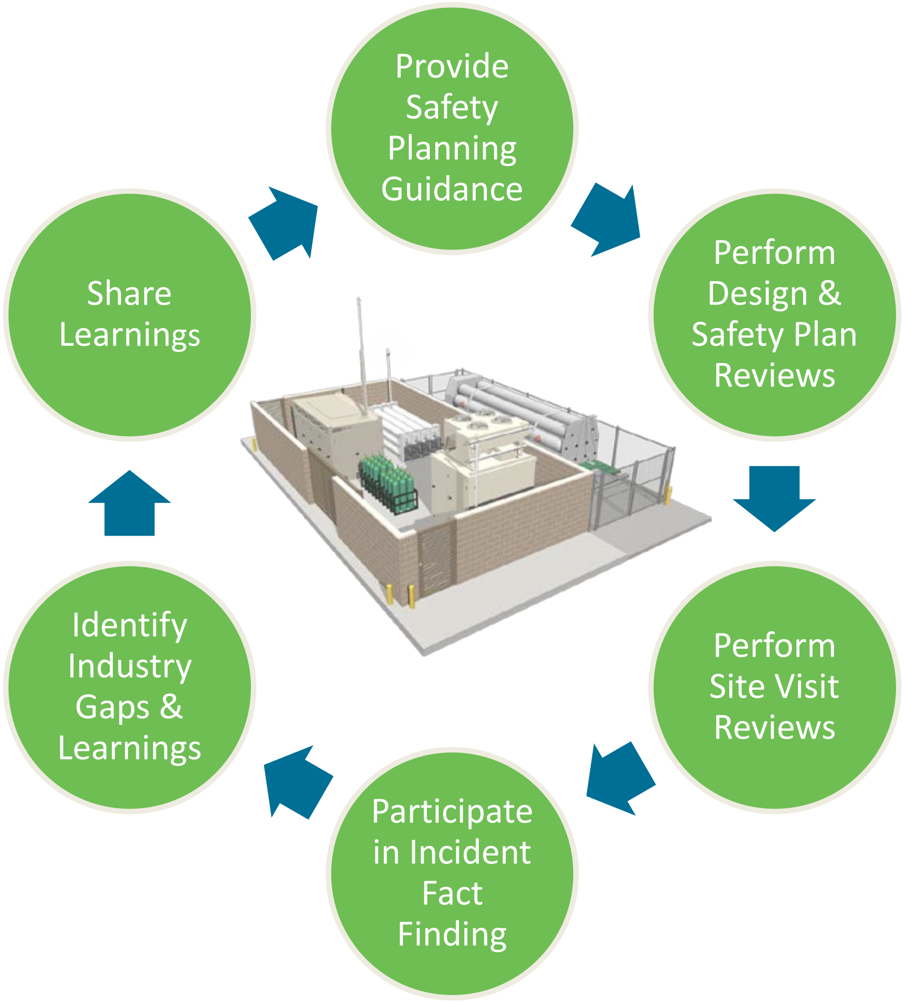
# Background on the Hydrogen Safety Panel

# Hydrogen Safety Panel: Objective and Activities

*The purpose of the HSP is to share the benefits of extensive experience by providing suggestions and recommendations pertaining to the safe handling and use of hydrogen.*

**Objective:** Enable the safe and timely transition to hydrogen technologies by:

- Participating in hydrogen projects to ensure safety is adequately considered
- Providing expertise and recommendations to stakeholders and assisting with identifying safety-related gaps, best practices and lessons learned



# Introducing the Hydrogen Safety Panel

## *Experienced, Independent, Trusted Expertise*

### *The HSP promotes safe operation, handling, and use of hydrogen*

- Formed in 2003
- 17 members with **500+ years** combined experience
- **Hydrogen safety reviews** – hydrogen fueling, auxiliary power, backup power, CHP, portable power, and lab R&D
- White papers, reports, and guides
- Provides support on the application of hydrogen codes and standards
- **$H_2$ safety knowledge shared through the $H_2$ Tools Portal** [(h2tools.org)](h2tools.org)

*Some of the fire officials and hydrogen experts that comprise the Hydrogen Safety Panel (25th meeting, 2019, New Orleans, LA)*

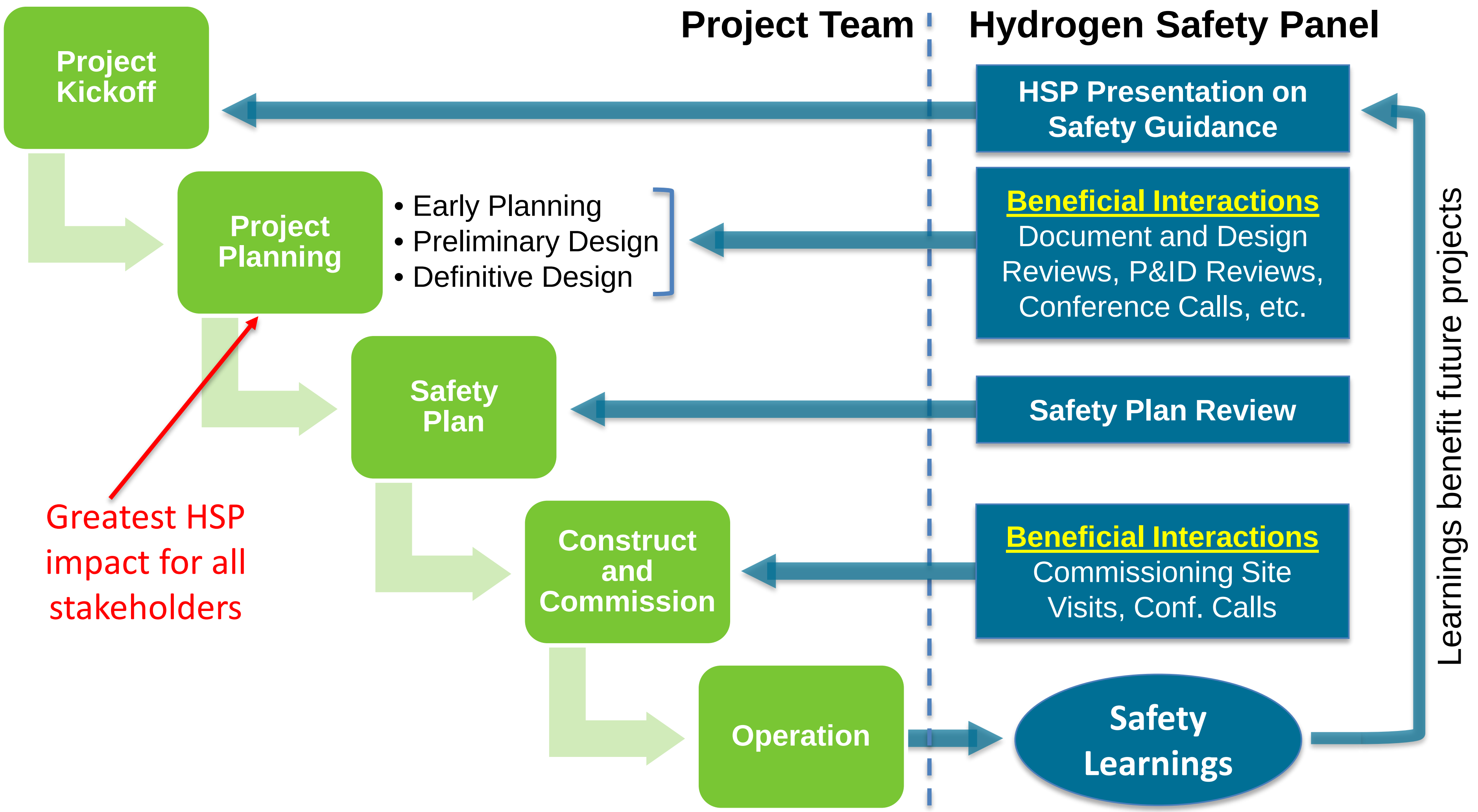
# HSP Membership

The HSP is a multidisciplinary team of engineers, code officials, safety professionals, equipment providers, and testing and certification experts. The Panel provides guidance for hydrogen projects and facilities, including design and process safety reviews, support/review of risk analyses, onsite safety presentations, and training.

| Name | Affiliation |
|---|---|
| Nick Barilo, Manager | Pacific Northwest National Laboratory |
| Richard Kallman, Chair | City of Santa Fe Springs Fire Dept. (retired) |
| Harold Beeson* | WHA International, Inc. |
| Ken Boyce | UL |
| David Farese | Air Products and Chemicals |
| Donald Frikken | Becht Engineering |
| Livio Gambone | Nikola Motors |
| Aaron Harris | Air Liquide |
| Chris LaFleur | Sandia National Laboratories |
| Miguel Maes | NASA-JSC White Sands Test Facility |
| Larry Moulthrop | Proton OnSite (retired) |
| Spencer Quong* | Toyota Motor Corporation |
| Gary Stottler* | GM (retired) |
| Tom Witte | Witte Engineered Gases |
| Robert Zalosh | Firexplo |

* New members 2019

# Optimal HSP Project Interaction



# Support for the Safe Implementation of $H_2$ Technologies

**Activities that can Benefit from HSP Support**

Early Concept Support

### Pre-Project

- Safety planning webinars
- Pre-project outreach to stakeholders
- *$H_2$ Safety training and orientation for code officials
- Project team safety planning consultations

### Early Design

- Safety plans reviews
- *Review project and facility early designs
- Participate in risk analyses development
- Review risk analyses
- *Address AHJ safety questions

### Early Operation

- Evaluate safety features of completed facilities
- Onsite safety evaluations
- Provide first responder $H_2$ safety training

### Program Support

- Identify safety gaps
- Develop safety guides
- *Expert support for incident fact-finding and investigations
- Bolster stakeholder and public confidence

Successful Project Implementation

* Support for AHJ and code officials can bridge the gap for inexperienced staff, facilitate faster approvals, support a greater confidence in project safety and provide more technically justified safety features

# Impact of the HSP

- Serves as a non-regulatory, objective, and neutral resource
- Sees the "big picture"
  - Shares learnings
  - Identifies gaps
- Can help reduce costs
  - Over-engineering resulting in unnecessary features
  - Delayed approvals
  - Missed safety considerations/features
- A group with diverse experience can:
  - Respond with a balanced solution to questions, problems, and issues
  - Aid in avoiding repeating costly mistakes among disparate project proponents
  - Help project proponents avoid industry-impacting incidents
  - **Help establish stakeholder and public confidence**

Since 2003

**517**
Reviews

**352**
Projects

**>100**
Presentations

**12**
Guides

# Safety Planning

# The Safety Challenge

- Safety issues must be addressed for successful hydrogen technology acceptance and deployment
- Safety issues can be a “deal breaker”
- Hydrogen technology stakeholders may not be able to identify and effectively address all safety issues
- Stakeholders benefit from an independent and experienced hydrogen safety review (ISR) resource involved in early design and safety planning activities
- Hydrogen Safety Panel feedback and learnings help individual projects and the entire industry remove barriers and ease future deployments

# 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
- minimize the risks associated with a project/facility

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.***

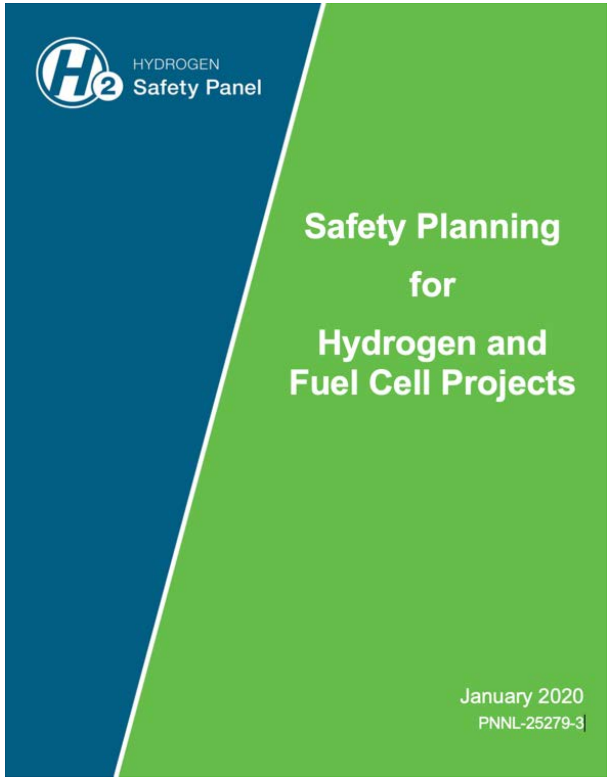
# Guidance for Effective Safety Plans

**The project safety planning process is meant to:**

- help identify and avoid potential hydrogen-related incidents
- generate an effective 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 operational work being conducted with emphasis on the aspects involving hydrogen and hazardous materials handling




*Safety Planning for Hydrogen and Fuel Cell Projects* is available download at
https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects.pdf

# Safety Plan Basics and Template

The following critical safety plan elements help ensure that safety is integrated into projects and demonstrations:

- Involve all parties and stakeholders
- Early involvement of safety expertise
- Compliance with codes and standards
- A knowledgeable emergency response team

**UTILIZE THE TEMPLATE!**

*The Safety Plan Template is included in the document "Safety Planning for Hydrogen and Fuel Cell Projects" and intended to help project teams verify that their safety plan addresses all the necessary elements. However, template elements should not be considered an exhaustive list of safety considerations for all projects.*

**Safety Plan Template**

| Element | The Safety Plan Should Describe |
|---|---|
| **Description of Work** | • Nature of the work being performed, including a description of the facility, pertinent processes or systems, partner organizations, and the anticipated quantity of stored/used hydrogen |
| **Organizational Policies and Procedures** | • Application of safety-related policies and procedures to the work being performed<br>• Project leadership responsible for safety approvals |
| **Hydrogen and Fuel Cell Experience** | • How previous organizational experience with hydrogen, fuel cell and related work is applied to this project |
| **Identification of Safety Vulnerabilities (ISV)** | • The ISV methodology applied to this project, such as FMEA, What If, HAZOP, Checklist, Fault Tree, Event Tree, Probabilistic Risk Assessment, or other method<br>• Who leads and stewards the use of the ISV methodology<br>• Significant accident scenarios<br>• Significant vulnerabilities associated with the scenarios<br>• Safety critical equipment<br>• Storage and handling of hazardous materials and related topics<br>  ○ ignition sources, explosion hazards<br>  ○ materials interactions<br>  ○ possible leakage and accumulation<br>  ○ detection<br>• Hydrogen handling systems<br>  ○ supply, storage, and distribution systems<br>  ○ volumes, pressures, estimated use rates<br>• Additional Documentation provided (see section below) |
| **Risk Reduction Plan** | • Prevention and mitigation measures for significant vulnerabilities |
| **Codes and Standards** | • Governing codes, standards, and regulations applicable to the project<br>• Alternate methods including their technical basis |
| **Procedures** | • Procedures applicable for the location and performance of the work<br>• Operating steps that need to be written for the particular project: critical variables, their acceptable ranges, and responses to deviations from them |
| Safety Plan Approval | • Safety plan review and approval process |

# 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.*

NFPA

NFPA 2 requires a hazard analysis to be conducted on every hydrogen fueling system installation by a qualified engineer(s) with proven expertise in hydrogen fueling systems, installations, and hazard analysis techniques.

# 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

# Common ISV Methods

Common methods employed by those involved in systems safety today include, but are not limited to:

- Hazard and operability studies (HAZOPs)
- Failure modes effects and criticality analysis (FMECA)
- Preliminary hazards analysis (PHA)
- Fault tree analysis (FTA)
- Event tree analysis (ETA)

Standard designs that have been analyzed by recognized methodology need not be studied each and every time such an installation occurs. Rather, site-specific elements that are unique to the installation should be reviewed in concert with the analysis performed on the standard system to ensure that the standard design has not been altered in a way that would negatively affect the hazard analysis. (NFPA 2)

The Hydrogen Safety Panel would also like to see two questions answered in the Safety Plan:

- ***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?***

*Awardees desiring to use previous project ISVs should provide information from those documents to the HSP for this submission along with site specific considerations. Additionally, whenever a change to a standard design occurs, the ISV should be revisited.*

# Codes and Standards

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

Codes and standards describe requirements that are developed with safety as the primary concern. Relevant codes and standards include:

- NFPA 2, Hydrogen Technologies Code, 2016 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)
- International Fire and Building Codes



NOTE: Where strict code compliance for a specific design, installation, and/or operation cannot be achieved, a sound technical basis for the proposed alternative safety approach should be formally agreed upon by all the relevant parties, including stakeholders and building and fire code officials.

# Additional Important Safety Considerations

- **Management of Change (MOC)** - The safety plan should describe the method that will be used to review proposed changes to materials, technology, equipment, procedures, personnel and facility operation for their effect on safety vulnerabilities. Also, the MOC procedure should also identify the project team members that will approve changes.

- **Compatibility of Materials** - Materials of construction, including materials used in piping, valves and seals, must be carefully selected to account for their deterioration when exposed to hydrogen at the intended operating conditions. How has the project validated the performance of materials that may be exposed to hydrogen?

# 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?
- What third-party reviews or certifications of any components, sub-systems, systems or products been considered and performed? What did this cover and what didn't it cover?

# Additional Documentation

To give the reviewers the best opportunity to judge the quality of the safety plan, the submittal should include, but not be limited to, the following additional documentation, as applicable:

| Minimum Required | Desired if Available |
|---|---|
| Flow diagram showing equipment | Flow diagram showing components including equipment, and safety related devices such as block valves, instruments and relief devices. |
| Preliminary functional description for equipment shown in the flow diagram | Design or functional description for each component in the diagram |
| Preliminary layout | Layout of the system including as applicable:<br>• Site plan showing distances to property lines and other separation distances<br>• Vehicle access to/from the equipment (including delivery vehicle)<br>• Hydrogen vent system considerations, including the number of vent stacks, and pressure/flow design of each stack<br>• Electrical classification and ignition source control<br>• Ventilation requirements for any enclosed spaces |
| Same as Desired if Available | Critical safety and shutdown table identifying shutdown events described in the ISV or risk reduction plan, including automatic and manual shutdowns, loss of electricity, and fail-safe features. |

# Working with First Responders

**Preplanning**

- Project teams 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.

**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.

# Did I mention Use the Template?!

The safety guidance document includes a template to help the project team verify that their safety plan addresses the important elements.

**Please use the template!**

**Safety Plan Template**

| Element | The Safety Plan Should Describe |
|---|---|
| **Description of Work** | • Nature of the work being performed, including a description of the facility, pertinent processes or systems, partner organizations, and the anticipated quantity of stored/used hydrogen |
| **Organizational Policies and Procedures** | • Application of safety-related policies and procedures to the work being performed<br>• Project leadership responsible for safety approvals |
| **Hydrogen and Fuel Cell Experience** | • How previous organizational experience with hydrogen, fuel cell and related work is applied to this project |
| **Identification of Safety Vulnerabilities (ISV)** | • The ISV methodology applied to this project, such as FMEA, What If, HAZOP, Checklist, Fault Tree, Event Tree, Probabilistic Risk Assessment, or other method<br>• Who leads and stewards the use of the ISV methodology<br>• Significant accident scenarios<br>• Significant vulnerabilities associated with the scenarios<br>• Safety critical equipment<br>• Storage and handling of hazardous materials and related topics<br>○ ignition sources, explosion hazards<br>○ materials interactions<br>○ possible leakage and accumulation<br>○ detection<br>• Hydrogen handling systems<br>○ supply, storage, and distribution systems<br>○ volumes, pressures, estimated use rates<br>• Additional Documentation provided (see section below) |
| **Risk Reduction Plan** | • Prevention and mitigation measures for significant vulnerabilities |
| **Codes and Standards** | • Governing codes, standards, and regulations applicable to the project<br>• Alternate methods including their technical basis |
| **Procedures** | • Procedures applicable for the location and performance of the work<br>• Operating steps that need to be written for the particular project: critical variables, their acceptable ranges, and responses to deviations from them |

# Learnings from California HSP Reviews and Activities

# HSP Activities for CA H2 Fueling Stations

- California hydrogen fueling station applicant safety plan reviews (GFO-15-605)
- March 2017 HSP visit to 7 California locations

South San Francisco


Woodside and Long Beach

# 2015 GFO for Light-duty $H_2$ Fueling Stations

Contracted by the California Energy Commission (CEC) to support the construction of new hydrogen fueling stations through the following services

- Provided guidance for preparing safety plans
- Participated in pre-award safety consultation for applicants
- Reviewed safety plans submitted by 12 applicants to California's GFO-15-605
- Provided comments to the CEC in support of award decisions
- Additional support to be provided until funded stations have been complete for three years

# Safety Plan Reviews of GFO-15-605 Applications

- Safety plans for 12 applications were reviewed
- Up to 35 locations per application
- Safety plans, narrative documents and site information reviewed
- Review report provided for each applicant (can be viewed at https://h2tools.org/hsp/reviews - screenshot on right)
- The reviews and process were evaluated for potential learnings
- The safety planning guidance document will be updated to benefit future station projects

## Safety Resources and Reviews

### SAFETY PLANNING RESOURCES

- Safety Planning for Hydrogen and Fuel Cell Projects - Latest Version
  - Safety Planning for Hydrogen and Fuel Cell Projects - March 2016
- Safety-Planning-for-the-2014-2016-H-Prize-Competition.pdf
- Safety Planning Guidance for Hydrogen and Fuel Cell Projects - April 2010 (DOE projects)
- Hydrogen Safety Checklist

### SAFETY PANEL REVIEWS

| Title | Activity Type | Project Number | Date | Links |
|---|---|---|---|---|
| Everfuel Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| A3L/Next Hydrogen Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| Shell Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| ITM Power/Greenlight Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| ITM Power/Linde Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| Jensen Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| Hydrogen-XT Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| Air Liquide Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| FirstElement Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| HTEC Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| Air Products Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |
| StratosFuel Hydrogen Fueling Station | Safety Plan Review | GFO-15-605 | December 2016 | Download |

# Technical Learnings from GFO-15-605 Reviews

- It is unclear how **equipment siting** from property lines will be made to conform with NFPA 2 requirements
- It is unclear how **courtyards** provided with four walls will be made to conform with NFPA 2 requirements
- **Certification** of unlisted equipment needs to be verified against all applicable standards and requirements
- It is unclear how the performance and reliability of **control equipment** for safety systems is validated

# Process Learnings from GFO-15-605 Reviews

- Detailed project-specific information is needed to perform a thorough evaluation
  - Timing of the review (application stage) may have affected the availability of important information
  - Utilizing the HSP for review at a later stage, perhaps early in the definitive design process, could result in a more impactful review and confidence in the project team's safety approach
- **The project safety plan should cover all project partners and project phases (design, commissioning, operation and maintenance)**

HSP learnings here are reflected in the new approach for GFO-19-602

# March 2017 California Stakeholder Meetings

- Meetings were held at 7 California locations to discuss fueling station deployments
- Attendance included:
  - hydrogen fueling station builders
  - code officials
  - other state officials and stakeholders
- Goal – discuss safety issues and lessons learned from recent station deployments
- Resulted in over 100 pages of notes which were subsequently reviewed, categorized and binned
- Results were assembled into learnings and further reviewed by the entire HSP

# Feedback and Learnings from CA Meetings

Items were organized into topical areas

- Separation distances
- Certification
- Emergency shutdown systems
- Permitting
- Training
- NFPA 2 considerations
- Public
- Miscellaneous

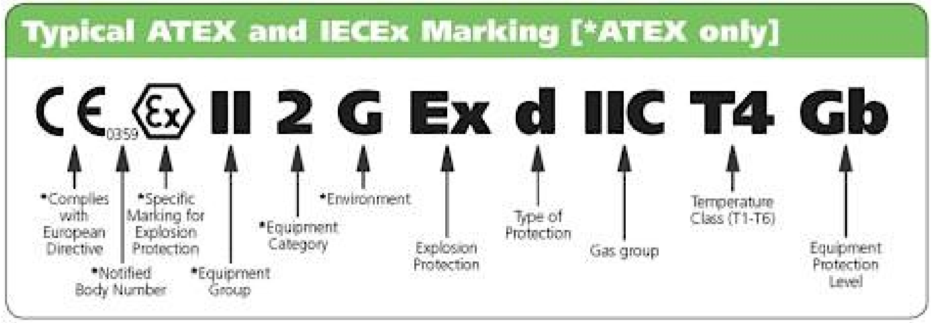
# Separation Distances

- Comparisons between hydrogen and other fuels need to be correct, especially when considering separation distances

- Some code officials (incorrectly) felt strongly that installing hydrogen tanks underground would fully address separation distances issues, including the future need for liquid hydrogen

# Certification

- The lack of listed hydrogen equipment may result in an increase in facility costs (third-party certification is needed for each new station)
- Hydrogen equipment having non-US listing/certifications may not be accepted by AHJs in the US




Typical CE ATEX Label

# Emergency Shutdown Systems (ESD)

- Projects should utilize control equipment for safety functions that has a high reliability and performance capabilities consistent with its intended use
- Station operators experience with false alarms of the flame detectors suggest that more reliable triple-IR detectors may be a better option
- There were variations between sites on how system alarms and shutdown functions operated, which could cause confusion for first responders

# Permitting

- Required prescriptive safety features should not be solely credited for establishing equivalent safety of unmet requirements
- Code officials may not be aware of the sources of independent information available to help them with their review
- Most code officials on their first hydrogen project did not reach out to their more experienced counterparts in other jurisdictions
  - Code officials that reviewed station designs were overwhelmingly supportive of allowing others to reach out to them for advice and support
- Permit applications should be comprised of succinct and accurate information to facilitate the code official's review

# Training

- There appears to be a lack of first responder (FR) training for new station locations
- Expand FR training beyond jurisdictions having a station
- Training for first responders and code officials should be in "fire-related language”
- Code official training before the design review stage may be beneficial
- Attendees will receive maximum value if they are involved in or affected by a hydrogen project

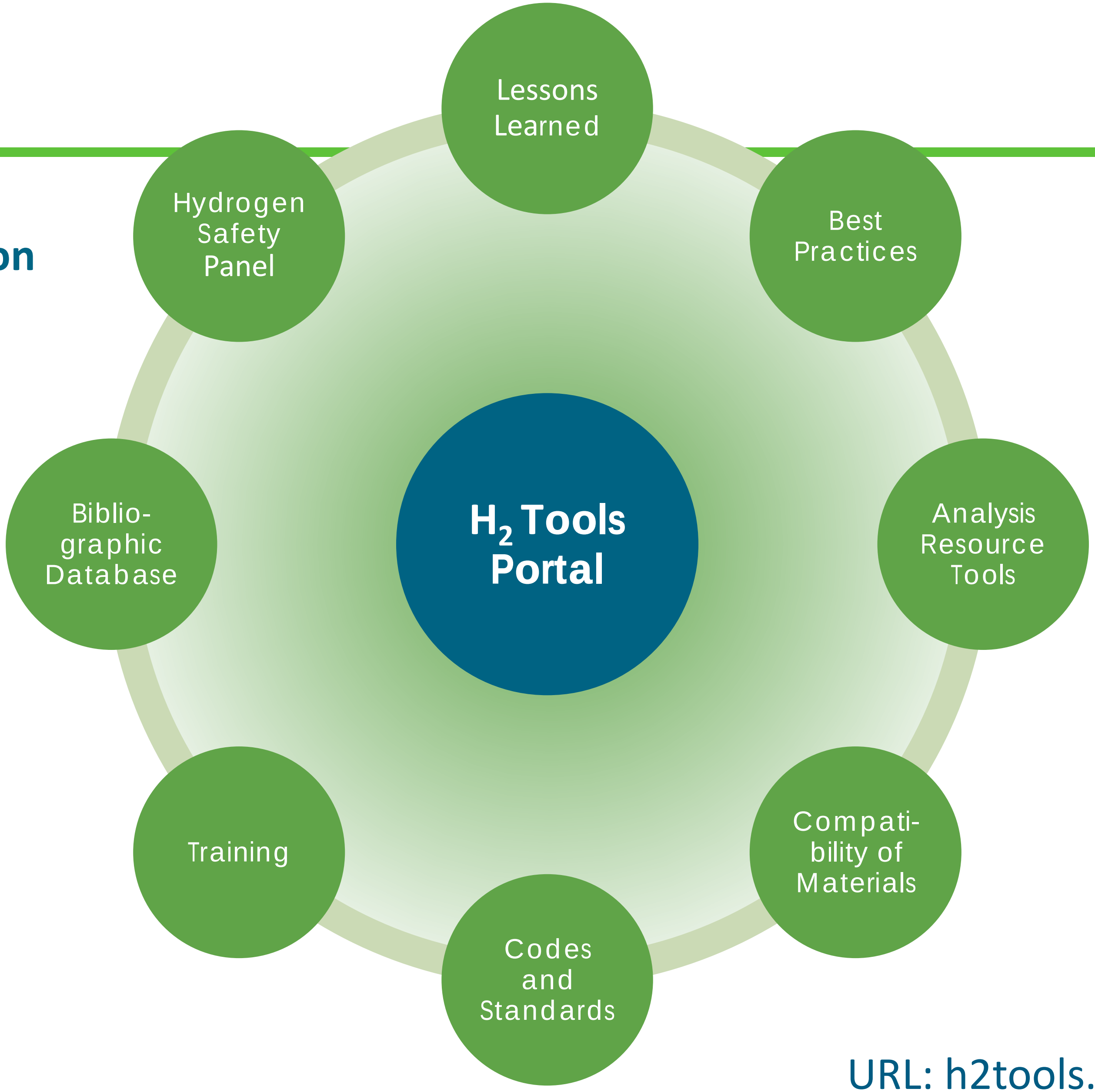
# Miscellaneous Observations and Learnings

- The sequence of operations (functions and shutdowns) for normal and off-normal events wasn't communicated well between station providers and operators/owners/first responders
- Safety information should be made available at an obvious location at the facility to assist in emergency response and for training first responders
- Code officials highlighted the benefits of NFPA 2 annex material

# Hydrogen Safety Resources

## Significant hydrogen safety resources in one location

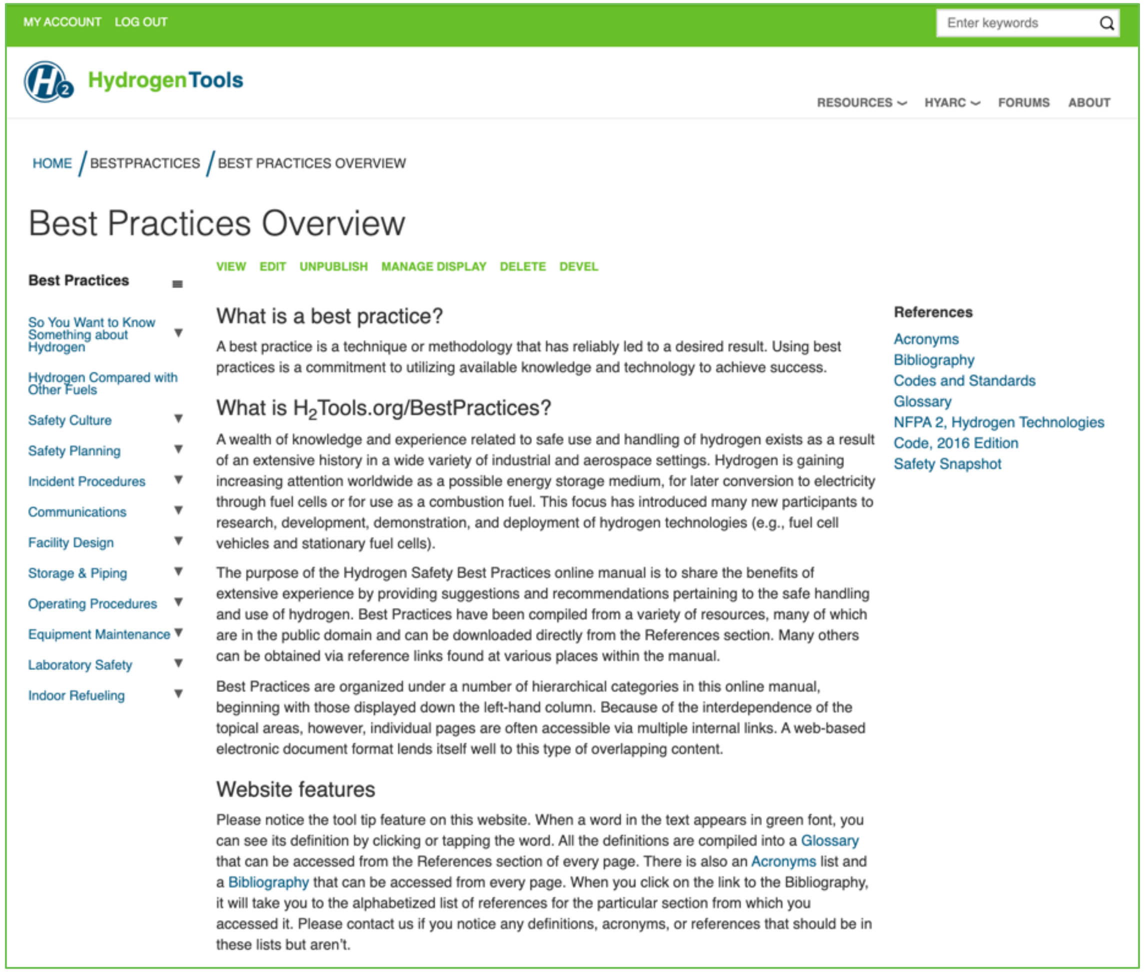
- Supports implementation of the practices and procedures that will ensure safety in the handling and use of hydrogen in a variety of fuel cell applications.
- Brings together and enhances the utility of a variety of tools and web-based content on safety of hydrogen and fuel cell technologies
- Informs those tasked with designing, approving or using systems and facilities, as well as those responding to incidents.




URL: h2tools.org

# 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

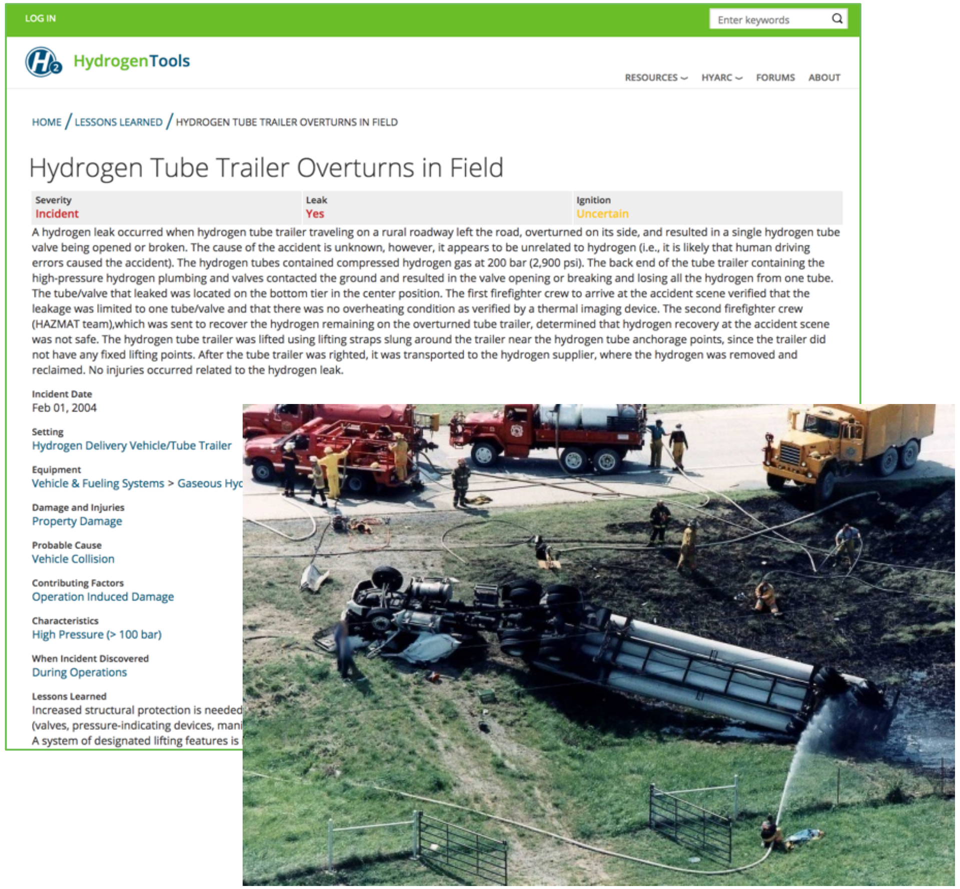



URL: https://h2tools.org/bestpractices/best-practices-overview

# **H2tools.org/lessons…** Capturing the Event, Focusing on Lessons Learned

**Each safety event record contains:**

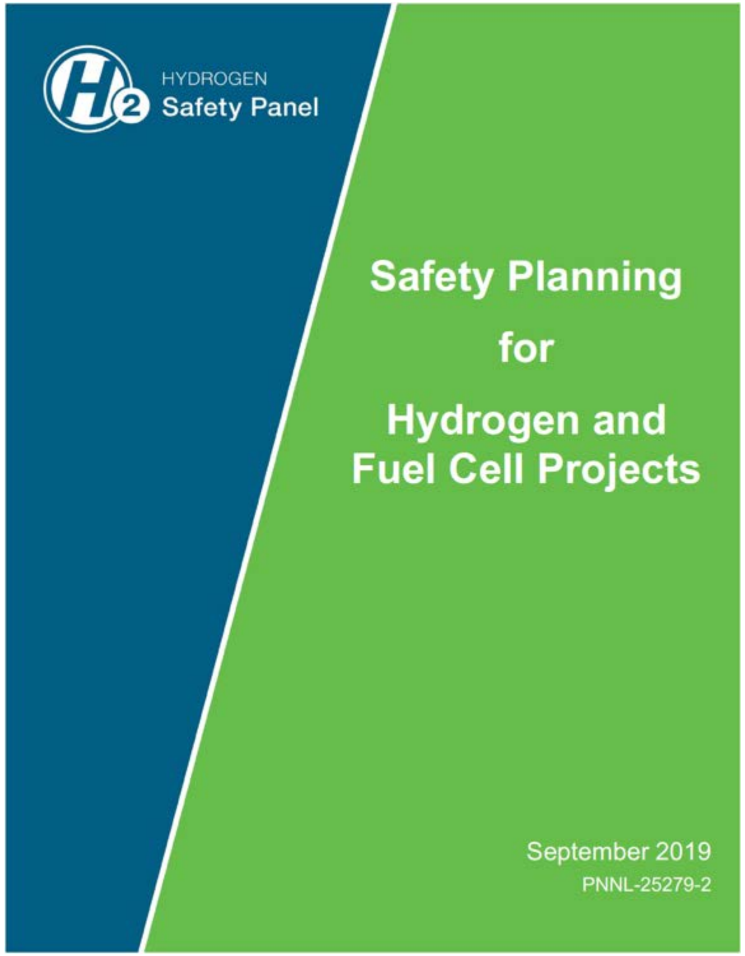
- Description
- Severity (Was hydrogen released? Was there ignition?)
- Setting
- Equipment
- Characteristics (High pressure? Low temperature?)
- Damage and Injuries
- Probable Cause(s)
- Contributing Factors
- Lessons Learned/Suggestions for Avoidance/Mitigation Steps Taken




URL: [http://h2tools.org/lessons](http://h2tools.org/lessons)

# Guidance for Safety Planning of $H_2$ Projects

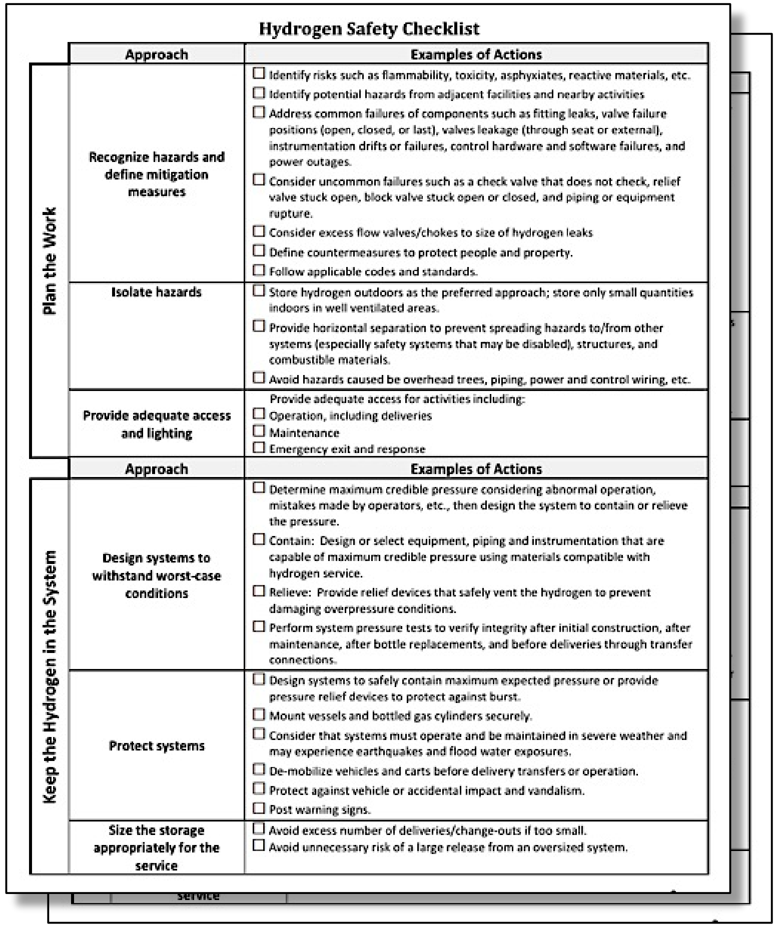
- Originally developed by the HSP for the U.S. Department of Energy in 2005
- The document provides information on safety practices for hydrogen and fuel cell projects
- The project safety planning process is meant to help identify risks and avoid potential hydrogen and related incidents.
- This document can aid in generating a good safety plan that will serve as a guide for the safe conduct of all work related to the development and operation of hydrogen and fuel cell equipment.




URL: https://h2tools.org/hsp/reviews

# Hydrogen Safety Considerations Checklist

- Intended users
  - Those developing designs for hydrogen systems
  - Those involved with the risk assessment of hydrogen systems.
- While fairly inclusive, it is not possible to include all variables that need to be considered
- A hazard analysis process should include
  - Personnel who are familiar with applicable codes and standards
  - Team members with expertise in the technical aspects of the specific project



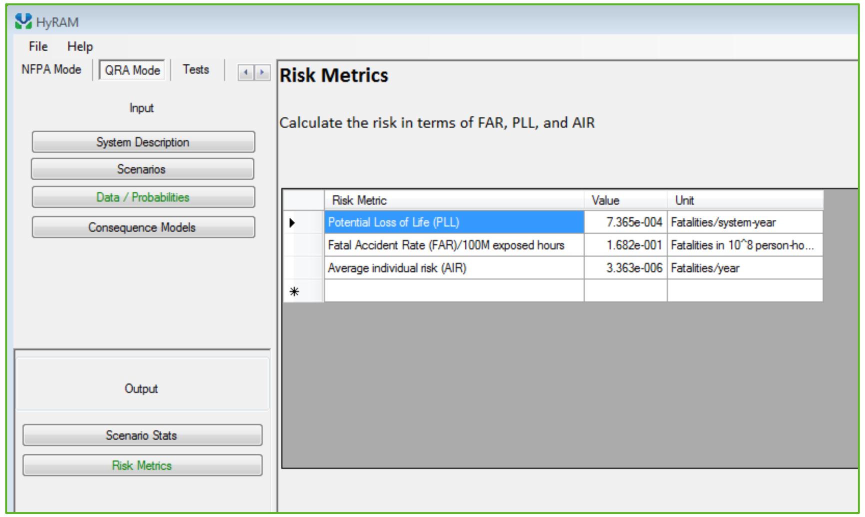
Hydrogen Safety Checklist

| | Approach | Examples of Actions |
|---|---|---|
| Plan the Work | Recognize hazards and define mitigation measures | ☐ Identify risks such as flammability, toxicity, asphyxiates, reactive materials, etc.<br>☐ Identify potential hazards from adjacent facilities and nearby activities<br>☐ 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.<br>☐ 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.<br>☐ Consider excess flow valves/chokes to size of hydrogen leaks<br>☐ Define countermeasures to protect people and property.<br>☐ Follow applicable codes and standards. |
| | Isolate hazards | ☐ Store hydrogen outdoors as the preferred approach; store only small quantities indoors in well ventilated areas.<br>☐ Provide horizontal separation to prevent spreading hazards to/from other systems (especially safety systems that may be disabled), structures, and combustible materials.<br>☐ Avoid hazards caused be overhead trees, piping, power and control wiring, etc. |
| | Provide adequate access and lighting | Provide adequate access for activities including:<br>☐ Operation, including deliveries<br>☐ Maintenance<br>☐ 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.<br>☐ Contain: Design or select equipment, piping and instrumentation that are capable of maximum credible pressure using materials compatible with hydrogen service.<br>☐ Relieve: Provide relief devices that safely vent the hydrogen to prevent damaging overpressure conditions.<br>☐ 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.<br>☐ Mount vessels and bottled gas cylinders securely.<br>☐ Consider that systems must operate and be maintained in severe weather and may experience earthquakes and flood water exposures.<br>☐ De-mobilize vehicles and carts before delivery transfers or operation.<br>☐ Protect against vehicle or accidental impact and vandalism.<br>☐ Post warning signs. |
| | Size the storage appropriately for the service | ☐ Avoid excess number of deliveries/change-outs if too small.<br>☐ Avoid unnecessary risk of a large release from an oversized system. |

URL: https://h2tools.org/sites/default/files/HydrogenSafetyChecklist.pdf

# Quantitative Risk Assessment Tool

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




HyRAM HYDROGEN RISK ASSESSMENT MODELS

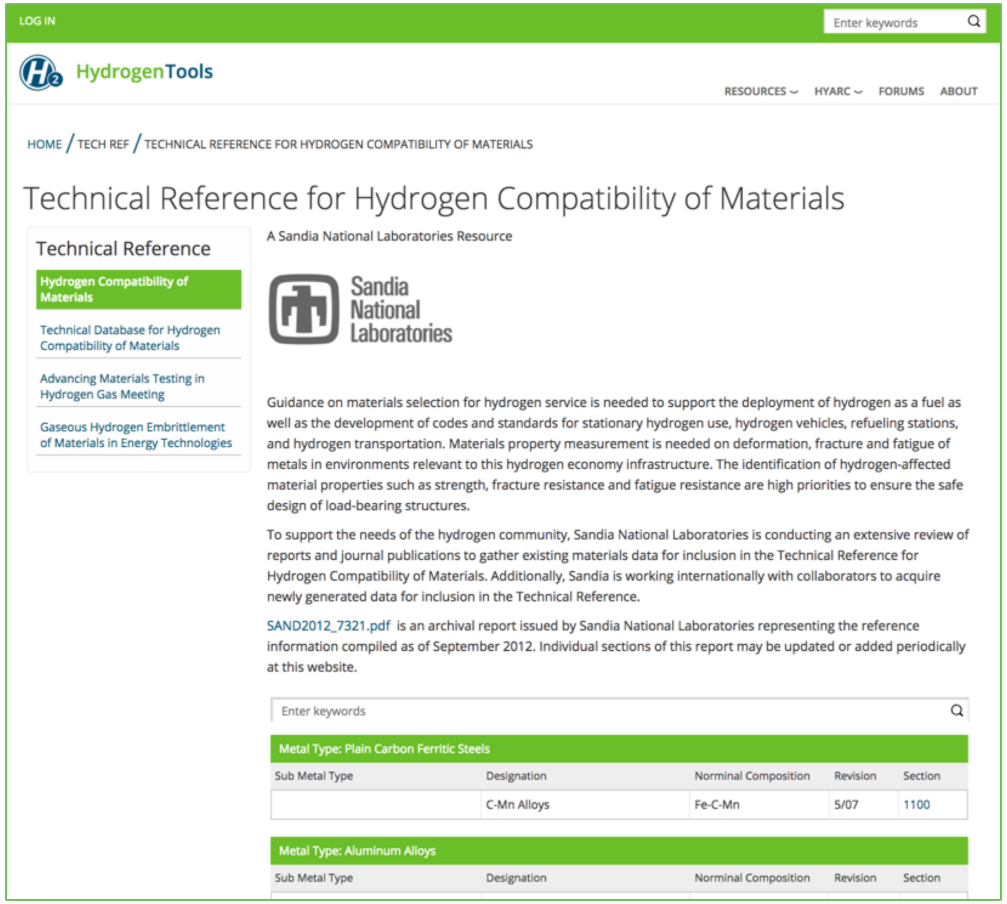
First-of-its-kind software tool for integrating $H_2$ consequence models w/ QRA models
Includes behavior models & data developed through FY12

URL: http://hyram.sandia.gov

# Technical Reference for Hydrogen Compatibility of Materials

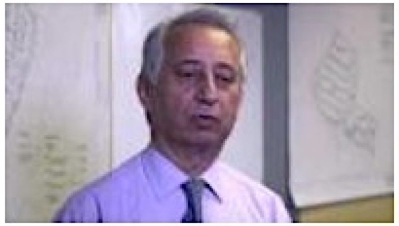
*Consists of material specific chapters (as individual PDF files) summarizing mechanical-property data from journal publications and technical reports*

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



# $H_2$ Fueling Station Permitting Videos

Permitting Hydrogen Fueling Stations Part One



Permitting Hydrogen Fueling Stations Part Two: Planning and Building Considerations


Permitting Hydrogen Fueling Stations Part Three: Fire Department Regulations

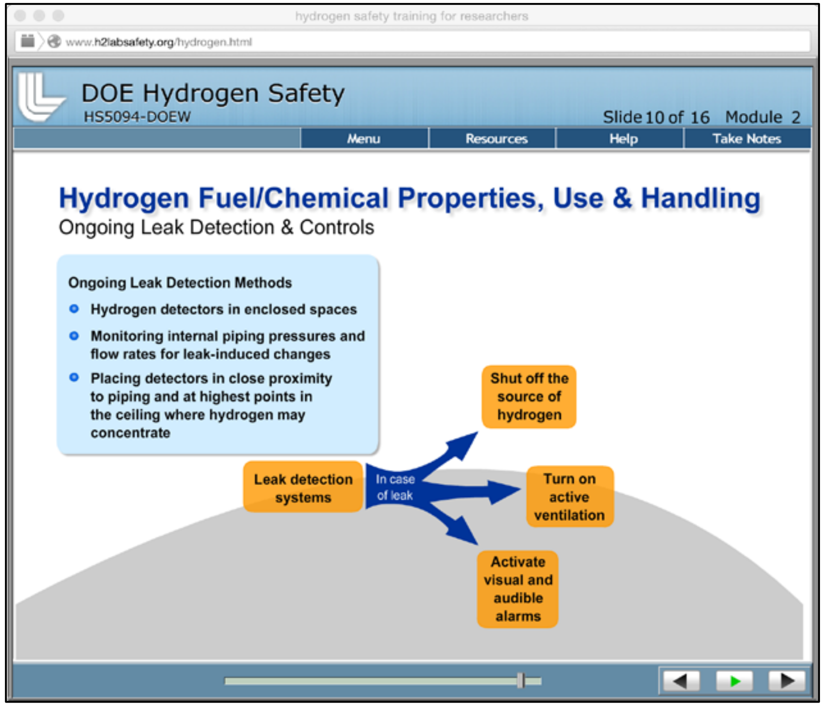
Permitting Hydrogen Fueling Stations Part Four: Annual Inspections

- Gives AHJs, Project Developers, and other interested parties a quick orientation in permitting hydrogen fueling stations.
- Provides basic background information on hydrogen technologies followed by a description of the permitting process including an overview of key codes and standards.
- Contains interviews with code officials, emergency responders, and technical experts as well as footage of hydrogen stations.

Videos available at [https://h2tools.org/videos](https://h2tools.org/videos)

# Hydrogen Safety Training for Researchers/Technicians

- **Objectives:** Provide basic hydrogen safety training through an interactive online course
- 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




URL: https://h2tools.org/content/training-materials

# And Our Newest Resource… HyARC

## Hydrogen Analysis Resource Center

- Well-documented, reliable data for use in evaluating hydrogen-related technologies
- Data can serve as the basis for calculations, modeling, and other analytical activities
- Data can be accessed from databases housed in the site itself as well as through links to important websites such as those maintained by the Energy Information Administration (EIA), DOE Programs, other U.S. Government Agencies, and non-government websites

**Data Books**

- Transportation Energy Databook
- Biomass Energy Data Book
- Buildings Energy Databook
- Power Technologies Energy Data Book
- NIST Chemistry WebBook

**EIA Data and Projections**

- Annual Energy Outlook
- International Energy Outlook
- Short Term Energy Outlook
- Monthly Energy Review
- Annual Energy Review

**Websites**

- Hydrogen Program Website
- IPHE Website
- Fuelcells.org Website
- H2Stations.org Website
- Fuel Cell and Hydrogen Energy Association Website
- California Fuel Cell Partnership Website

URL: https://h2tools.org/hyarc

# 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 (https://www.aiche.org/academy/courses/ela253/introduction-hydrogen-safety-first-responders)
  - 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.*

# 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 | Example Uses of Training Slides: L1 Overview | L2 Short Course | L3 Full Course |
|---|---|---|---|
| Slide #1: What and Why | | | |
| Slide #2: National Hydrogen and Fuel Cells Emergency Response Training | | | |
| **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

URL: http://h2tools.org/fr/nt/

CENTER FOR

# Hydrogen

SAFETY

Connecting a Global Community





# Safely Fueling Our Future…

## by building and enabling a global community

- A global, neutral and nonprofit resource
- Supports and promotes the safe handling and use of hydrogen across industrial and consumer applications in the energy transition
- Provides assurance that groups of experts have a common communication platform with a global scope to ensure safety information, guidance and expertise is available to all stakeholders

# Membership Benefits

### Project/facility support

- Design Reviews
- Hazard Analysis Support
- Facility/Site Reviews

### Outreach

- Stakeholders
- Code Officials
- Communities

### Networking

- $H_2$ Safety Conferences
- Collaborative Teaming

### Training & Education

- First Responders
- Researchers
- Technicians

### Incident Response Resource

- Timely Information on Incidents
- Facts Sheets
- Resource Guides

## MEMBERS

- DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V.
- SCEJ The Society of Chemical Engineers, Japan
- PLUG POWER
- BAYOTECH A CHEMICAL REACTOR COMPANY
- Rocket Company A ASTRA
- HySUT
- TRUE ZERO
- FirstElement
- Nebraska Public Power District Always there when you need us
- Air Liquide
- PROTIUM
- SHELL
- ALAKAI TECHNOLOGIES
- STATE OF CALIFORNIA ENERGY COMMISSION
- AIR PRODUCTS
- TOYOTA
- PDC MACHINES.COM
- Pacific Northwest NATIONAL LABORATORY
- UL
- nel
- NREL NATIONAL RENEWABLE ENERGY LABORATORY
- HySA Infrastructure Hydrogen South Africa
- Sandia National Laboratories
- WASHINGTON STATE UNIVERSITY
- POWER INNOVATIONS
- nationalgrid
- SunLine TRANSIT AGENCY

## EXECUTIVE BOARD

- AIChE
- hySafe INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY
- Air Liquide
- STATE OF CALIFORNIA ENERGY COMMISSION
- SHELL

## STRATEGIC PARTNERS

- Hydrogen Council
- California FUEL CELL PARTNERSHIP DRIVING FOR THE FUTURE
- U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

# Considerations…

- **The Hydrogen Safety Panel’s Role**
  - The HSP serves as an asset for an awardee’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**
  - Awardees 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**
  - Awardees may request assistance from or provide input to the safety review team/Hydrogen Safety Panel on any safety-related topic

# Questions and Discussion

# 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:

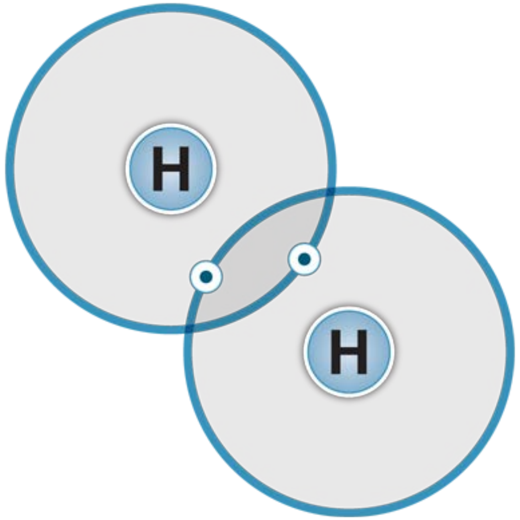
**http://h2tools.org**

for more Hydrogen Safety related news and the latest resources

# Properties of Hydrogen

# Hydrogen Properties and Behavior

- **Gas** at ambient conditions
  - Rises and disperses rapidly (14x lighter than air)
  - Flammable range 4-75% in air
- **Liquid** at -423°F (-253°C) – a *cryogen*
  - $LH_2$ stored at 50 psi in vacuum insulated tanks
  - No liquid phase in compressed gas H2 storage
- **Energy content comparison** :
  - 1kg of Hydrogen ~ 1 gallon gasoline
  - 33.3 kWh/kg hydrogen vs 32.8 kWh/gal gasoline




*Molecular Hydrogen Model:*
*2 protons (H+) sharing 2 electrons (e-)*

# Additional Properties of Hydrogen

## Description

- Colorless, odorless, tasteless

## General Properties

- Flammable
- Non-irritating, nontoxic, asphyxiant
- Non-corrosive
- Lightest gas, buoyant, can escape earth's gravity

## Physical Properties

| | |
|---|---|
| $GH_2$ density @ NTP | 0.0838 $kg/m^3$ ($1/15^{th}$ air) |
| $GH_2$ specific gravity | 0.0696 (Air = 1.0) |
| Viscosity | $33.64 \times 10^{-3}$ kg/m hr (1/2 air) |
| Diffusivity | 1.697 $m^2$/hr (4x NG in air) |
| Thermal Conductivity | 0.157 kcal/m hr K (7 x air) |

**Potential Hazards**

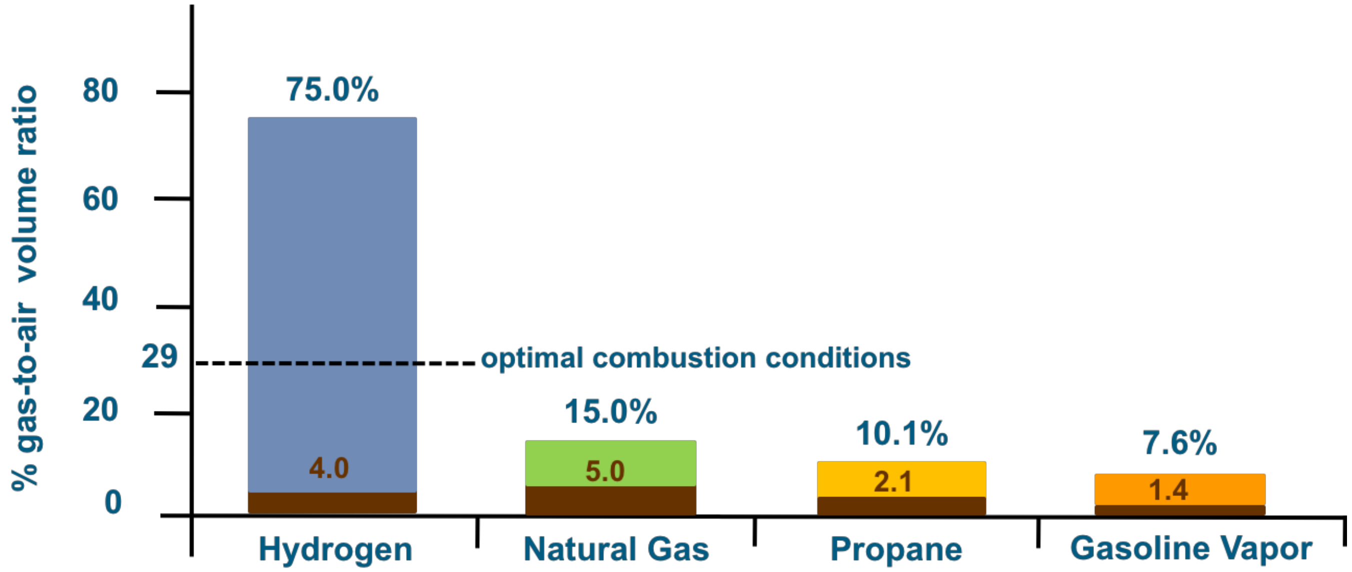
- Combustion
- Pressure hazards
- Low temperature
- Hydrogen-induced material embrittlement
- Exposure and health

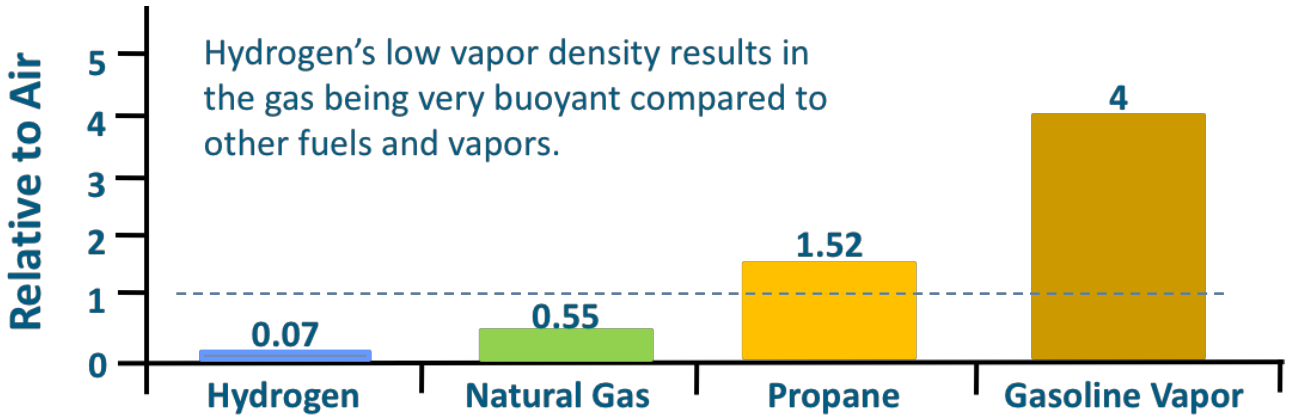
# Hydrogen Properties: A Comparison

| Property | 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

# Flammable Range and Vapor Density



# Primary Codes and Standards

# Design Consideration: Codes & Standards

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


# Important IFC Code References

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


**Significant changes in the 2015 IFC**

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

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

# The Need for a National Hydrogen Code

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

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


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

# NFPA 2 Scope

**NFPA 2 applies to the use of gaseous and liquefied hydrogen in**

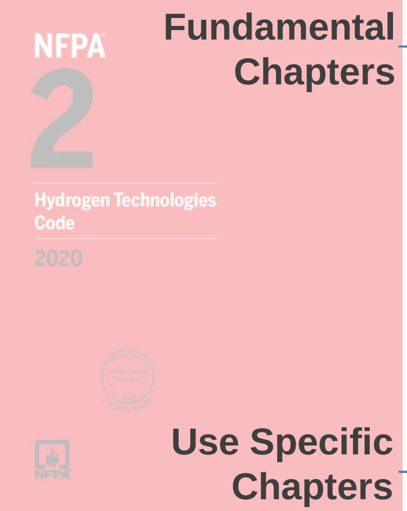
- Storage
- Transfer
- Production
- Use

Fundamental requirements are provided for:

- Storage
- Piping
- Installation
- Handling
- Generation

**NFPA 2 does <u>not</u> cover**

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




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

# Fundamental Safety Considerations

# Hydrogen Safety Basics

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

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


Fuel cell backup power connected to a data center

# General Indoor Safety Considerations

Safety considerations for the indoor storage or use of bulk gaseous hydrogen include:

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

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

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

# Ventilation

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

Is there a problem here?

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

# Active Ventilation

- If passive ventilation is insufficient, active (mechanical, forced) ventilation can be used to prevent the accumulation of flammable mixtures.
  - Equipment used in active ventilation systems (e.g., fan motors, actuators for vents and valves) should have the applicable electrical classification and be approved for hydrogen use.
  - If active ventilation systems are relied upon to mitigate gas accumulation hazards, procedures and operational practices should ensure that the system is operational at all times when hydrogen is present or could be accidentally released.
  - Hydrogen equipment and systems should be shut down if there is an outage or loss of the ventilation system if LFL quantities of hydrogen could accumulate due to the loss of ventilation. If the hazard is substantial, an automatic shutdown feature may be appropriate.
- Ventilation (passive or active) should be at a rate not less than 1 scf/min/ft$^2$ (0.3048 Nm$^3$/min/m$^2$) of floor area over the area of storage or use.

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

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

# Leak Detection

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

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

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

Code and Standards: IFC 5003.2.2, NFPA 2-7.1.22

# Leak Detection Design and Performance

**Goals for an area hydrogen leak detection system include:**

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

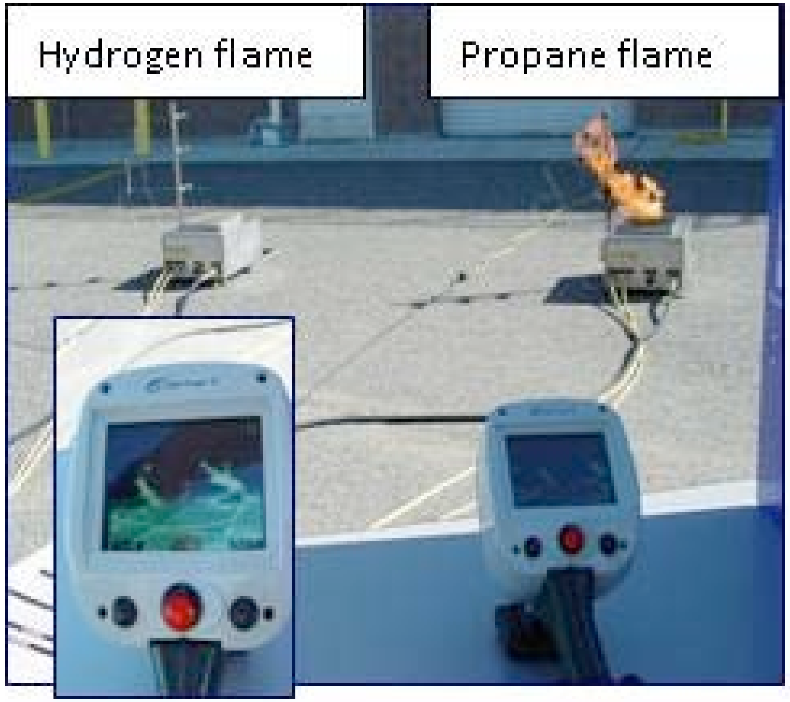
**Specific performance considerations:**

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

# Checking for Leaks

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

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




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

# A Lesson Learned on Hydrogen Leaks

## Hydrogen Explosion and Iron Dust Flash Fires in Powdered Metals Plant

- Operators in a powdered metals production facility heard a hissing noise near one of the plant furnaces and determined that it was a gas leak in the trench below the furnaces. The trench carried hydrogen, nitrogen, and cooling water runoff pipes as well as a vent pipe for the furnaces.
- ***Maintenance personnel presumed that the leak was nonflammable nitrogen because there had recently been a nitrogen piping leak elsewhere in the plant***. Using the plant's overhead crane, they removed some of the heavy trench covers. They determined that the leak was in an area that the crane could not reach, so they brought in a forklift with a chain to remove the trench covers in that area.
- Eyewitnesses stated that as the first trench cover was wrenched from its position by the forklift, friction created sparks followed immediately by a powerful explosion. Several days after the explosion, Chemical Safety Board (CSB) investigators observed a large hole (~3x7 inches) in a corroded section of hydrogen vent piping inside the trench.

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

# Flame Detection

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

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

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

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

Photo courtesy of HAMMER

# Electrical Equipment

Specific considerations:

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

**Example of Electrical Equipment Requirements – Hydrogen Fueling Stations (NFPA 2, Table 10.4.6.1)**

| Location | Division or Zone | Extent of Classified Area |
|---|---|---|
| Outdoor dispenser enclosure — exterior and interior | 2 | Up to 5 ft (1.5 m) from dispenser |
| Indoor dispenser enclosure — exterior and interior | 2 | 15 ft (4.6 m) from the point of transfer in accordance with 10.4.1.1 |
| Outdoor discharge from relief valves or vents | 1 | 5 ft (1.5 m) from source |
| Outdoor discharge from relief valves or vents | 2 | 15 ft (4.6 m) from source |
| Discharge from relief valves within 15 degrees of the line of discharge | 1 | 15 ft (4.6 m) from source |

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

# The Certification Challenge

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

## Certification presents significant challenges.

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

**Development of a Certification Guide**

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

The Guide is available at: [https://h2tools.org/hsp/certification-guide](https://h2tools.org/hsp/certification-guide)

Code and Standards: IFC 2309.2.2, NFPA 2-7.1.3

# Outdoor Separations

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

| Pressure (psig)<br>Pipe Internal Diameter (in.) | > 15 to ≤ 250<br>2.07 | > 250 to ≤ 3000<br>0.75 | > 3000 to ≤ 7500<br>0.29 | > 7500 to ≤ 15000<br>0.28 |
|---|---|---|---|---|
| **Exposure Group 1**<br>a) Lot lines<br>b) Air intakes (HVAC, compressors, Other)<br>c) Operable openings in buildings and Structures<br>d) Ignition sources such as open flames and welding | 16 ft | 20 ft | 13 ft | 16 ft |
| **Exposure Group 2**<br>a) Exposed persons other than those servicing the system<br>b) Parked cars | 16 ft | 20 ft | 10 ft | 13 ft |
| **Exposure Group 3**<br>a) Buildings of non-combustible non-fire-rated construction<br>b) Buildings of combustible construction<br>c) Flammable gas storage systems above or below ground<br>d) Hazardous materials storage systems above or below ground<br>e) Heavy timber, coal, or other slow-burning combustible solids<br>f) Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, or combustible waste and vegetation other than that found in maintained landscaped areas<br>g) Unopenable openings in building and structures<br>h) Encroachment by overhead utilities (horizontal distance from the vertical plane Below the nearest overhead electrical wire of building service)<br>i) Piping containing other hazardous materials<br>j) Flammable gas metering and regulating stations such as natural gas or propane. | 13 ft | 16 ft | 10 ft | 13 ft |

# Selection of Materials

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

**Preferred**

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

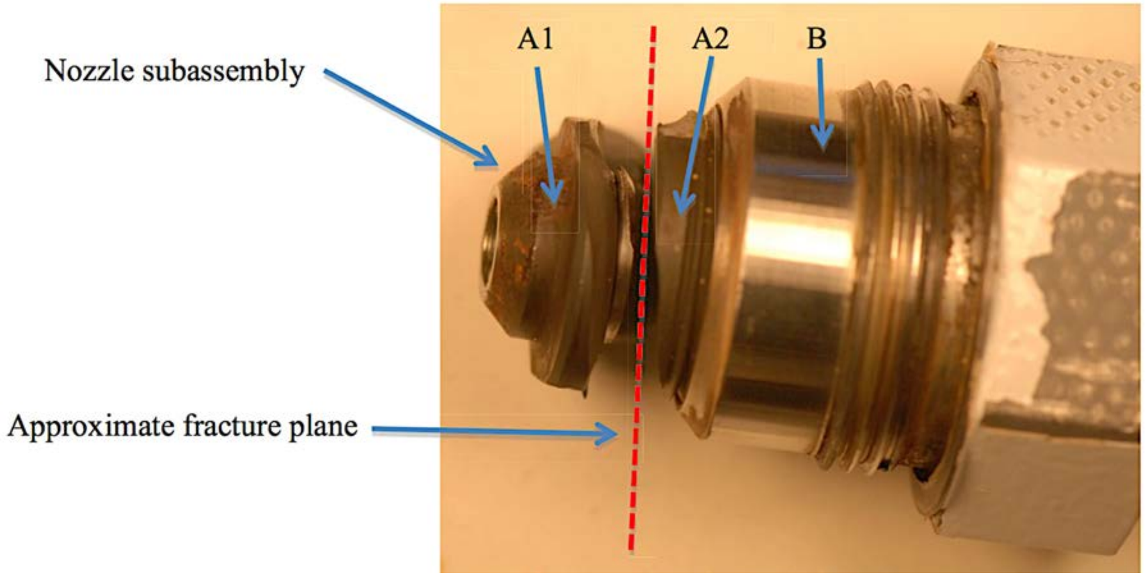
**Avoid**

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

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

# A Lesson Learned on Material Selection

A pressure relief device (PRD) valve failed on a high-pressure storage tube at a hydrogen fueling station, causing the release of hydrogen gas. The gas ignited at the exit of the vent pipe.




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

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

Source: [http://www.h2tools.org/lessons](http://www.h2tools.org/lessons)

# Piping Layout and Design

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

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

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

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

**Vent Lines**

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

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

# Working with First Responders

**Preplanning**

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

**Training**

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

**Equipment**

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

Photo: Volpentest HAMMER Federal Training Center

Code and Standards: IFC 5003.9.1

# Safety Considerations for Liquid Hydrogen

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

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

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

# Concluding Thoughts

- Safe practices in the production, storage, distribution and use of hydrogen are essential for deployment of hydrogen and fuel cell technologies. ***A significant incident involving a hydrogen project could negatively impact the public's perception of hydrogen systems as viable, safe, and clean alternatives to conventional energy systems.***

- Hydrogen CAN be used safely. However, because hydrogen's use as a fuel is still a relatively new endeavor, the proper methods of handling, storage, transport and use are often not well understood across the various communities either participating in or impacted by its demonstration and deployment. Those working with hydrogen and fuel cell technologies should utilize the online resources discussed in this presentation to become familiar with the technology.

- The IFC, IFCG and NFPA 2 provide fundamental requirements for the use of hydrogen and fuel cell technologies. Online resources are available to help code officials and project proponents better understand and apply the necessary safe practices for the successful deployment of this technology.

- The Hydrogen Safety Panel, Center for Hydrogen Safety and Hydrogen Tools Portal (http://h2tools.org) are available to help project participants to understand and apply safe practices.

# Questions and Discussion

# 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