CENTER FOR Hydrogen SAFETY
Connecting a Global Community

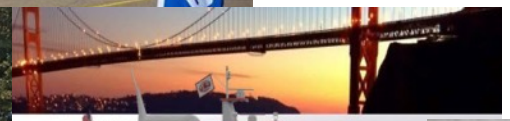


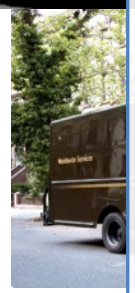


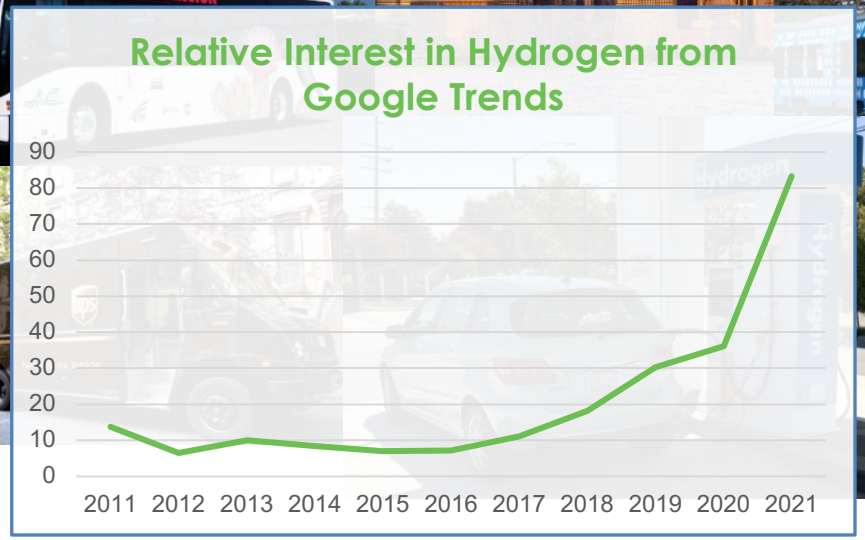
Hydrogen Safety Considerations and Resources

Nick Barilo
Executive Director, Center for Hydrogen Safety
March 25, 2022

Hydrogen's Great Potential







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)

Failure 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Did Outdated System Kill 128?--Col. 6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.**

Hydrogen Incidents… Seeing the Common Thread

- **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

Courtesy of Gangwon Fire HeadQuarter

Damage from Electrolyzer Incident

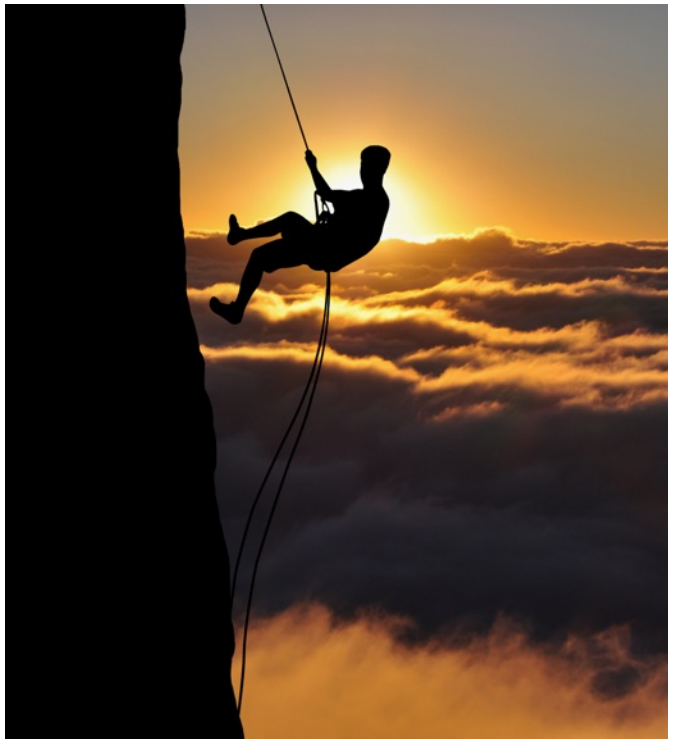
Three Parts, One Purpose, Strong Together

A threefold cord is not quickly broken

Implement Regulations, Codes and Standards

Utilize Best Safety Practices

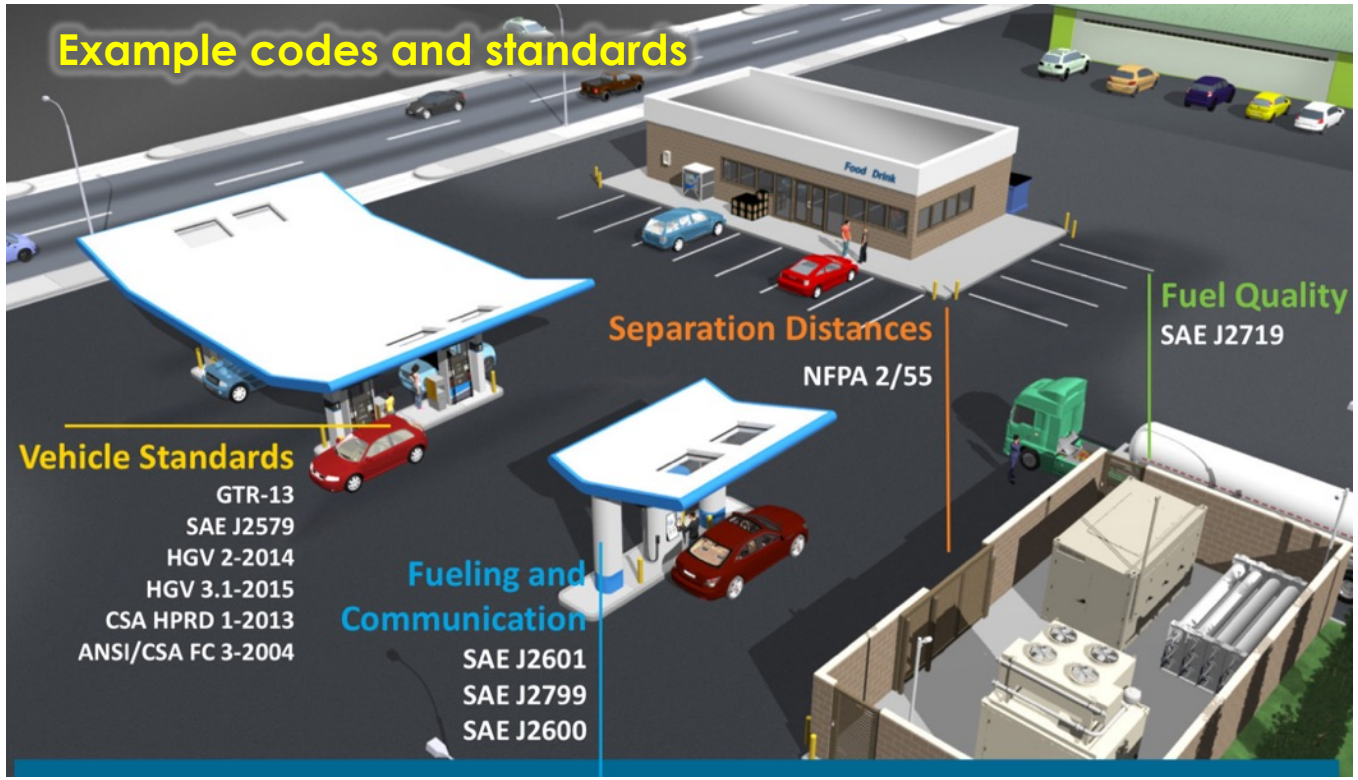
Be Invested in Safety



Implement Regulations, Codes and Standards

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

ISO/TC 197 Standards

Equipment	ISO Standard	CSA Group Standard	Other NA Standard
Fueling Stations	ISO 19880-1	CSA HGV 4.9	NFPA 2 BNQ 1784
Cylinders & Tubes for Stationary Storage	ISO 19884	---	ASME
Vehicle Fuel Tanks	ISO 19881	CSA HGV 2*	---
Pressure Relief Devices	ISO 19882	CSA HPRD 1*	---
Dispensers	ISO 19880-2	CSA HGV 4.1*	---
Station Valves	ISO 19880-3.2	CSA HGV 4.4* CSA HGV 4.6* CSA HGV 4.7*	---

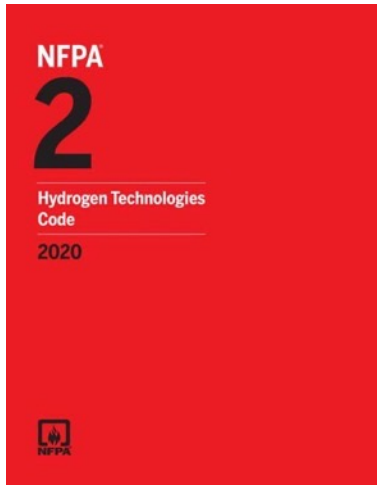
Equipment	ISO Standard	CSA Group Standard	Other NA Standard
Station Compressors	ISO 19880-4	CSA HGV 4.8*	---
Station Hoses	ISO 19880-5	CSA HGV 4.2*	---
Fueling Connection Device	ISO 17268	---	SAE J2600
Hydrogen Generators - Electrolysis	ISO 22734	CSA IR-4-14	---
Hydrogen Generators – Fuel Processing	ISO 16110	CSA FC 5 CSA 5.99	---
Hydrogen Fuel Quality	ISO 14687	----	SAE J2719 CGA G5.3

Info source: CSA Group

* CSA Group provided to ISO as a seed document

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*

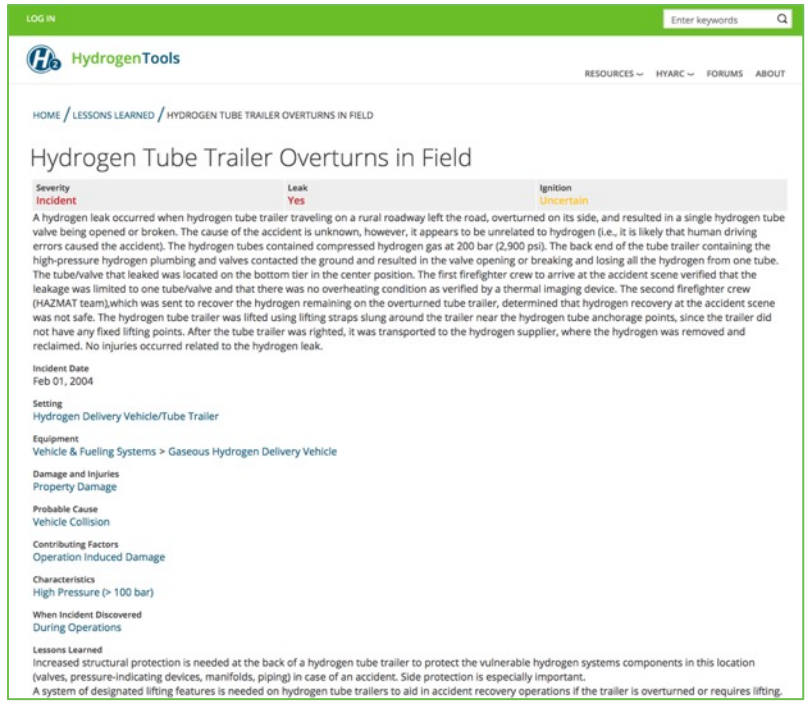
Utilizing Best Safety practices:

- 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.

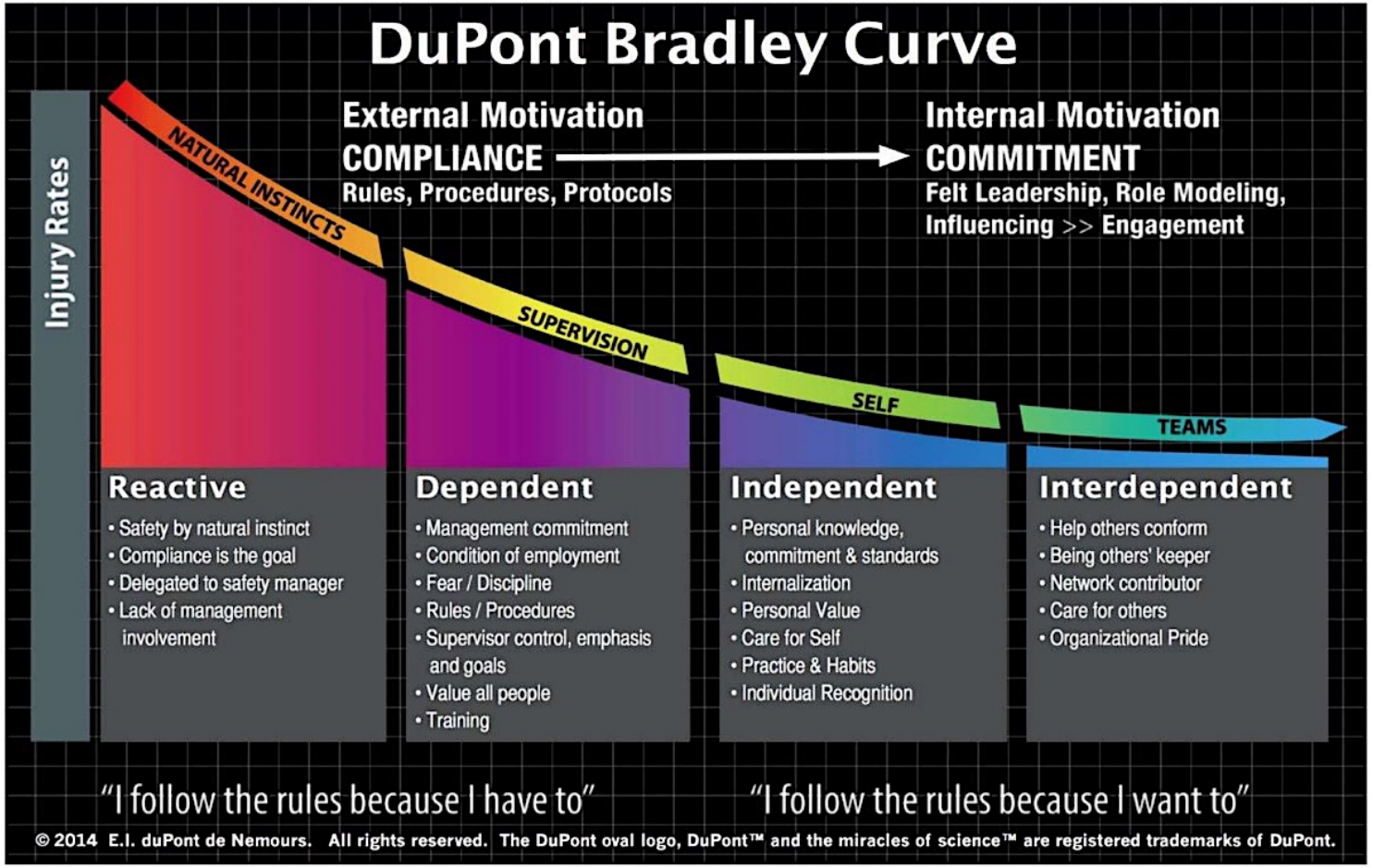


A best practice record from h2tools.org

Be Invested in Safety

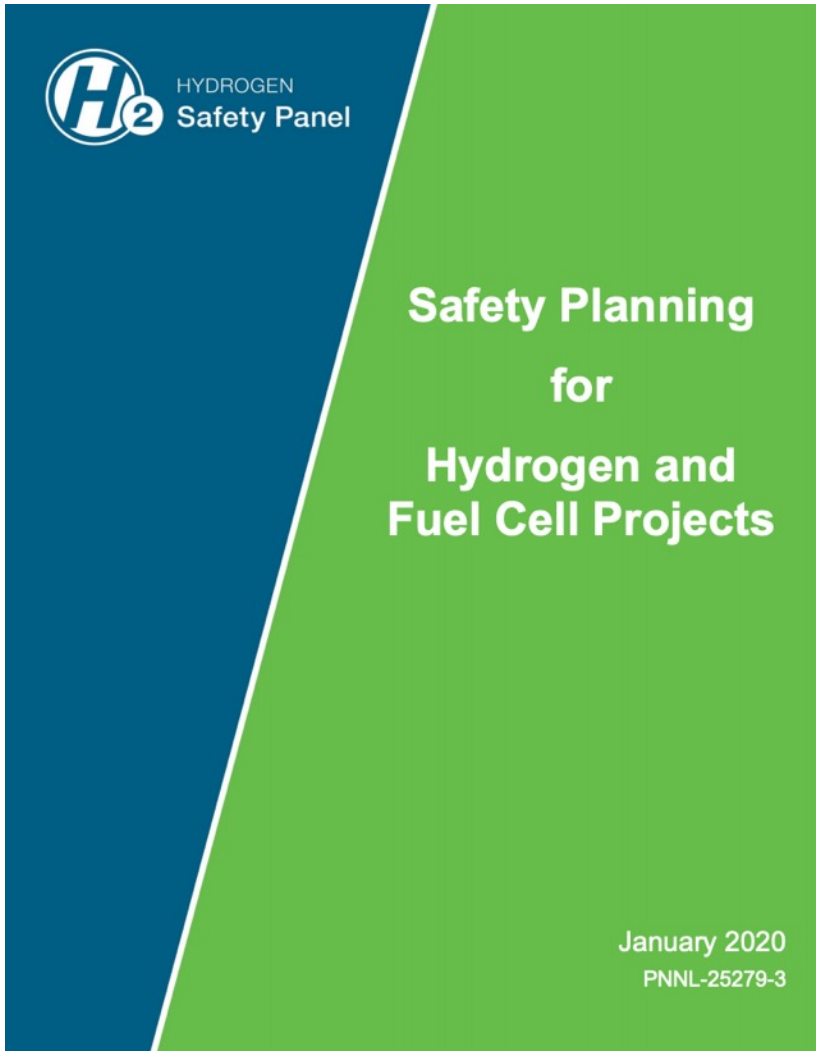
Investment in Safety:

- Is directly impacted by your organization's:
  - Beliefs
  - Perceptions
  - Values
- Is critical for:
  - Building a sustainable legacy
  - Maximizing an organization's impact and reaching goals
  - Ensuring long-term acceptance of the hydrogen industry
- Must be demonstrated
  - A culture of safety



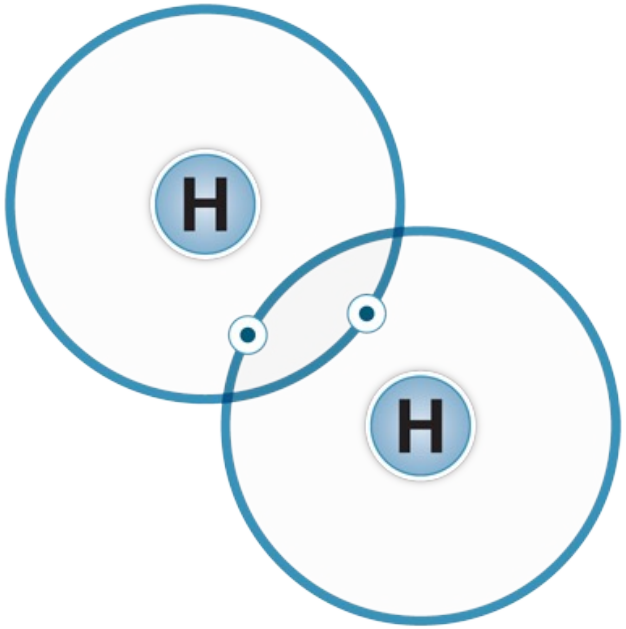
General Safety Planning

- Safety planning should be embraced as an integral part of the design, construction, operation and maintenance of a system rather than being considered an after thought or a barriers to overcome
- Safe practices in the production, storage, distribution, and use of hydrogen are **essential to protect people from injury or death, and to minimize damage to facilities**
- Safe practices will also help avoid negatively impacting the public's perception of hydrogen systems
- Helpful guidance on safety planning can be found at https://h2tools.org/bestpractices/safety-planning.



Hydrogen Properties and Behavior

- **Gas** at ambient conditions
  - Rises and disperses rapidly (14x lighter than air)
  - Flammable range 4-75% in air
- **Liquid** at -253°C (-423°F) – a *cryogen*
  - LH_2 stored at 50 psi in vacuum insulated tanks
  - No liquid phase in compressed gas H_2 storage
  - Liquid hydrogen expands about 850 times when transitioning transforming from liquid to gas phase
- **Energy content comparison** :
  - 1 kg 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 (1/15th air)
• GH_2 specific gravity	0.0696 (Air = 1.0)
• Viscosity	33.64 x 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 (fire and explosion)
- Pressure hazards
- Low temperature
- Hydrogen-induced material embrittlement
- Asphyxiation (rare)

Hydrogen Properties: *A Comparison*

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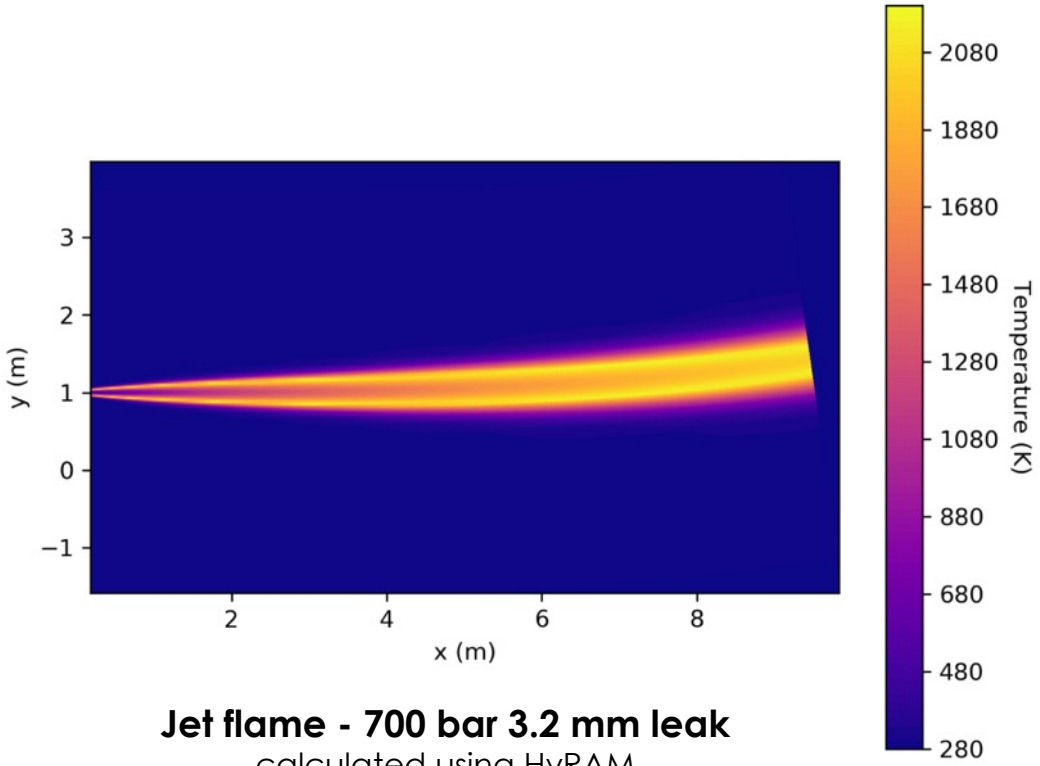
	Hydrogen Gas	Natural Gas	Gasoline
Toxicity	None	Some	High
Odor	Odorless	Yes (mercaptan)	Yes (benzene)
Buoyancy *Relative to **Air***	14X Lighter	2X Lighter	Vapor is 3.75X Heavier
Flammable Range by volume in air	4-75%	5-15%	1.4-7.6%
Autoignition Temperature (C)	585°	539°	232°
Minimum Ignition Energy (mJ)	0.017	0.288	0.250-0.300
Energy by Weight	2.8X > Gasoline	~1.2X > Gasoline	43 MJ/kg
Energy by Volume	4X < Gasoline	1.5X < Gasoline	120 MJ/Gallon

Characteristics of Hydrogen Gas Leaks

- Because of the small molecule, small leaks are common… and most are insignificant
- Virtually undetectable by human senses; could accumulate in confined locations, could result in
  - Asphyxiation or
  - Explosion and fire
- Leaking hydrogen <u>at ambient pressure</u> will rise and diffuse quickly in air because its low density results in high buoyancy
- High-pressure leaks can lead to explosions and/or jet flame fires



Jet flame - 700 bar 3.2 mm leak
calculated using HyRAM

The Safety Basics

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

- Eliminate hazards or define mitigation measures
- Ensure system integrity
- Provide proper ventilation to prevent accumulation
- Manage discharges
- Detect and isolate leaks
- Train personnel

Photo courtesy of Cummins

There is Much to Consider for Hydrogen Safety

Resources to Help You Navigate to Safety

HydrogenTools

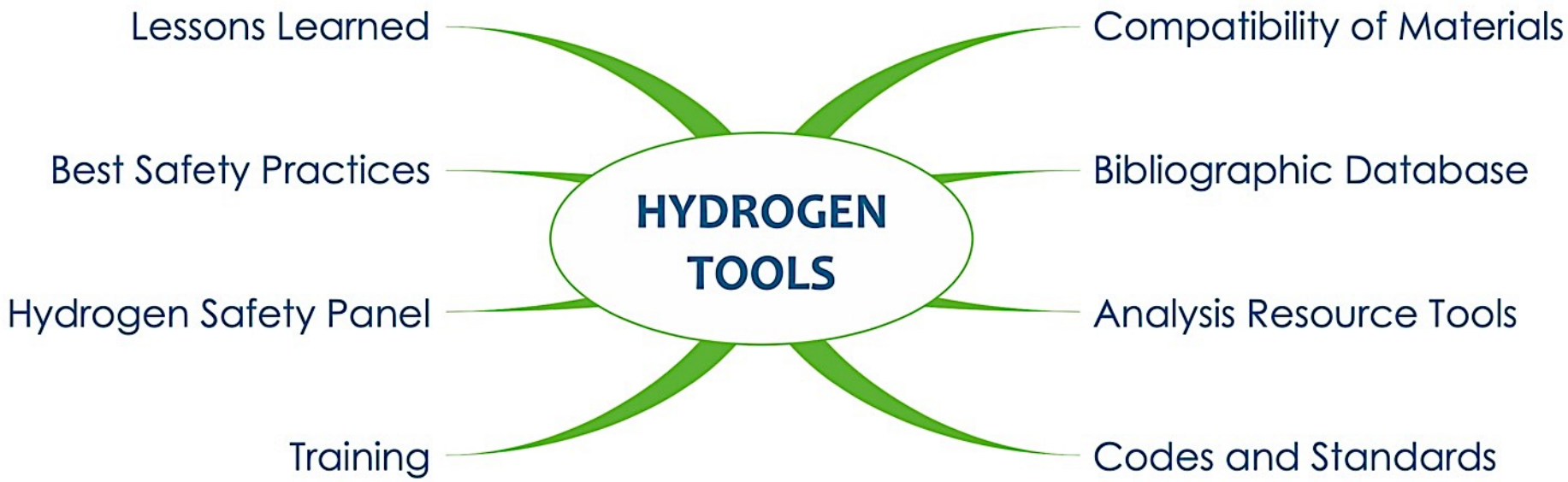
An online hydrogen information portal

CENTER FOR Hydrogen SAFETY

An international nonprofit focused on applied hydrogen safety

HydrogenTools URL: h2tools.org

Significant hydrogen safety resources in one location



- Supports implementation of the safe handling practices and procedures
- Brings together a variety of tools and web-based content on safety of hydrogen
- Informs designers, stakeholders and first responders

Center for Hydrogen Safety

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

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Organizations demonstrating a commitment to hydrogen safety

MEMBERS

STRATEGIC PARTNERS

Education and Training

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https://tinyurl.com/CHS-Course

Fundamental Hydrogen Safety E-Courses

- Hydrogen as an Energy Carrier
- Properties and Hazards
- Safety Planning
- Facility Design*
- Equipment and Components*
- Liquid Systems*
- Material Compatibility
- System Operation
- Inspection & Maintenance
- Laboratories**
- Electrolyzer Safety**
- Fueling Stations**
- Repair Garages**
- Hazard Analysis for H_2 Facilities**

First Responder Hydrogen Safety E-Courses

- Introduction to Hydrogen Safety for First Responders
- First Responders Micro Training Learning Plan
- Introduction to Hydrogen Fuel Cell Vehicles for Incident Response
- Fire Response & Extrication of a Hydrogen Fuel Cell Vehicle
- Transport of Hydrogen Fuel
- Hydrogen Fueling Station Incident Response

Other Training Resources

- Safety of Water Elecrolysis [Recorded Webinar]
- Global Hydrogen Safety Codes and Standards [Recorded Webinar]
- Ventilation Considerations for Hydrogen Safety [Recorded Webinar]
- Custom Virtual or In Person Hydrogen Safety Training

* Available early 2022 **Available mid-late 2022

Keep First Responders Informed & Prepared

- **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://tinyurl.com/yxfy66rp) and video-based training courses (https://tinyurl.com/y64q48ck)
  - Classroom and hands-on operations-level training
  - Trainer material (PowerPoint slides with speaker notes)

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.

Hydrogen Safety Panel (HSP)

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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)

19 Years

584 Reviews

413 Projects

200+ Presentations

15 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

HSP Members

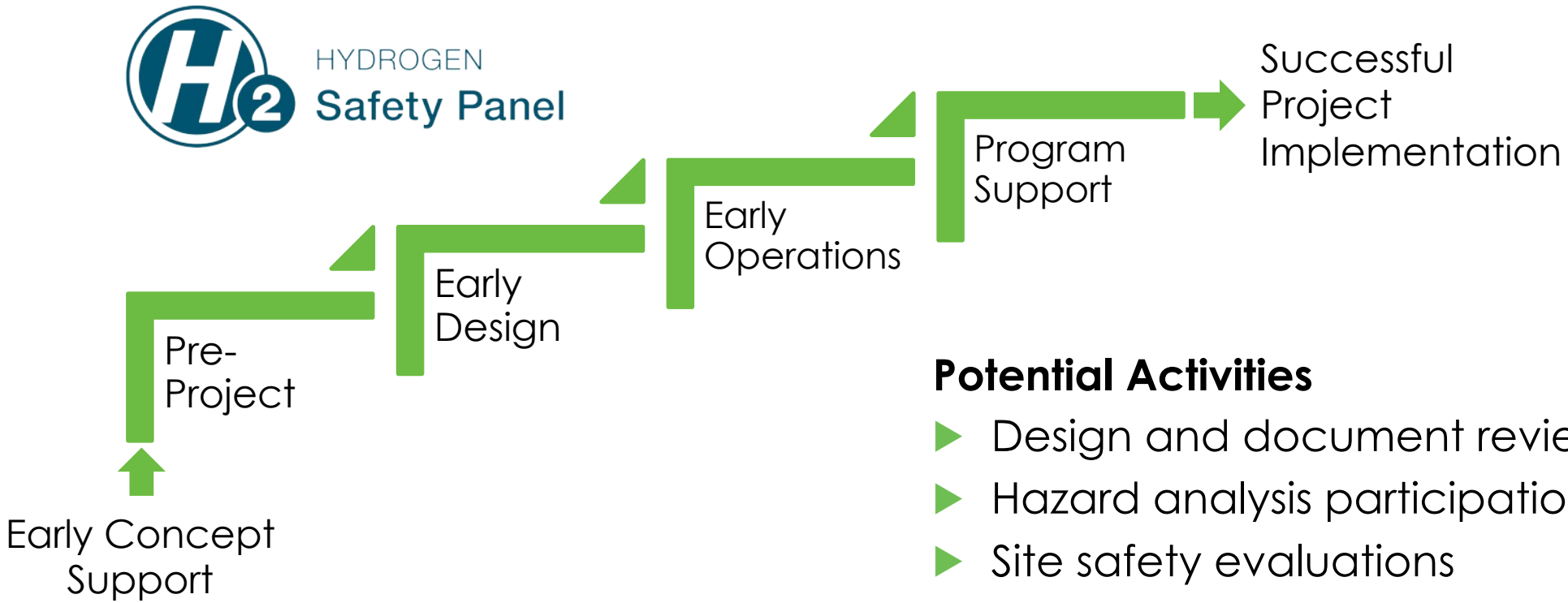
The HSP is a multidisciplinary team of engineers, code officials, safety professionals, equipment providers, and testing and certification experts.

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.

HSP at 2019 Panel Meeting

Name	Affiliation
Nick Barilo, Manager	Pacific Northwest National Laboratory
Rick Tedeschi, Chair	Tedeschi Consulting Solutions, LLC
Harold Beeson	WHA International, Inc
Ken Boyce	UL, LLC
David Farese	Air Products and Chemicals
Donald Frikken	Becht Engineering
Livio Gambone	Nikola Motors
Aaron Harris	Air Liquide
Brian Ladds	Calgary Fire Department
Chris LaFleur	Sandia National Laboratories
Miguel Maes	NASA-JSC White Sands Test Facility
Larry Moulthrop	Proton Onsite (retired)
Dani Murphy	WHA International, Inc.
Spencer Quong	Quong & Associates
Brian Somerday	Somerday Consulting, LLC
Gary Stottler	Stottler Development, LLC
Kelly Thomas	BakerRisk
Tom Witte	Witte Engineered Gases and Cryogenics
Robert Zalosh	Firexplo

CHS Use of the Hydrogen Safety Panel



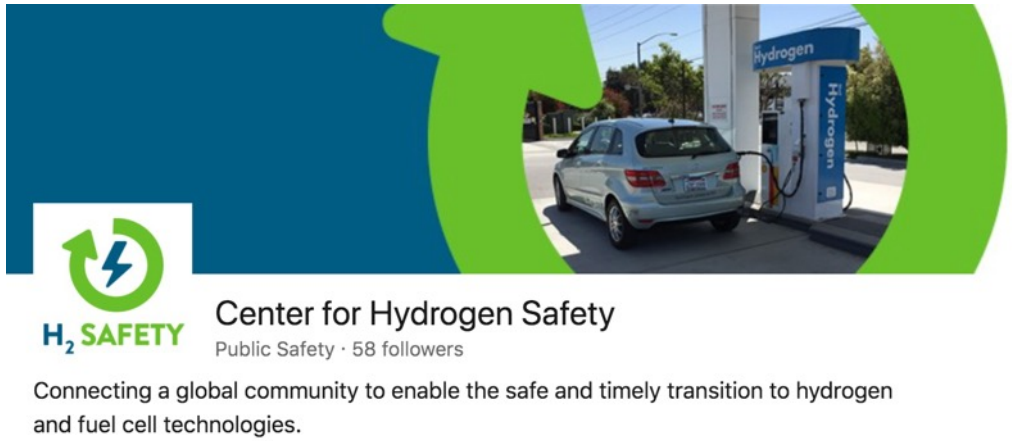
Potential Activities

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

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



Upcoming Webinar

- Covers metals and polymers
- R&D, real world application, lessons learned
- 60 min presentation, 30 min Q&A
- Live event free for non-members and members alike, invite your colleagues
- Archived version free to CHS members

Americas Hydrogen Safety Conference

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ANAHEIM

September 20-22, 2022

Anaheim, CA, US

The organizing committee will be forming in January. Let us know if you are interested in helping plan our next conference.

In conjunction with:

SOLAR POWER INTERNATIONAL

ESI ENERGY STORAGE INTERNATIONAL

SMART ENERGY MARKETPLACE + MICROGRID

H2 fci Hydrogen+ Fuel Cells International

wind ENERGY INTERNATIONAL

EV INTERNATIONAL

Concluding Thoughts

We must recognize that with the promise of hydrogen comes the responsibility of safety

- How will you ensure that hydrogen safety is a demonstrated value in your project and activities?
- How will you identify and address hydrogen safety vulnerabilities in your project or activities?
- How will you ensure that your staff are trained and equipped to identify and address hydrogen safety questions, concerns and challenges?

Being prepared and avoid having to deal with the consequences from an incident

Thanks for Your Attention!

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