CENTER FOR Hydrogen SAFETY
Connecting a Global Community

Hydrogen: The Significance of Safety

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April 17, 2024

Center for Hydrogen Safety (CHS)

A global non-profit community dedicated to promoting hydrogen safety and best practices worldwide

Our Vision

A world committed to hydrogen safety

Our Mission

As the recognized leader in hydrogen safety, we provide guidance, education, and collaborative forums to realize the successful and transformative benefits of hydrogen

CHS Will:

- Serve as the Global Champion for Hydrogen Safety
- Foster a Vibrant Community Committed to Hydrogen Safety
- Be the Premier Resource for Applied Hydrogen Safety

Rich in Resources
Strong in Collaboration
Focused on Impact

- ✓ Best Practices
- ✓ Lessons Learned
- ✓ Expert Reviews
- ✓ Education & Training
- ✓ Conferences
- ✓ Webinars & Workshops
- ✓ Incident Coordination
- ✓ Working Groups

See www.aiche.org/chs for more info

Why Safety?

- It is morally right
- Secures long-term benefits for you, your organization, and the wider community
- An organization's workplace is more efficient and productive
  - Workers are more productive
  - Reduce downtime
- Organizations are legally obliged to comply
- A good health and safety record is a source of competitive advantage
  - To attract investors and partnerships
  - Customers want to buy products and services that are produced ethically
- More and more, job hunters seek roles with employers who share their values

From https://iosh.com/news/why-health-and-safety-is-important/

Safety? Really?

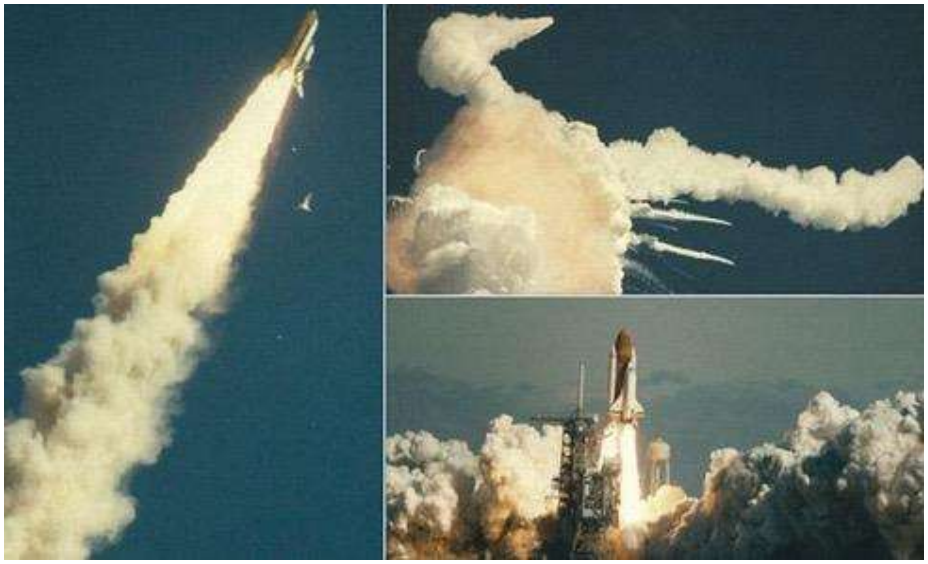
Can you prosper without an emphasis on safety?

- If you have a costly incident… **Do you have extra financial resources to cover it?**
- If the media identifies safety issues with your business... **Can you afford a good crisis communications team to deflect it?**
- If your product has safety issues… **Will your customers overlook it?**
- If your worker has an injury… **Will people will get over it?**
- If a permitting official doesn't think your activities are safe… **Can you afford the extra time and resources to convince them?**
- If a safety issue results in business interruption… **Can your assets cover the business loss?**
- Do your actions and behaviors have any affect on the industry or its public acceptance…

Incidents Won’t Happen to Me

An Incident Won't Happen to Me

December 1984



January 1986

Recent Hydrogen Incidents

- **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

These incidents and their consequences were avoidable

Courtesy of Gangwon Fire HeadQuarter

Damage from Electrolyzer Incident

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%

All Fuels Contain Energy…

…and can be hazardous if handled improperly

- **Gasoline**
  - ~1,000 fueling station fires per year in the U.S. as a result of gasoline ignition (2004-2008) (NFPA)
  - 345 deaths
  - 1,300 injuries
  - $1.1 billion USD in property loss
- **Natural Gas** – average/year (U.S. 2007-2011) (NFPA)
  - 13,730 fires
  - 35 deaths
  - 254 injuries
  - $303 million USD property damage

2019 Gasoline Station Fire

However, new fuels face a challenge for public acceptance

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)

Failing to address the knowledge gaps can result in impactful incidents and industry setbacks

Unique Properties and Hazards of Hydrogen

General Properties of Hydrogen

- **Description**
  - Colorless, odorless, tasteless

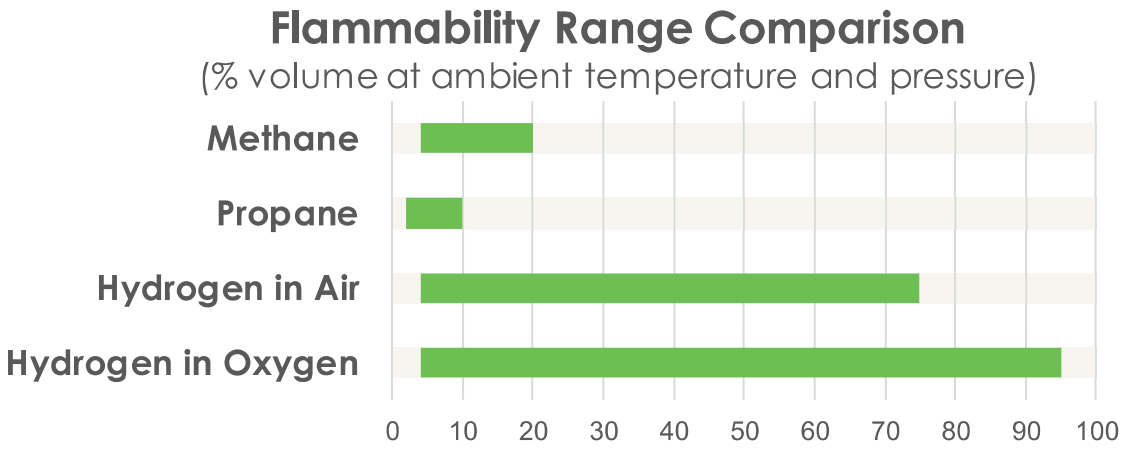
- **General Properties**
  - Flammable
  - Non-irritating, nontoxic, asphyxiant
  - Non-corrosive
  - Lightest gas, buoyant, can escape earth's gravity

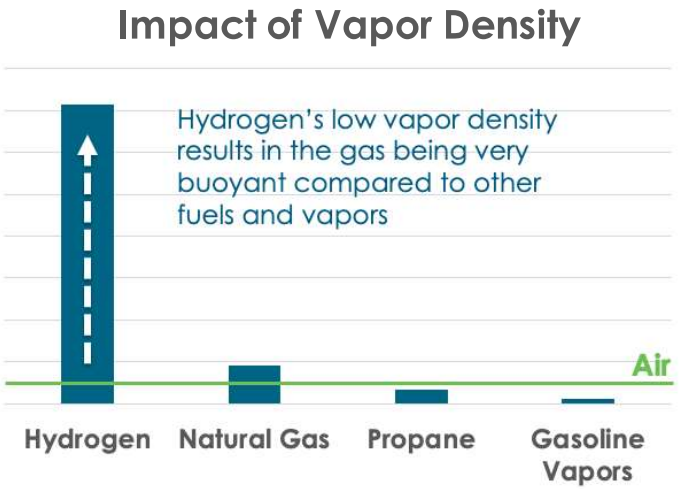
- **Physical Properties**
  - GH_2 density @ NTP — 0.0838 kg/m^3 (1/15th air)
  - GH_2 specific gravity — 0.0696 (Air = 1.0)
  - Viscosity — 33.64 x 10^{-3} kg/m hr (1/2 air)
  - Diffusivity — 1.697 m^2/hr (4x NG in air)
  - Thermal Conductivity — 0.157 kcal/m hr K (7 x air)

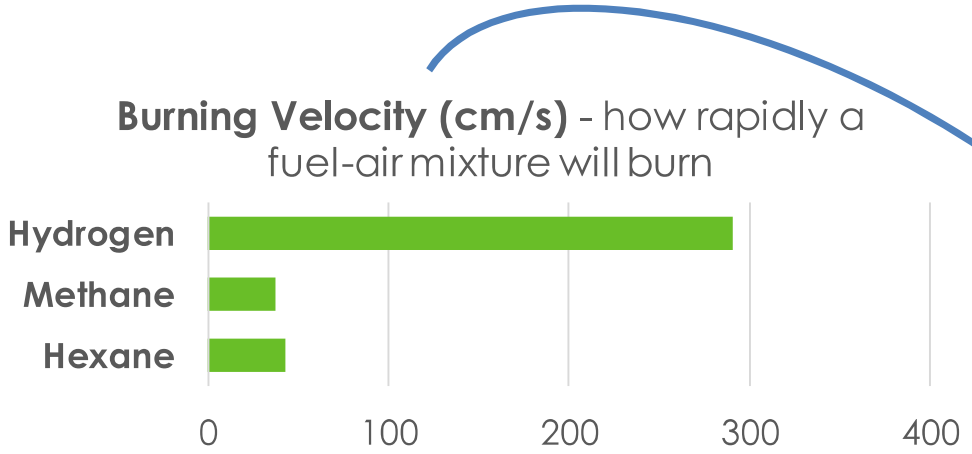
Potential Hazards

- Combustion (fire and explosion)
- Pressure hazards
- Hydrogen-induced material embrittlement
- Asphyxiation (rare)
- Low temperature (LH2)

Comparing Properties







Higher burning velocities are more likely to generate explosive overpressure, especially when in confined or congested areas

Comparing Fuels

	Hydrogen Gas	Natural Gas	Gasoline
Toxicity	None	Yes (mercaptan)	Yes (benzene)
Odor	None	Mercaptan	Yes
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%
Most Easily Ignited Mixture in air	29%	9%	2%
Autoignition Temperature (C)	585°	539°	232°
Flame Temperature (C)	2,210°	1,961°	1,977°
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

Comparing Common Fuel Leaks

Hydrogen

- Will disperse quickly after pressure has equalized

Natural Gas

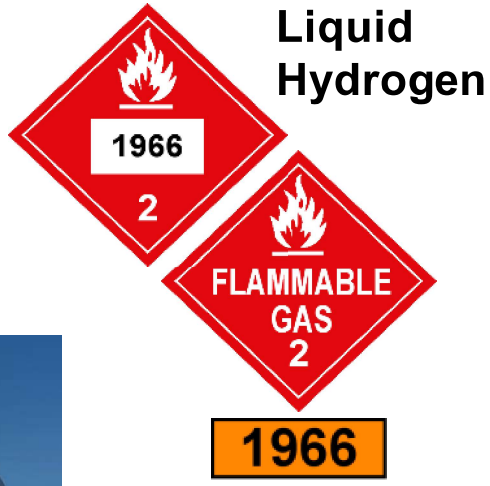
- Will disperse more slowly

Gasoline

- Will pool
- Vapors will remain on the ground until the liquid:
  - Volatilizes
  - Is cleaned up
  - Is consumed

Liquid Hydrogen Properties and Behaviors

- Liquid at –423°F (–252.8°C)
- Can lead to cryogenic burns if it has contact with human tissue
- Liquid H_2 rapidly vaporizes
- Liquid to gas volume ratio is 1:848 at STP
- Approximately 14 x less dense than water
- Non-corrosive with light-blue tint
- LH_2 spill will result in condensation of water vapor creating a fog-like plume even in dry climates

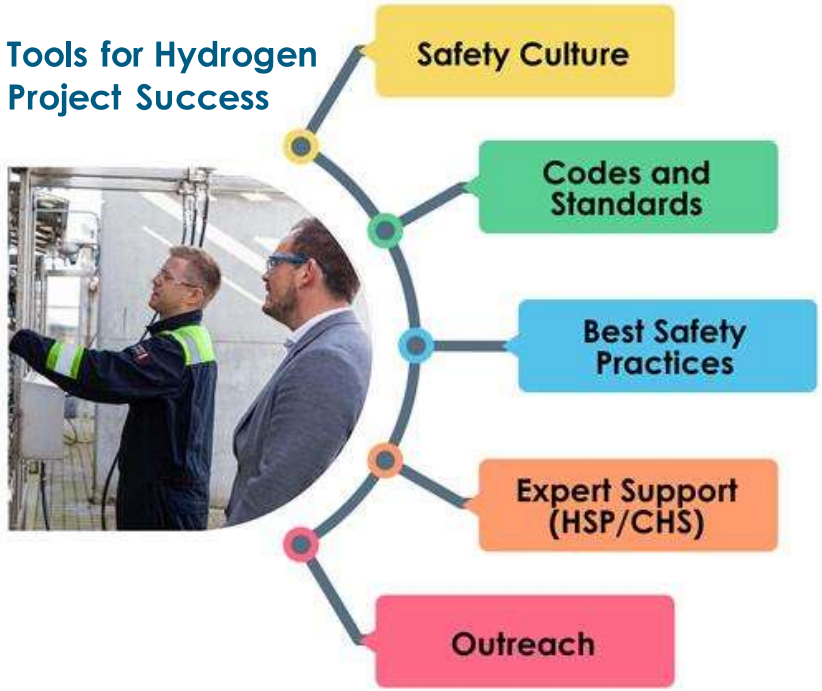


Source: U.S. Department of Transportation

What's Needed for Success?

Steps to Safely Power Progress

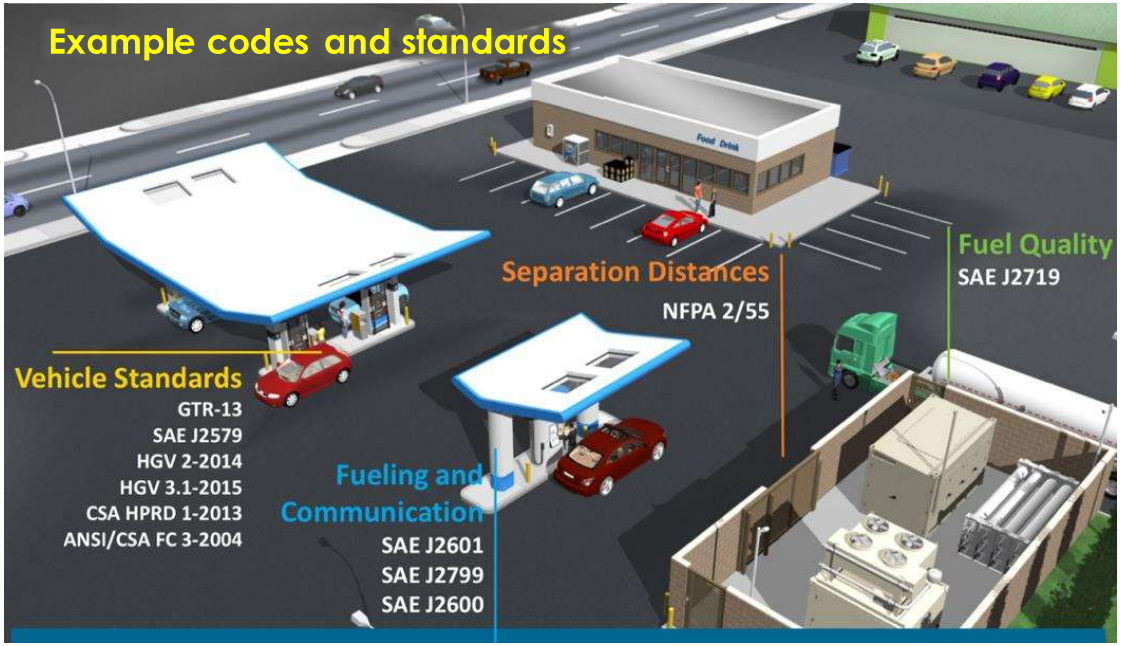
- Require an emphasis on safety for hydrogen projects
  - Establish minimum safety criteria
  - Ensure that a hydrogen safety plan is developed
  - Emphasize the need for a strong safety culture
- Prepare approval authorities
  - Provide education opportunities
  - Connect them with helpful resources and others who have been involved in similar projects
- Train first responders
- Connect with the community… outreach
- Engage with outside resources to help
  - Hydrogen Safety Panel
  - Center for Hydrogen Safety



Regulations, Codes and Standards

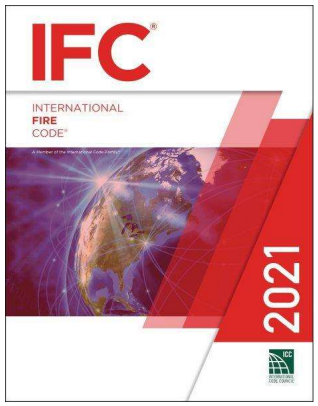
Hydrogen regulations, codes and standards (RCS) are maturing quickly for many mainstream fuel cell applications. RCS:

- Provide the information needed to safely build, maintain, and operate equipment, systems, and facilities
- Ensure uniformity of safety requirements
- Provide inspectors and safety officials the information needed to approve systems and installations
- Bolster public and stakeholder confidence
- Help protect investments

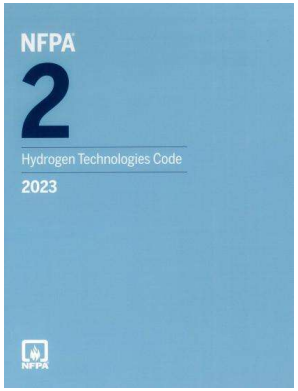


BUT… just following codes and standards is not enough

U.S. Codes and Standards



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

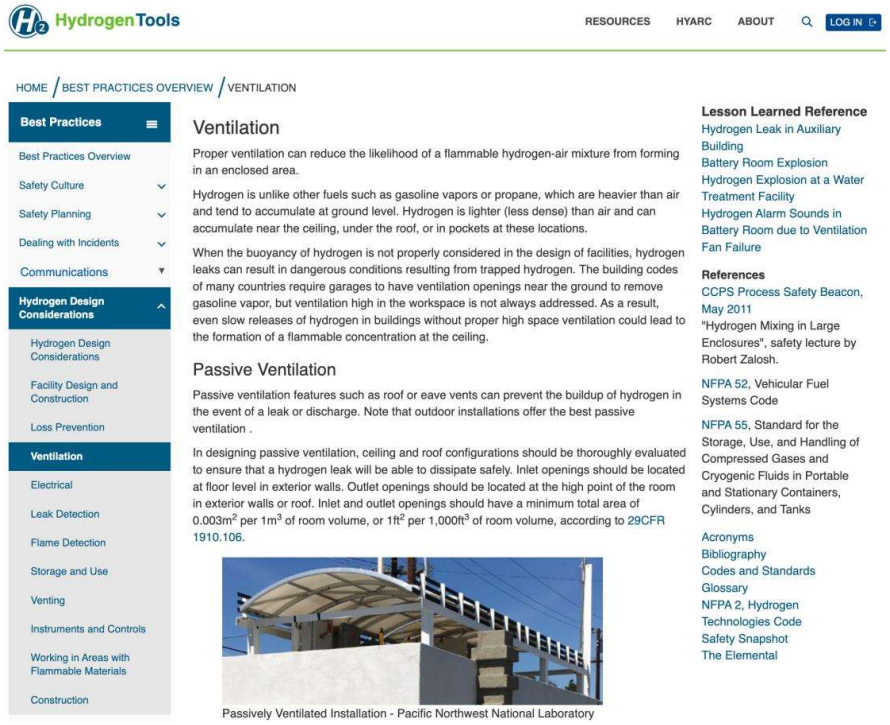
Those who cannot remember the past are condemned to repeat it. - George Santayana

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.

H2Tools.org contains 100 pages of best safety practices.



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

Start by Making Safety a Culture

Safety Culture Framework

- ✓ Safety is a Clearly Recognized Value
- ✓ Leadership for Safety is Clear
- ✓ Accountability for Safety is Clear
- ✓ Safety is Integrated into All Activities
- ✓ Safety is Learning Driven

An established best safety culture practice will ensure consistency in hydrogen energy equipment and facilities and help create trust in the ability of the hydrogen energy industry to deliver safe, reliable, and high-quality products and services. - A. Tchouvelev

How's your organization's safety culture?
Take our questionnaire at: https://h2tools.org/form/hydrogen-safety-culture-question

Engage Your Community

An uninformed community is less likely to accept or embrace new technology

Outreach Focus:

- In-person events offer the best opportunity for a positive impact
- Include stakeholders, approval authorities, first responders, and the public
- Highlight technology differences and address safety issues
- Provide significant time for questions and interaction

In-person outreach will yield a positive experience for most attendees and bolsters public confidence

Workforce Development

Creating, Sustaining, and Retaining a Viable Workforce

In the face of rapid technological change, industrialized economies worldwide share concerns about a growing mismatch between employers' needs and workers' skills.[1]

- Hydrogen's use as an energy carrier is new to much of the population, and workers lack the basic knowledge and skills
- The need for workers is likely to grow very quickly
- Short- and long-term planning is needed
  - Short courses, technical schools, colleges, and universities may all be needed
- Key aspects needed for the success of hydrogen and fuel cell technologies
  - Recruitment
  - Training and Education
    - Pre-employment
    - On-the-Job
    - Incumbent worker training
    - Apprenticeships
  - Retention and up-skilling

[1] https://workofthefuture.mit.edu/wp-content/uploads/2020/07/WotF-Working-Paper-04-2020.pdf

CHS and H2Tools

Connecting 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

Resources to Help You Navigate to Safety

HydrogenTools

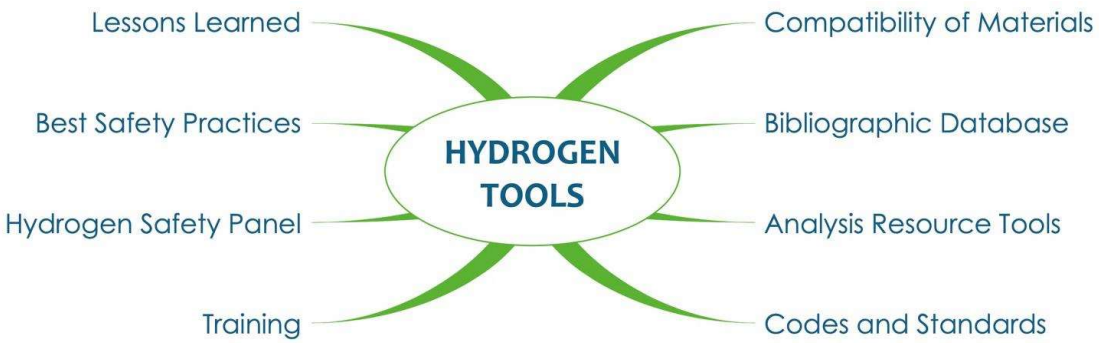
An online hydrogen information portal

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

Site Content

3,661	Total pages
2,768	Bibliographic references
221	Lessons learned pages
100	Best safety practices pages
503	Hydrogen/Fuel Cell Codes & Standards
135	(NEW) FAQs

Usage Stats*

46,559	Maximum pageviews in one month
42,335	Average pageviews/month
4.58	Avg. Pages visited per session
7	Minutes per session

* Nonbounce statistics January 1, 2023 through October 31, 2023

Center for Hydrogen Safety (CHS)

- **A global community working together** to:
  - Resolve hydrogen safety issues
  - Develop and promote hydrogen safety best practices
  - Demonstrate the industry's commitment to using hydrogen safety

- **Expert hydrogen safety review services** help organizations evaluate risk and remove barriers by:
  - Reviewing facility/equipment design and operations
  - Participating in formal hazard evaluation (HAZOPs, etc.)
  - Assisting in incident fact-finding and investigation

- **Essential resources to increase knowledge** and expertise, including:
  - eLearning courses and credentialing
  - Technical webinars
  - Conferences and workshops

CHS - 5 Years of Accomplishments

CELEBRATING 5 YEARS

CENTER FOR Hydrogen SAFETY
Connecting a Global Community

Training & Education

11 Webinars
4,000 Attendees

16 eLearning Courses
17,000 Attendees

Live Training
1,500 Attendees

120 Credentials Earned

Knowledge Sharing

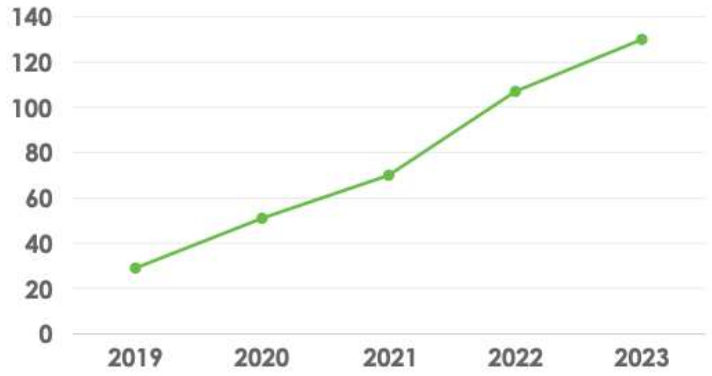
7 Global Conferences
900 Attendees

20 Incidents Tracked

90 Average Number of Members in Monthly Meetings

3,300 LinkedIn Followers

Members & Strategic Partners



ICC PREFERRED EDUCATION PROVIDER

Education and Training

CELEBRATING 5 YEARS

CENTER FOR Hydrogen SAFETY Connecting a Global Community

https://tinyurl.com/CHS-Training

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

- Electrolyzer Safety
- Hydrogen Laboratory Safety
- H_2 Fueling Station Safety (in development)

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

Recorded Webinars

- Safety of Water Electrolysis
- Global Hydrogen Safety Codes and Standards
- Ventilation Considerations for Hydrogen Safety
- Material Compatibility Considerations for Hydrogen
- Overview of Hazard Analysis for Hydrogen Applications
- Safety for the Transportation and Delivery of Hydrogen
- Liquid Hydrogen: Safety and Design Considerations
- Gaseous Hydrogen: Safety Considerations
- Laboratory Hydrogen Safety
- Vent System Design Considerations

CHS Hydrogen Incident Response Activities

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


CENTER FOR Hydrogen SAFETY
Connecting a Global Community
MEMBERS
achs
AcuTech PROCESS RISK MANAGEMENT
ASTRA
Air Liquide
AIR PRODUCTS
BAKERRISK
Atura Power
APEX CLEAN ENERGY
BLACK & VEATCH
Bloomenergy
BrainDrip
Brookhaven National Laboratory
BUREAU VERITAS
CATERPILLAR
Center of Excellence for Clean Energy
CF
Chevron
Chevron Phillips Chemical Company LP
ENERGY INSTITUTE COLORADO STATE UNIVERSITY
conEdison
Constellation
CSA GROUP
CSIRO
Cummins
Dräger
Downer Relationships creating success
ELECTRIC HYDROGEN
Endress+Hauser People for Process Automation
EPRI ELECTRIC POWER RESEARCH INSTITUTE
EMCARA
Element A Resourceful Company
ENEOS
ENGIE
equinor
EVERSOURCE
ExxonMobil
TRUE ZERO
bp
FLUOR
FuelPositive Fuel For A Mindful World
GEXCON
GTI ENERGY
HTEC FUELING THE DRIVE TO HYDROGEN
HY STOR ENERGY
Hysata
HYSTER-YALE GROUP
HYUNDAI
HAVRAND
Hydro
Honeywell
HYDROGEN RESEARCH INSTITUTE UQTR
IH Independence Hydrogen
intertek
Iwatani Group Iwatani Corporation of America
JENSEN HUGHES
JGC
Kawasaki
Kiewit
한국가스안전공사 KOREA GAS SAFETY CORPORATION
Linde
MACQUARIE University SYDNEY·AUSTRALIA
MITSUBISHI HEAVY INDUSTRIES
MYONGJI UNIVERSITY
nationalgrid
NREL NATIONAL RENEWABLE ENERGY LABORATORY
Nebraska Public Power District Always there when you need us
PETRONAS
NIKOLA
HySA Infrastructure Hydrogen South Africa
NOVO HYDROGEN
NW Natural
NEW YORK STATE OF OPPORTUNITY. NYSERDA
OAK RIDGE National Laboratory
Pacific Northwest NATIONAL LABORATORY
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SAN JUAN COLLEGE School of Energy
Sandia National Laboratories
PowertechUSA
Savannah River National Laboratory
ICC INTERNATIONAL CODE COUNCIL
ohmium
MISSISSIPPI POLYMER INSTITUTE
origin
stanwell
STAR SCIENTIFIC
TC Energy
SAPPHIRE GAS SOLUTIONS
aramco
Sargent & Lundy
UL
UNIVERSITY OF DELAWARE
RIO HONDO COLLEGE AUTOMOTIVE
Swagelok
Southern Company
WOODWARD
tenova
Chemours
PILOT COMPANY
TOYOTA
UNIVERSITY OF MARYLAND
slb
SoCalGas
A Sempra Energy utility
WASHINGTON STATE UNIVERSITY
WHA
Williams
Woodside
Xcel Energy
UNIVERSITY of HOUSTON
THE HANG UNIVERSITY

Hydrogen Safety Panel (HSP)

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

Background

- Formed in 2003
- 22 members with 600+ 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)

21 Years

643 Reviews

462 Projects

300+ 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

CHS Use of the Hydrogen Safety Panel

HYDROGEN Safety Panel

Early Concept Support

Pre-Project

Early Design

Early Operations

Program Support

Successful Project Implementation

Potential Activities

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

2024 CHS Americas Conference

Conference Dates: May 21-23, 2024

Location: Las Vegas, US

Topics include:

- Fundamental Safety Considerations and Best Safety Practices
- Regulations, Codes and Standards
- Incidents and Lessons Learned
- Blending Applications
- Safe Storage and Production

Gaseous Hydrogen: Safety Considerations (2 hours)

Learn about the unique properties of hydrogen, along with its hazards and crucial safety considerations.

Course credits: Earn 2 PDHs or 0.2 CEUs

Vent System Design (2 hours)

Explore vital design considerations for hydrogen vent systems during this insightful session.

Course credits: Earn 2 PDHs or 0.2 CEUs

NFPA 2 Hydrogen Technologies Code (4 hours)

Gain the basic knowledge needed to begin applying this code.

Course credits: Earn 4 PDHs or 0.4 CEUs

Learn more and register at: https://www.aiche.org/chs

Committed to Safety

CENTER FOR Hydrogen SAFETY
Connecting a Global Community
MEMBER

Steps to ensure hydrogen safety is a part of your organization's priority

- **Participate** – attend a conference or webinar
- **Educate** – fundamental and intermediate continual learning
- **Belong** – be a part of the CHS community and help power progress together

Join the CHS Community

CELEBRATING 5 YEARS

CENTER FOR Hydrogen SAFETY Connecting a Global Community

Become part of a vibrant community to network, learn and make a difference

- **Access to a Vibrant Community**
  - The network provides an excellent platform for exchanging ideas, sharing experiences, and fostering collaborations
- **Educational Opportunities**
  - Access to both free and discounted eLearning courses and webinars, helping members to be prepared to be well prepared to help their organization's success
- **Participation in Member Meetings**
  - The meetings provide valuable platforms for networking, learning from peers, and discussing recent developments in hydrogen safety
- **Learning from Recent Incidents**
  - Stay updated on recent incidents and engage with the community to analyze and learn from what occurred
- **Participation in Working Groups**
- **Support from the Hydrogen Safety Panel at the exclusive member rate**

Want more information?
Schedule a short virtual meeting

For more information, see https://www.aiche.org/chs/membership

Together, we can create

A world committed to hydrogen safety

Thanks for Your Attention

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