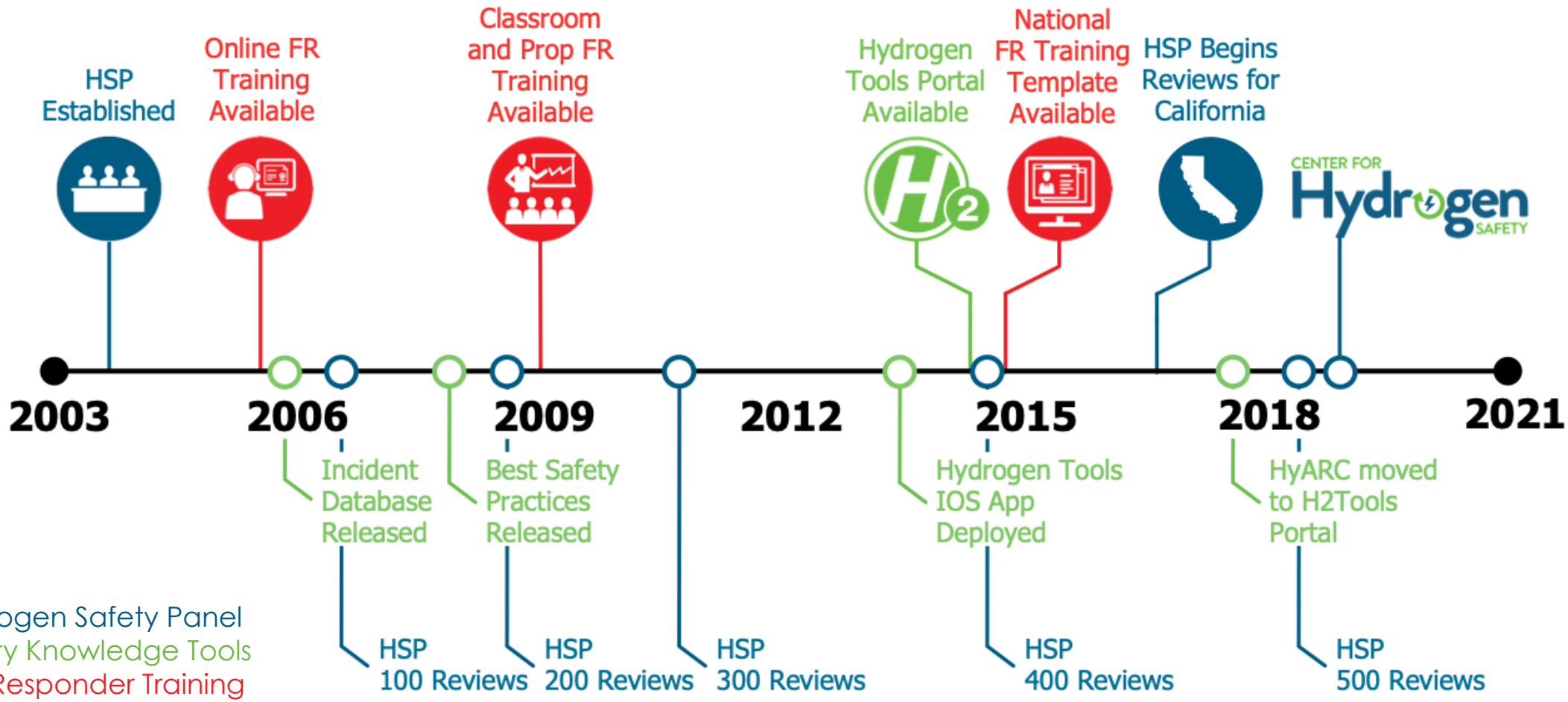
CENTER FOR Hydrogen SAFETY
Connecting a Global Community

Overview of the Center for Hydrogen

Nick Barilo
Executive Director, Center for Hydrogen Safety
February 15, 2021

Timeline of Our Hydrogen Safety Resources



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

State of Hydrogen Safety

Safety issues can be a 'deal breaker' and must be addressed for successful hydrogen technology acceptance and deployment

Its Use as a Fuel is New to Many

- Users may lack experience or expertise for its safe use
- Some users have misconceptions… and may not know that they don't know

Stable Foundation

- Hydrogen can be used safely… It has been for nearly a century by industry
- Safety knowledge and best practices exist

Dangerous Assumptions

- "We already know how to use hydrogen safety" (apathy - established users)
- "Hydrogen is like any other flammable gas" (misconceptions - new players)
- "Hydrogen is too dangerous" (fear - general public/AHJ's)

Hydrogen can be used safely but failing to address the knowledge gaps can result in impactful incidents and industry setbacks

The Impact of Incidents

- June 30, 1956, two airliners, TWA Flight 2 and United Airlines Flight 718 collided in mid-air near the Grand Canyon, killing 128 persons. Known as the 1956 Grand Canyon Collision, this disaster changed the airline industry forever.

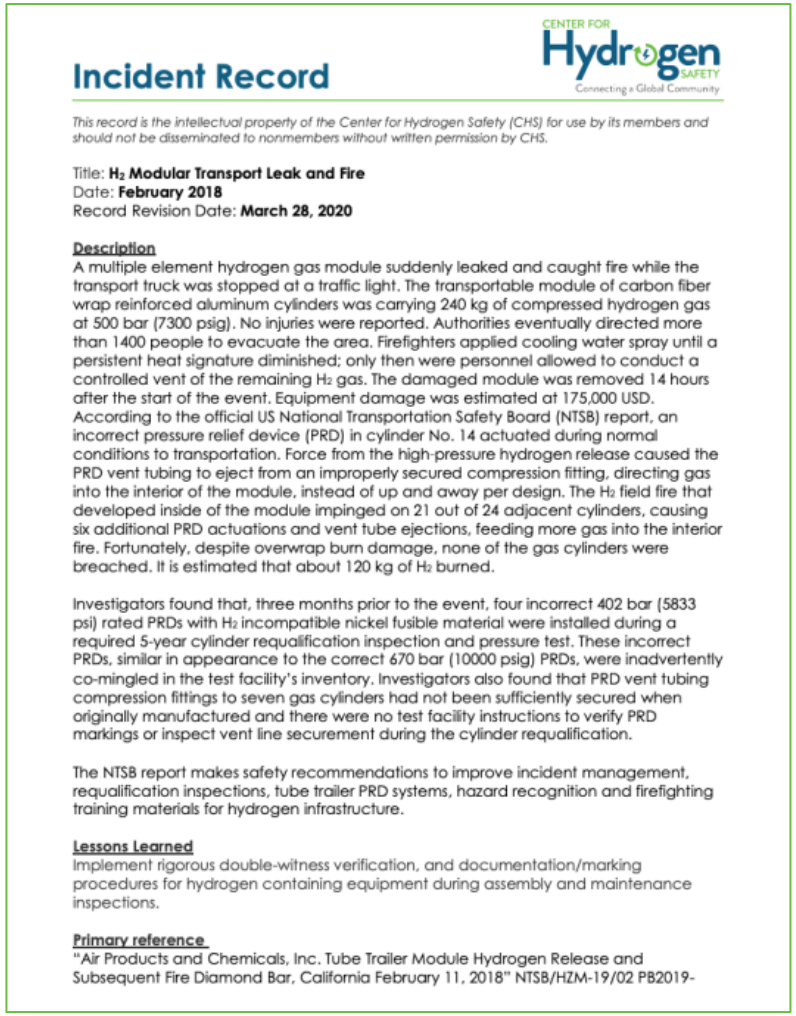

Did Outdated System Kill 128?--Col. 6
The Detroit Free Press
2 PLANES IN WHICH 128 DIED FOUND IN CANYON'S DEPTHS
13 from Detroit Area Claimed in Disaster
Automotive Executives Are Victims
CAB Teams Hunt Clues of Collision

- Dec. 2, 1984, the Union Carbide pesticide plant in Bhopal, India, released more than 40 tons of highly toxic methyl isocyanate gas, killing 3,800 people, causing significant morbidity and premature death for many thousands more, and forever changing the chemical industry.

- Jan. 28, 1986, the Space Shuttle Challenger exploded 73 seconds after take-off, killing all seven crewmembers and forever changing the **space industry.**

CHS Hydrogen Incident Records

- **Electrolyzer**
  - Personnel did not fully understand the interrelation of electrolyzer membrane gas permeability, membrane degradation, and dynamic operating range
- **Hydrogen Vehicle Fueling Station**
  - Assembly error of an end plug for the high-pressure hydrogen tank
- **Hydrogen Transport**
  - Incorrect pressure relief devices installed during maintenance
- **Hydrogen Tanker Loading**
  - Unauthorized repair and failure to follow procedures
- **Hydrogen Bus Fueling Station**
  - Incompatible pressure relief device installed
- **TPRD Release During Tank Testing**
  - Catalytic combustion hydrogen sensor did not operate



Incident Record

This record is the intellectual property of the Center for Hydrogen Safety (CHS) for use by its members and should not be disseminated to nonmembers without written permission by CHS.

Title: **H_2 Modular Transport Leak and Fire**
Date: **February 2018**
Record Revision Date: **March 28, 2020**

Description
A multiple element hydrogen gas module suddenly leaked and caught fire while the transport truck was stopped at a traffic light. The transportable module of carbon fiber wrap reinforced aluminum cylinders was carrying 240 kg of compressed hydrogen gas at 500 bar (7300 psig). No injuries were reported. Authorities eventually directed more than 1400 people to evacuate the area. Firefighters applied cooling water spray until a persistent heat signature diminished; only then were personnel allowed to conduct a controlled vent of the remaining H_2 gas. The damaged module was removed 14 hours after the start of the event. Equipment damage was estimated at 175,000 USD. According to the official US National Transportation Safety Board (NTSB) report, an incorrect pressure relief device (PRD) in cylinder No. 14 actuated during normal conditions to transportation. Force from the high-pressure hydrogen release caused the PRD vent tubing to eject from an improperly secured compression fitting, directing gas into the interior of the module, instead of up and away per design. The H_2 field fire that developed inside of the module impinged on 21 out of 24 adjacent cylinders, causing six additional PRD actuations and vent tube ejections, feeding more gas into the interior fire. Fortunately, despite overwrap burn damage, none of the gas cylinders were breached. It is estimated that about 120 kg of H_2 burned.

Investigators found that, three months prior to the event, four incorrect 402 bar (5833 psi) rated PRDs with H_2 incompatible nickel fusible material were installed during a required 5-year cylinder requalification inspection and pressure test. These incorrect PRDs, similar in appearance to the correct 670 bar (10000 psig) PRDs, were inadvertently co-mingled in the test facility's inventory. Investigators also found that PRD vent tubing compression fittings to seven gas cylinders had not been sufficiently secured when originally manufactured and there were no test facility instructions to verify PRD markings or inspect vent line securement during the cylinder requalification.

The NTSB report makes safety recommendations to improve incident management, requalification inspections, tube trailer PRD systems, hazard recognition and firefighting training materials for hydrogen infrastructure.

Lessons Learned
Implement rigorous double-witness verification, and documentation/marking procedures for hydrogen containing equipment during assembly and maintenance inspections.

Primary reference
"Air Products and Chemicals, Inc. Tube Trailer Module Hydrogen Release and Subsequent Fire Diamond Bar, California February 11, 2018" NTSB/HZM-19/02 PB2019-

Perspective on Incidents Throughout Industry

United States Occupational Incidents in 2018[1]

Industry	Total Incidents – Nonfatal	Incidence Rate* - Nonfatal	Total Incidents - Fatal
Agriculture, forestry, fishing and hunting	64,200	3.7	574
Oil and Gas Extraction	1,100	0.8	13
Construction	199,100	3.0	1,008
Petroleum and coal products manufacturing	900	1.3	5
Chemical Manufacturing	16,100	1.9	18
Industrial Gas Manufacturing (Hydrogen)	200	1.0	1
Grocery Stores	86,000	4.5	38
Gasoline Stations	17,100	2.4	47
Power gen., trans., & distr.	6,800	1.7	5
Investment Banking and Securities	1,900	0.2	4

* Incident rate is number of incidents per 100 full time employees per year

[1] Data Retrieved from U.S. Bureau of Labor Statistics

Human Error/Factors as a Contributing Cause to Accident:

Cybersecurity Breaches: 90 – 95 %

Nuclear Industry: > 90%

Chemical Industry: 80%

Maritime Industry: >75%

Airplane Accidents: 60 - 80%

Common Fuels Incidents

- **Gasoline**
  - ~1,000 fueling station fires per year in the U.S. as a result of gasoline ignition (2004-2008) (NFPA)
  - ~171,500 highway vehicle fires in the U.S. between 2014 and 2016 (FEMA)
    - 345 deaths
    - 1,300 injuries
    - $1.1 billion USD in property loss
    - 13% of all fires responded to by fire departments
- **Natural Gas** – average/year (U.S. 2007-2011) (NFPA)
  - 13,730 fires
  - 35 deaths
  - 254 injuries
  - $303 million USD property damage

Did you know? All fuels contain energy and can be hazardous if handled improperly.

2019 Gasoline Station Fire

Safety…

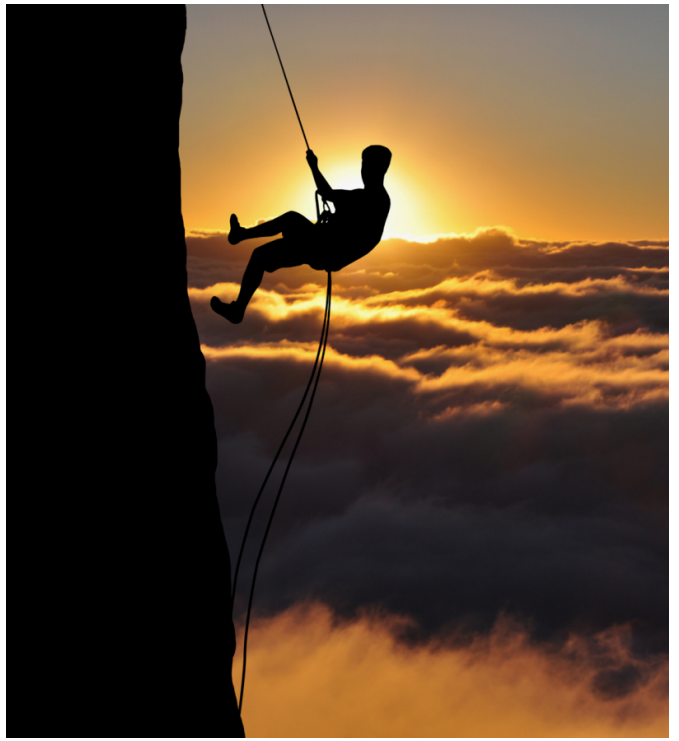
Three Parts, One Purpose, Strong Together

A threefold cord is not quickly broken

Implement Regulations, Codes and Standards

Utilize Best Safety Practices

Be Invested in Safety



Implement Regulations, Codes and Standards

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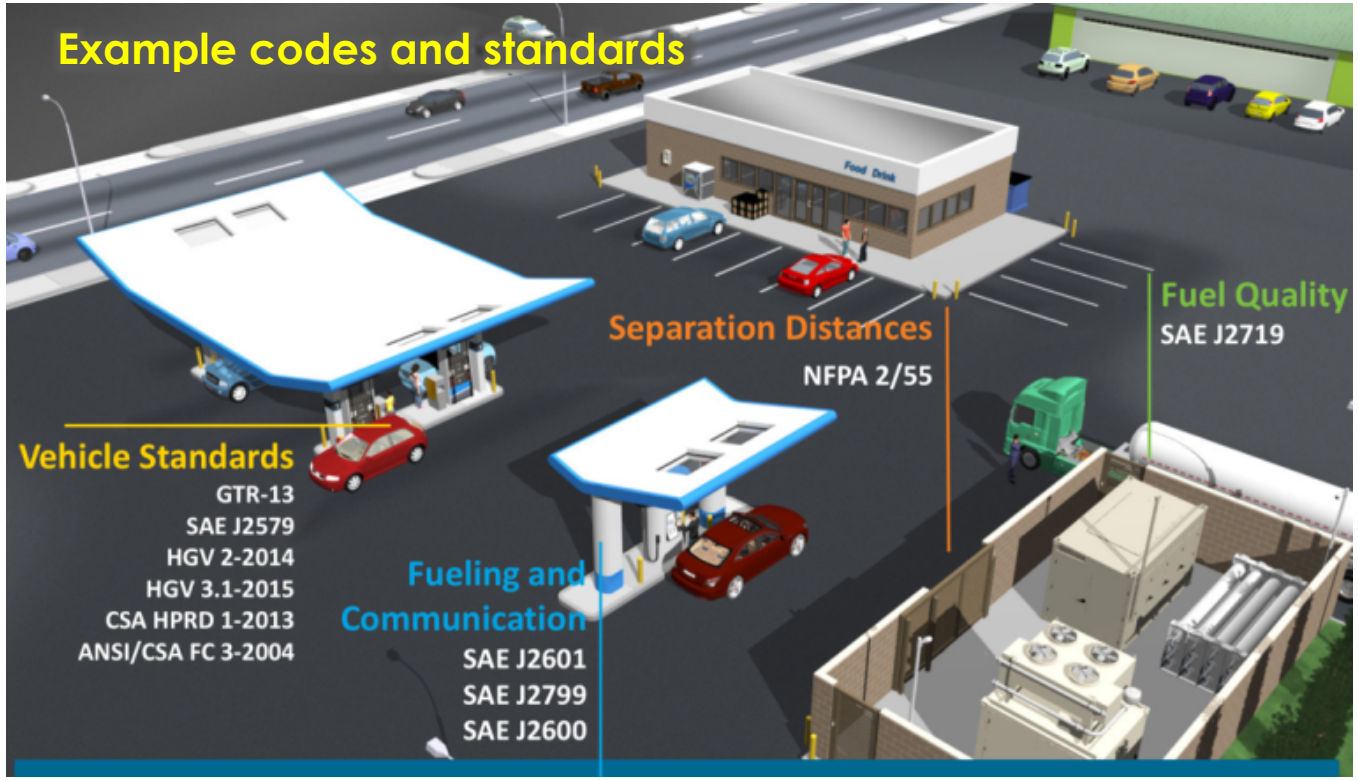
Hydrogen regulations, codes and standards (RCS) are maturing quickly for many mainstream fuel cell applications

- RCS provide the information needed to safely build, maintain, and operate equipment, systems, and facilities
- Ensures uniformity of safety requirements
- Provides inspectors and safety officials the information needed to approve systems and installations
- Bolsters public and stakeholder confidence and helps protect investments



Did you know? Many codes and standards were developed using industry best practices.

See http://www.fuelcellstandards.com/... a database of international codes and standards

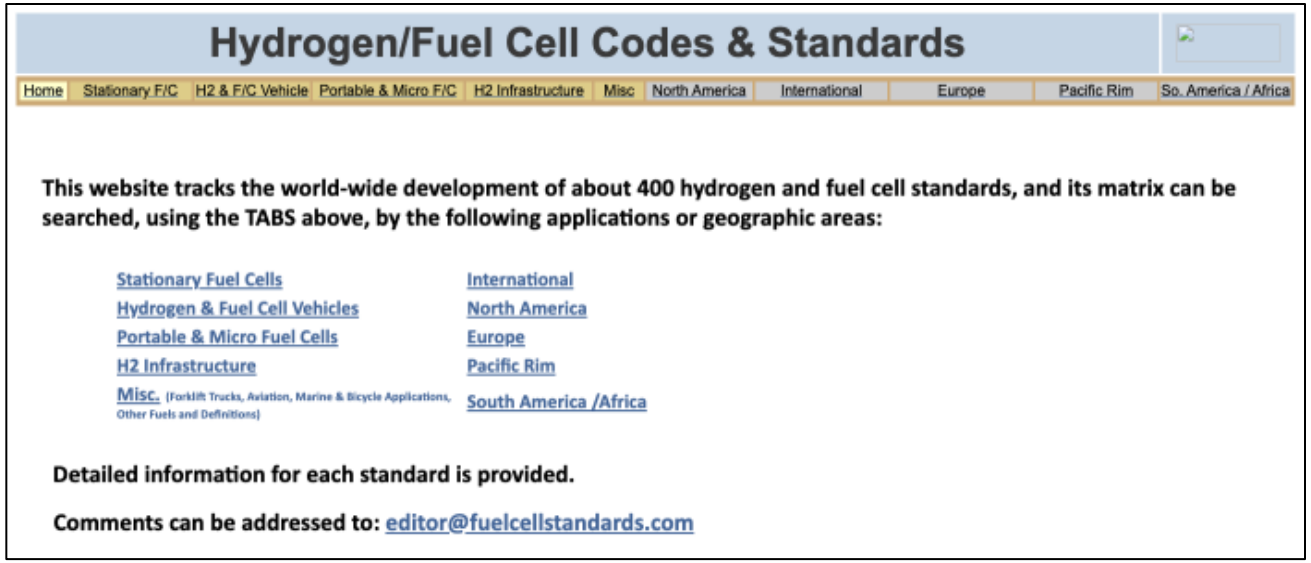
Example International Codes and Standards

International

- ISO TC/197 Hydrogen Technologies
  - 17 published standards (4 in development)
  - 22 participating countries
- IEC TC/105 Fuel Cell Technologies
  - 24 published standards (11 in development)
  - 19 participating countries

North America

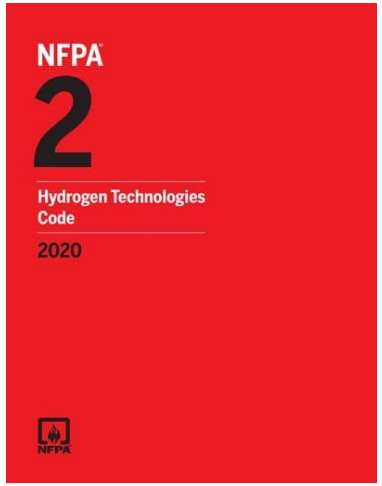
- NFPA 2 Hydrogen Technologies Code
- CAN/BNQ 1784 Canadian Hydrogen Installation Code



Codes and Standards Resource: **fuelcellstandards.com**

U.S. Codes and Standards for Hydrogen Facilities

Model Code References to NFPA 2



National Hydrogen Specific Codes[78]

- NFPA 2 Hydrogen Technologies Code
- NFPA 30A Motor Fuel Dispensing Facilities and Repair Garages
- NFPA 55 Compressed Gases and Cryogenic Fluids Code

Component Design Standards

- ASME Boiler and Pressure Vessel[79]
- ASME B31.12–Hydrogen Piping and Pipelines
- ASME B31.1–Power Piping
- ASME B31.8–Gas Transmission and Distribution Piping Systems
- ASME B31.8S–Managing System Integrity of Gas Pipelines
- ASME B31.3–Process Piping
- CGA S-1.1-3: Pressure Relief Device Standards
- CGA-G-5.5: Hydrogen Vent Systems
- SAE J2600–Compressed Hydrogen Surface Vehicle Fueling Connection Devices
- UL 2075–Standard for Gas and Vapor Detectors and Sensors
- NFPA 77 and API RP 2003 offer guidance on grounding and static electricity

Model Codes

- International Fire Code
- International Building Code

Component Listing and Design Standards

Currently, few existing components are tested to listing standards implemented by a nationally recognized testing laboratory (NRTL). AHJs may allow the station manufacturer to provide technical information to prove that the compression, storage, and dispensing components used are fit for service. As the market develops, the list of listed components (and systems) is expected to grow.

Station Developer Standards (For informational use)

- SAE J2601–Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles[80]
- SAE J2799–Hydrogen Surface Vehicle to Station Communications Hardware and Software
- SAE J2719–Hydrogen Fuel Quality for Fuel Cell Vehicles
- HGV CSA Series Standards (currently being updated)

Utilize Best Safety Practices

Best practice… a technique or methodology that has reliably led to a desired result

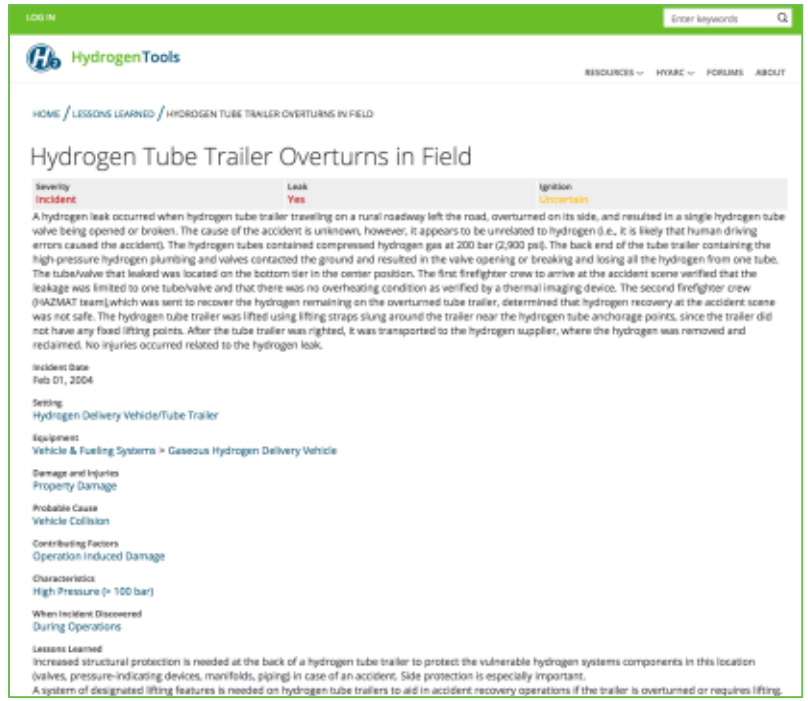
Utilizing Best Safety practices:

- Implements the benefits of extensive experience in the safe use of hydrogen
- Protects people, equipment and environment and minimizes risk of incidents
- Is demonstrated by their incorporation into designs, standard operating procedures, etc.

Those who cannot remember the past are condemned to repeat it.
- George Santayana

More info… https://h2tools.org/bestpractices/best-practices-overview

Did you know? Hydrogen best safety practices are based on a wealth of knowledge and experience related to safe use and handling of hydrogen exists as a result of an extensive history in a wide variety of industrial and aerospace settings.

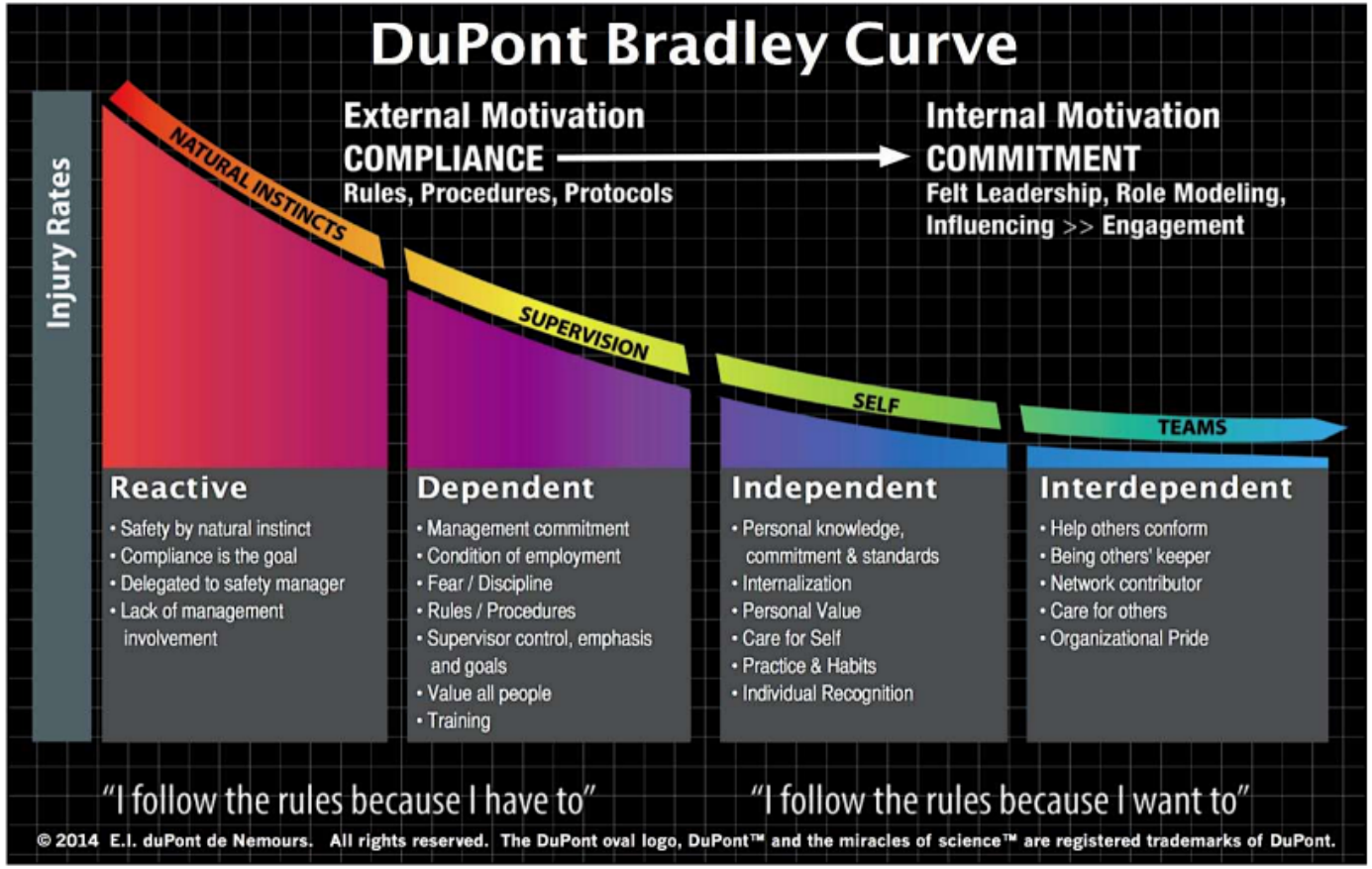


A best practice record from h2tools.org

Be Invested in Safety

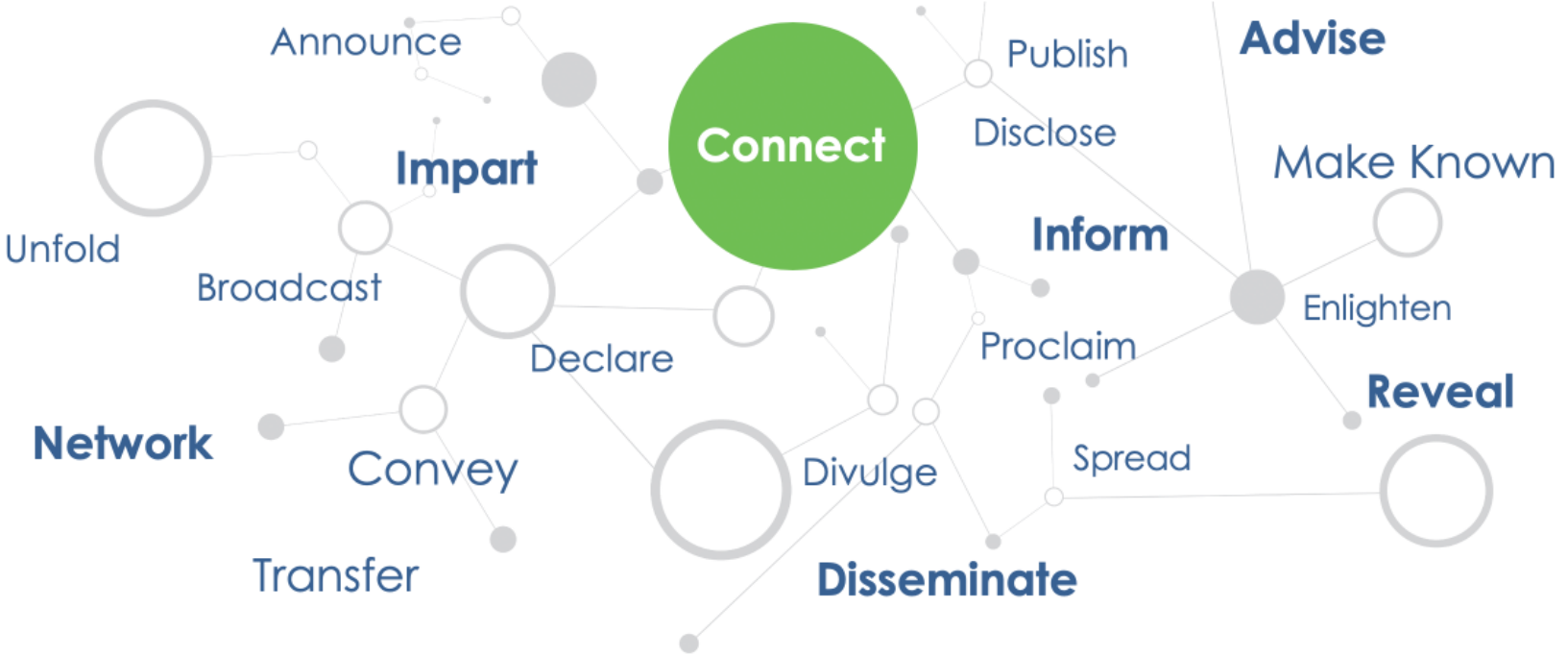
Investment in Safety:

- Is directly impacted by your organization's:
  - Beliefs
  - Perceptions
  - Values
- Is critical for:
  - Crafting a sustainable legacy
  - Maximizing your organization's impact and reaching its goals
  - Ensuring long-term acceptance of the hydrogen industry
- Enables to RCS and best safety practices to bring significant benefit
- Must be demonstrated
  - A culture of safety



Connecting People to Safety Knowledge

- **Communication of hydrogen specific safety guidance** will be critical to the success of hydrogen as a part of the global energy transition
- Establishing and communicating best practices **from a trusted, independent safety resource** is a valuable part of the hydrogen safety ecosystem



CHS is connecting the community with safety knowledge to enable the safe and timely transition to hydrogen and fuel cell technologies

Center for Hydrogen Safety

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Connecting a Global Community

Bringing together a global membership to expand the body of safety knowledge

Vision

- The Center for Hydrogen Safety (CHS) is a global non-profit dedicated to promoting hydrogen safety and best practices worldwide

Mission

- Support and promote the safe handling and use of hydrogen across industrial/commercial uses and applications in the energy transition
- Provide a common communication platform with a global scope to ensure safety information, guidance and expertise is available to all stakeholders

First Responder Hydrogen Safety Training

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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.

- **Goal**
  - Educate first responders on unique hydrogen hazards
- **Integrated Activities**
  - Online, awareness-level training[1]
  - Video-based training courses[2]
  - Classroom and hands-on operations-level training
  - Trainer material (PowerPoint slides with speaker notes)

(1) https://tinyurl.com/yxfy66rp
(2) https://tinyurl.com/y64q48ck

New Safety Courses and Updated Best Practices

Activity Benefits

- Running start – New courses based on existing best safety practices
- Extensive review – HSP and CHS members provide feedback and validates content
- Broad availability – Courses available through AIChE Academy
- Safety credentialing – Enabling confidence in hydrogen work force
- Best Practices refresh – Process will lead to new and updated H2Tools BSP content

Coming Soon CHS Courses

- Fundamentals Technology
- Properties and Hazards
- Safety Planning
- Facility Design and Construction
- Hydrogen System and Components
- Liquid Systems
- Material Compatibility
- Operating Systems
- Inspection and Maintenance
- Laboratory – Safe Design
- Laboratory – Safe Operations
- Chemical Hydrogen Storage and Metal Hydrides
- Fuel Cell Forklifts and Indoor Refueling

AIChE CREDENTIAL

To support the need for workforce development and validation CHS anticipates making a hydrogen safety credential available in late 2021

CHS Webinars and Mini-Workshops

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Hydrogen Safety Webinar Series

- Will start in April 2021
- Intermediate and advanced topics
- Speakers from CHS membership and other invited experts
- Free, but recorded presentations available for purchase (free to CHS members)

Mini Workshops

- Half-day virtual session
- Multiple presentations to set the stage for breakout sessions
- Produce a product for members and stakeholders
- Will start in mid-2021

Potential Webinar Series Topics

- Safety of Electrolysis Equipment
- Ventilation Considerations
- Laboratory Hydrogen Safety

Potential Mini Workshop Topics

- Public Safety — What information is needed?
- Safety Culture for Hydrogen Applications
- Hazard Analyses — Options, best practices and approaches, etc.

Conference Update

- June 2021 – Virtual Asia-Pacific Conference

Previous Conferences

- October 2020 – Virtual Europe Conference
- September 2020 – Virtual U.S. Conference
- October 2019 – Sacramento, CA

Update on CHS Working Groups

The Center convenes groups of CHS members around topics of shared interest to facilitate collaboration. Specific objectives and deliverables set by individual groups.

- **Introducing H_2 into Natural Gas Infrastructure**
  - 11 member organizations
  - Answering key H2 safety questions related to blending H2 & NG
- **Hydrogen Safety Credential**
  - 19 member organizations
  - Reviewing courses that will become the CHS Hydrogen Safety Credential
- **Hydrogen Equipment and Component Failure Rates**
  - 12 member organizations
  - Developed a process for collecting failure rate data for specific components
  - Developing a document that contains recommended failure rate data for H2 specific equipment & components

Hydrogen Safety Credential Working Group

The Hydrogen Safety Credential Working Group will work in an advisory role to create a hydrogen safety body of knowledge and roadmap, which will serve as a foundation for the courses required to obtain a credential through AIChE's Credential program.

Key Deliverables

- Provide feedback and input to CHS on the hydrogen safety body of knowledge and roadmap
- Provide industry perspective on the needs of industry for a hydrogen safety credential
- Provide input while the CHS develops series of courses for the Hydrogen Safety Credential

H2 to NG Working Group

The working group will focus on identifying safety considerations for projects related to introducing hydrogen into existing natural gas pipelines. This group will share best practices and identify safety topics that need further consideration.

Key Deliverables

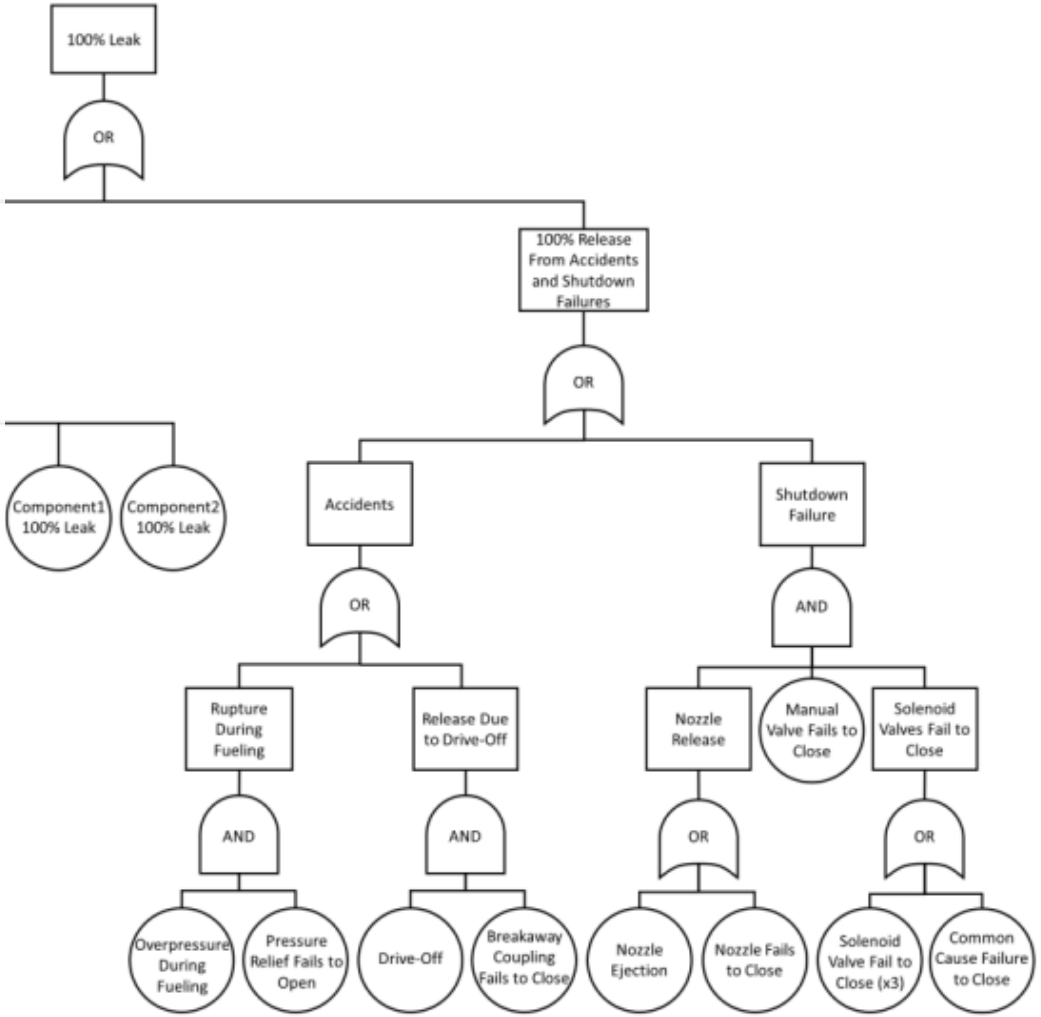
- Living Document that identifies the following:
  - Existing information and safety practices across the supply chain
  - Areas with conflicting information/best practices
  - Areas of importance where no information exists
- Prioritize "gaps" and Identify Solutions:
  - Which gaps in existing information are most important to solve first?
  - Identify potential solutions for closing this gap
- Recommendation for Next Steps

Risk Assessment/Failure Rates Working Group

This working group was initiated based on the need to identify global uniform failure rates for hydrogen for the purpose of conducting risk assessments.

Key Deliverables

- Short Term Goal – Identify what data is currently out there and what are the common risk assessment processes
- Long Term Goal- Compiling living document or database available for CHS Members, which can be updated with incident data



CHS Hydrogen Incident Response Activities

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Hydrogen Incident Occurs

CHS reaches out through established channels to gather all relevant information

CHS Holds Member Meeting

CHS convenes members to discuss incident and share information

CHS-HSP Participates in Fact Finding

HYDROGEN Safety Panel

CHS and the Hydrogen Safety Panel are available to help determine cause

CHS Develops Incident Record

CHS creates members-only incident report to track latest information and lessons learned

CHS Publishes Lessons Learned

HydrogenTools

CHS translates information into public lessons learned and publishes on H2Tools.org

Other resources CHS may use for responding to an incident:

- Education Materials – new courses, revised course content, etc.
- Technical Bulletins – members only and public safety bulletins developed and disseminated
- Working Groups – to address important safety issues and develop learnings for community and industry
- Conferences & Workshops – share incident information and learnings
- Incident Management Guide

Hydrogen Safety Panel (HSP)

CENTER FOR Hydrogen SAFETY Connecting a Global Community

THE HSP PROMOTES SAFE OPERATION, HANDLING, AND USE OF HYDROGEN

Background

- Formed in 2003
- 17 members with 500+ yrs 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)

18 Years

556 Reviews

389 Projects

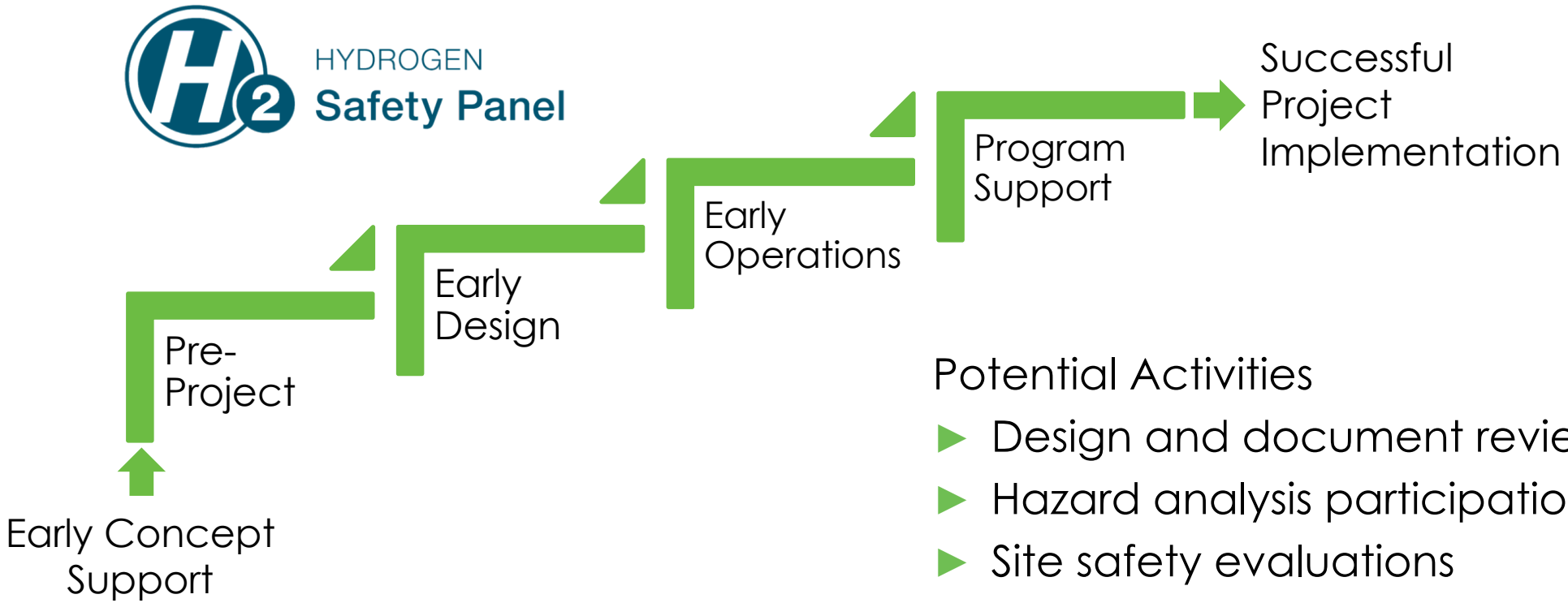
150+ Presentations

14 Guides

Impact

- Non-regulatory, objective, and neutral
- Helps reduce costs
  - Costs from over-engineering
  - Delayed approvals
  - Missed safety considerations/features
- Provides a balanced solution to questions and problems
- Helps projects avoid safety incidents
- Helps establish stakeholder and public confidence

CHS Use of the Hydrogen Safety Panel



Potential Activities

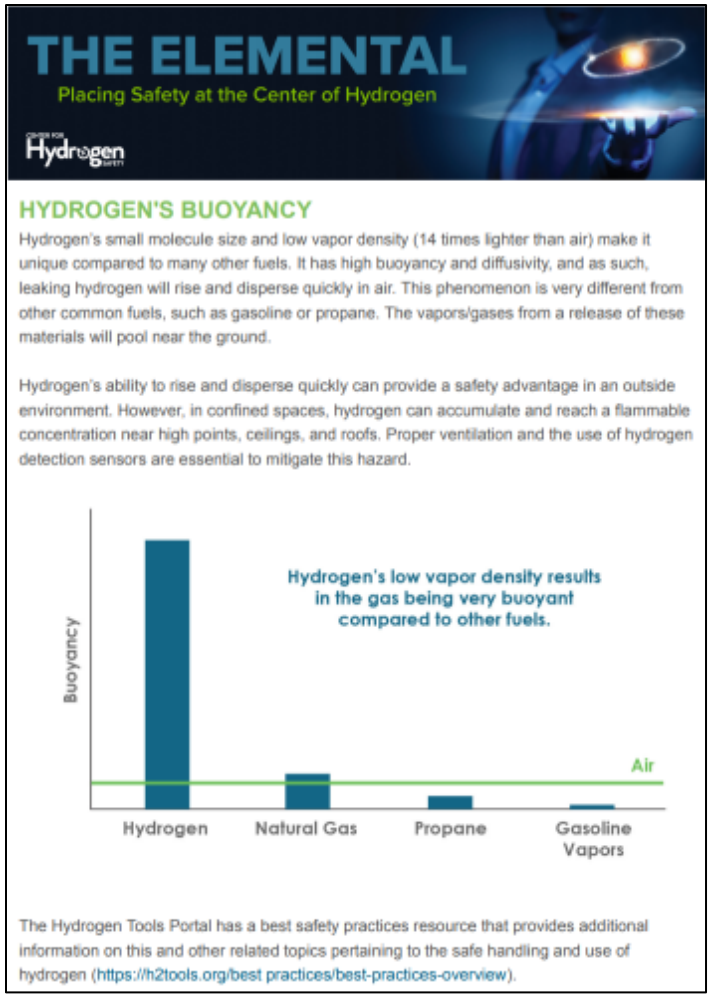
- Design and document reviews
- Hazard analysis participation/review
- Site safety evaluations
- Safety training and webinars
- Outreach
- Incident investigation

The Elemental

- CHS released its inaugural issue of our technical bulletin titled The Elemental: Placing Safety at the Center of Hydrogen on 10/08/2020. This bulletin provides a means to learn about and share hydrogen in an easy-to-access format.

- Available from www.aiche.org/chs. You can also subscribe to receive future newsletters and The Elemental at www.aiche.org/chsmailings.

- Let us know if you have suggestions for The Elemental? Email chs@aiche.org



THE ELEMENTAL

Placing Safety at the Center of Hydrogen

HYDROGEN'S BUOYANCY

Hydrogen's small molecule size and low vapor density (14 times lighter than air) make it unique compared to many other fuels. It has high buoyancy and diffusivity, and as such, leaking hydrogen will rise and disperse quickly in air. This phenomenon is very different from other common fuels, such as gasoline or propane. The vapors/gases from a release of these materials will pool near the ground.

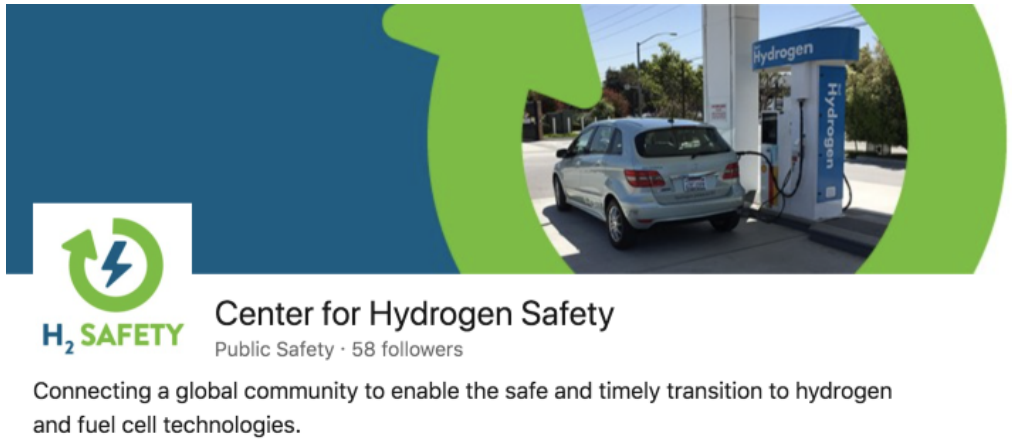
Hydrogen's ability to rise and disperse quickly can provide a safety advantage in an outside environment. However, in confined spaces, hydrogen can accumulate and reach a flammable concentration near high points, ceilings, and roofs. Proper ventilation and the use of hydrogen detection sensors are essential to mitigate this hazard.

The Hydrogen Tools Portal has a best safety practices resource that provides additional information on this and other related topics pertaining to the safe handling and use of hydrogen (https://h2tools.org/best practices/best-practices-overview).

Follow Us on LinkedIn

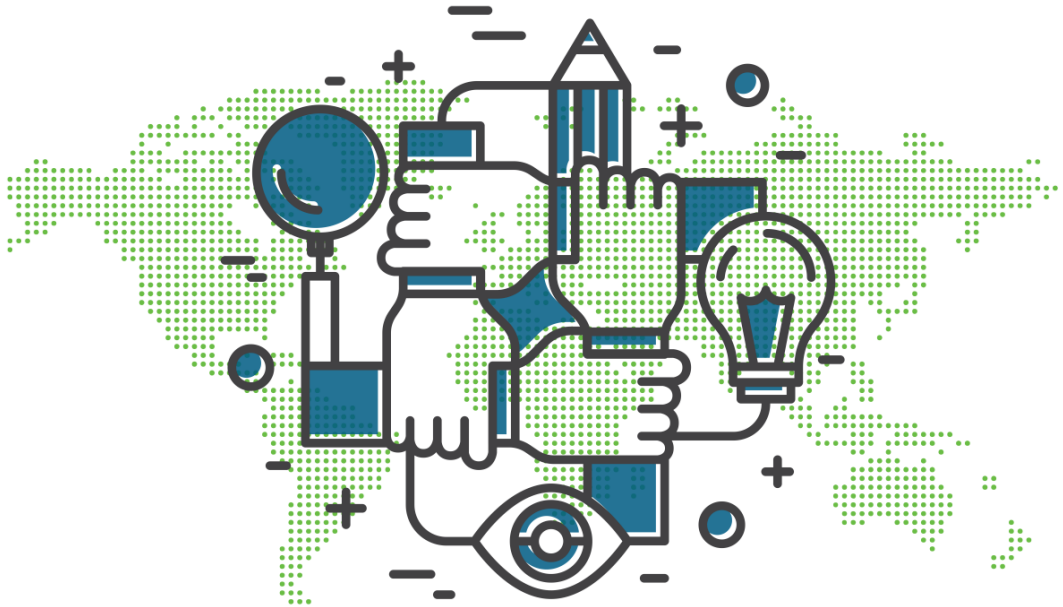
CHS Showcase Page

- Follow us at www.linkedin.com/showcase/center-for-hydrogen-safety/
- Posts will include member highlights and news, h2tools resources, upcoming events, conference promotion and snapshots, among others
- Let us know if you have news for us to cross-post



The CHS Growing Community Is...

- Demonstrating that safety is a fundamental principal for those deploying hydrogen technologies
- Ensuring that neutral and trustworthy hydrogen safety resources will be sustained and have global impact
- Ensuring safety is not a significant impediment to stakeholder and public acceptance of hydrogen technologies



Thanks for Your Attention!

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CHS… Bringing together individuals and organizations to develop and share best safety practices and learnings