

Hydrogen Safety: An Elemental Need for Powering Progress

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November 1, 2023



Hydrogen's Great Potential



Why Safety?

- ▶ It is morally right
- ▶ Secures long-term benefits for you, your business, and the wider community
- ▶ Workplace are 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/>

The Impact of Incidents

The Impact of Incidents



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



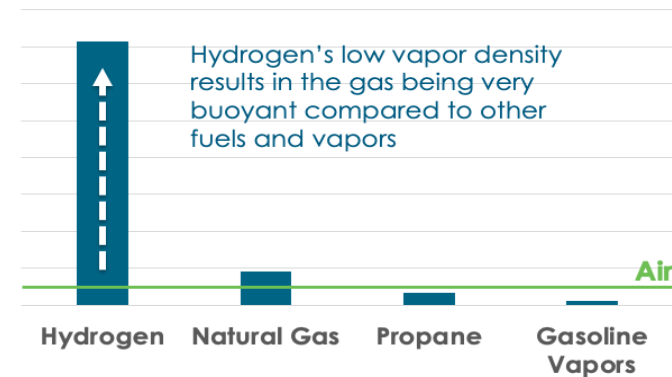
Courtesy of Gangwon Fire HeadQuarter

Damage from Electrolyzer Incident

Unique Hydrogen Properties

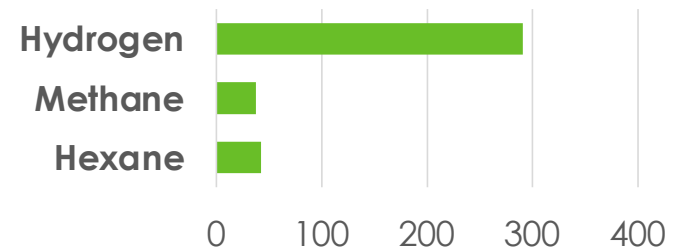
- ▶ Most abundant element in the universe
- ▶ Excellent energy carrier
- ▶ Ultra-low/Zero emissions (when used in fuel cells)
- ▶ Rises and disperses rapidly (14x lighter than air)
- ▶ Easily ignitable
- ▶ Large flammability range: 4-75% in air
- ▶ High burning velocity
- ▶ Smallest molecule
- ▶ Can embrittle some materials
- ▶ Pure hydrogen flames are difficult to see
- ▶ Pressure hazards (GH₂)
- ▶ Low-temperature hazards (LH₂)
- ▶ No odorant (yet)

Impact of Vapor Density



Burning Velocity (cm/s)

how rapidly a fuel-air mixture will burn



Let's Stay Balanced... but Focused

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

Safely Powering Progress with Hydrogen

There is Much to Consider



Tools for Hydrogen Project Success



- Safety Culture
- Codes and Standards
- Best Safety Practices/Lessons Learned
- Expert Support (HSP/CHS)
- Outreach

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>

Implement Regulations, Codes and Standards

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

- ▶ Provides 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
- ▶ Helps protect investments



BUT... just following codes and standards is not enough

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>

H₂ HydrogenTools RESOURCES HYARC ABOUT LOG IN

HOME / BEST PRACTICES OVERVIEW / VENTILATION

Best Practices

- Best Practices Overview
- Safety Culture
- Safety Planning
- Dealing with Incidents
- Communications
- Hydrogen Design Considerations**
- Hydrogen Design Considerations
- Facility Design and Construction
- Loss Prevention
- Ventilation**
- Electrical
- Leak Detection
- Flame Detection
- Storage and Use
- Venting
- Instruments and Controls
- Working in Areas with Flammable Materials
- Construction

Ventilation

Proper ventilation can reduce the likelihood of a flammable hydrogen-air mixture from forming in an enclosed area.


Hydrogen is unlike other fuels such as gasoline vapors or propane, which are heavier than air and tend to accumulate at ground level. Hydrogen is lighter (less dense) than air and can accumulate near the ceiling, under the roof, or in pockets at these locations.

When the buoyancy of hydrogen is not properly considered in the design of facilities, hydrogen leaks can result in dangerous conditions resulting from trapped hydrogen. The building codes of many countries require garages to have ventilation openings near the ground to remove gasoline vapor, but ventilation high in the workspace is not always addressed. As a result, even slow releases of hydrogen in buildings without proper high space ventilation could lead to the formation of a flammable concentration at the ceiling.

Passive Ventilation

Passive ventilation features such as roof or eave vents can prevent the buildup of hydrogen in the event of a leak or discharge. Note that outdoor installations offer the best passive ventilation .

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. Outlet openings should be located at the high point of the room in exterior walls or roof. Inlet and outlet openings should have a minimum total area of 0.003m² per 1m³ of room volume, or 1ft² per 1,000ft³ of room volume, according to 29CFR 1910.106.



Passively Ventilated Installation - Pacific Northwest National Laboratory

Lesson Learned Reference

- Hydrogen Leak in Auxiliary Building
- Battery Room Explosion
- Hydrogen Explosion at a Water Treatment Facility
- Hydrogen Alarm Sounds in Battery Room due to Ventilation Fan Failure

References

- CCPS Process Safety Beacon, May 2011
- "Hydrogen Mixing in Large Enclosures", safety lecture by Robert Zalosh.
- NFPA 52, Vehicular Fuel Systems Code
- NFPA 55, Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks

Acronyms
Bibliography
Codes and Standards
Glossary
NFPA 2, Hydrogen Technologies Code
Safety Snapshot
The Elemental

How Do I Get Expert Support?

Two Vital Resources



Online hydrogen safety information tools

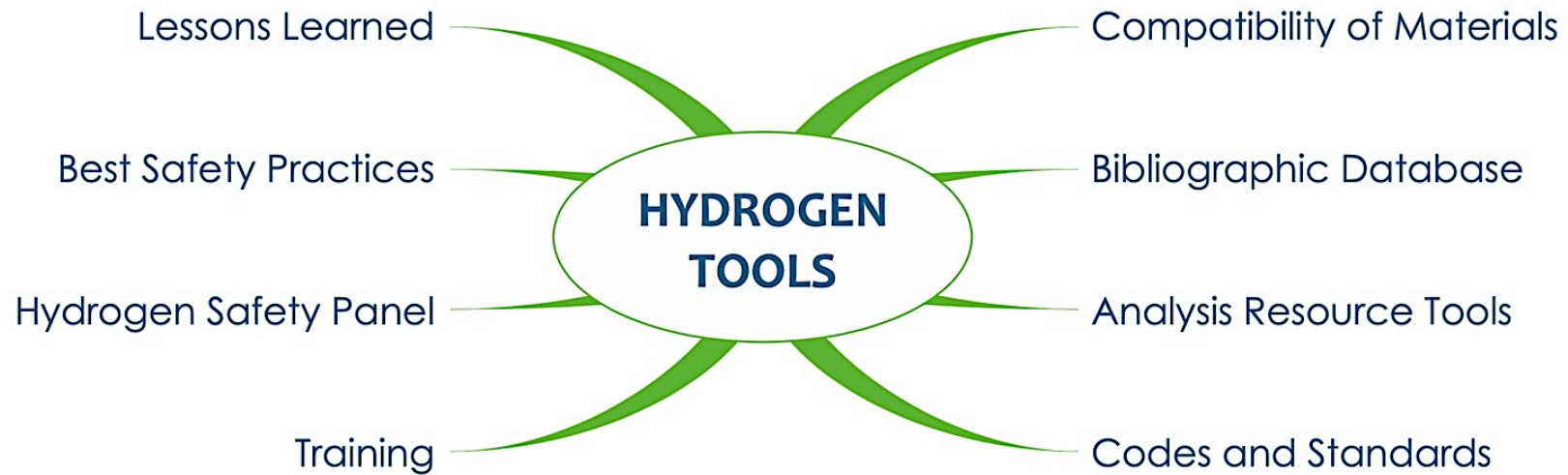


An international community focused
on applied hydrogen safety





Essential “no cost” hydrogen safety resources in one location



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

Hydrogen Tools Content and Use

Site Content

3,467	Total pages
2,385	Bibliographic references
222	Lessons learned pages
100	Best safety practices pages
449	Hydrogen/Fuel Cell Codes & Standards

Usage Stats*

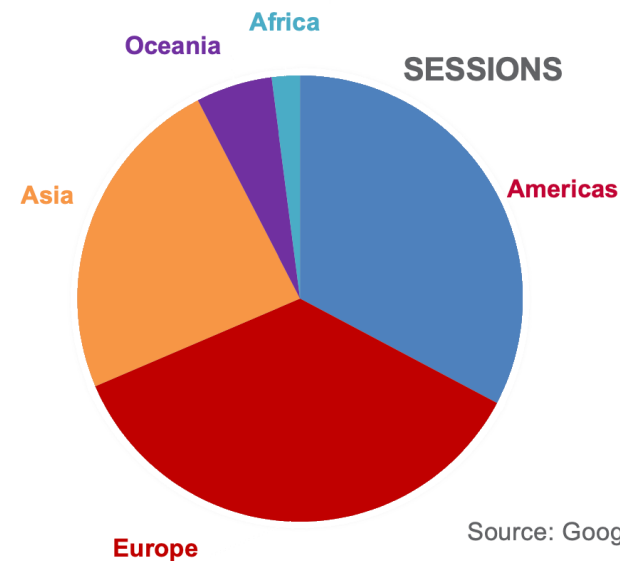
44,416	Maximum pageviews in one month
36,944	Average pageviews/month
4.62	Avg. Pages visited per session
06:54	Minutes per session

* Nonbounce statistics through December 31, 2022



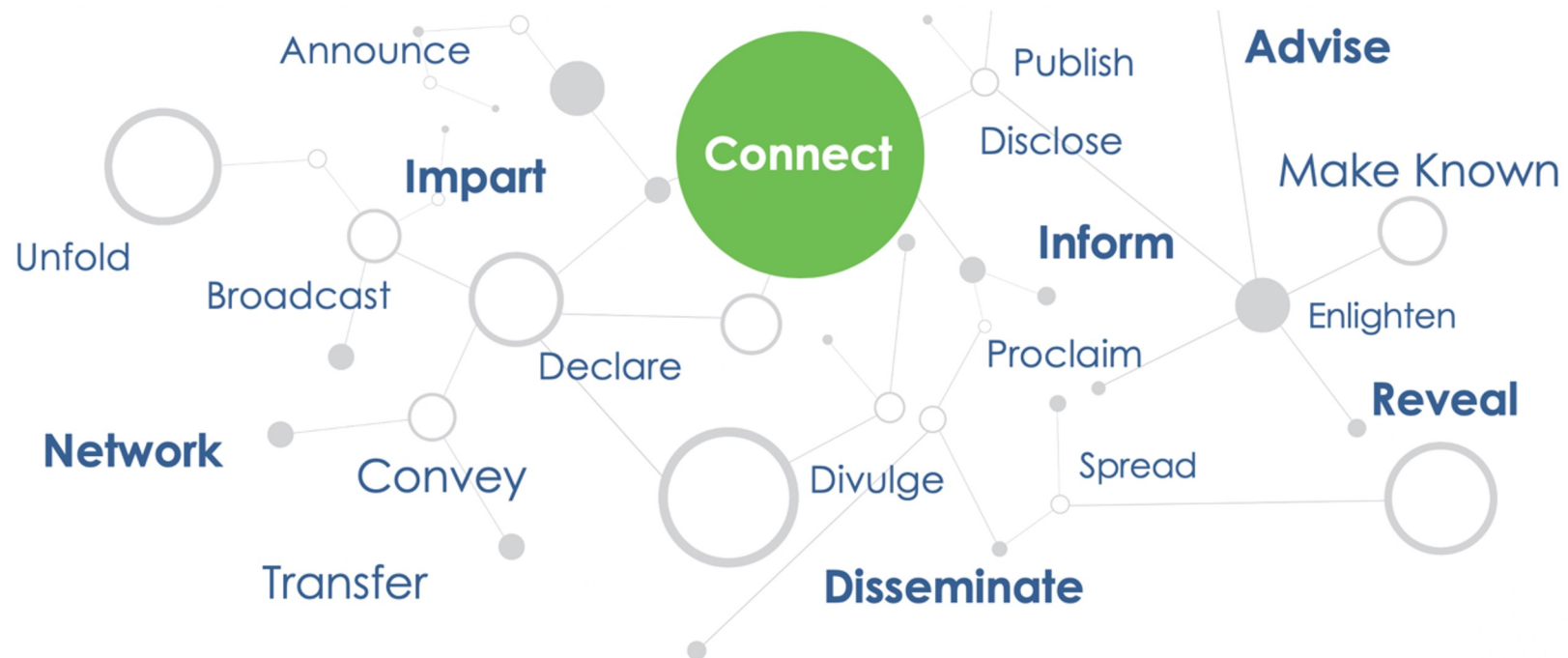
HydrogenTools

A Global Resource!



Source: Google Analytics

Connecting People to Safety Knowledge



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

**TOGETHER
WE CAN...**



CHAMPION

hydrogen safety best
practices worldwide



EMPOWER

stakeholders and the
workforce



ENSURE

the safe and timely transition
to hydrogen and fuel cell
technology

**YOUR ORGANIZATION IS
CRITICAL TO THIS VISION.
LET'S DO IT TOGETHER.**

aiche.org/chs

Center for Hydrogen Safety



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

With more than 100 member organizations and 15 strategic partners, CHS:

- ▶ Connects a global community to enables the safe and timely transition to hydrogen and fuel cell technologies
- ▶ Supports and promotes the safe handling and use of hydrogen in all applications
- ▶ Provides resources to ensure safety information, guidance, and expertise is available to all users and stakeholders

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aiche.org/chs

Dedicated to Applied Safety

Focused on Impact
Strong in Collaboration

Rich in Resources

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



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

Collaborate on Important Topics

Facilitating collaboration around topics of shared needs and interest

▶ **Introducing H₂ into Natural Gas Infrastructure**

- Currently developing best safety practices

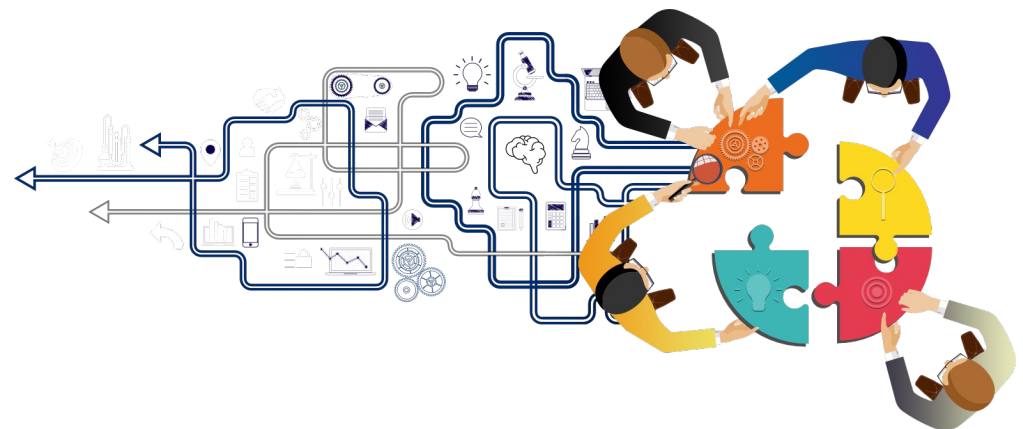
▶ **H₂ Equipment and Component Failure Rates**

▶ **New Working Group – Academia**

- Aimed at universities and research needs and issues that affect them

▶ **New Working Group – Safety Culture**

- Best safety culture practice will ensure consistency and help create trust in the ability of the hydrogen energy industry to deliver safe, reliable, and high-quality products and services. This working group also supports the Hydrogen Council and an International Energy Agency Hydrogen Safety Task



***** New working groups are established based on CHS member needs and requests *****



Hydrogen Safety Panel (HSP)

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

Background

- ▶ Formed in 2003
- ▶ 23 members with 700+ 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
- ▶ H₂ safety knowledge shared through the H₂ Tools Portal (h2tools.org)

20 Years

614 Reviews

440 Projects

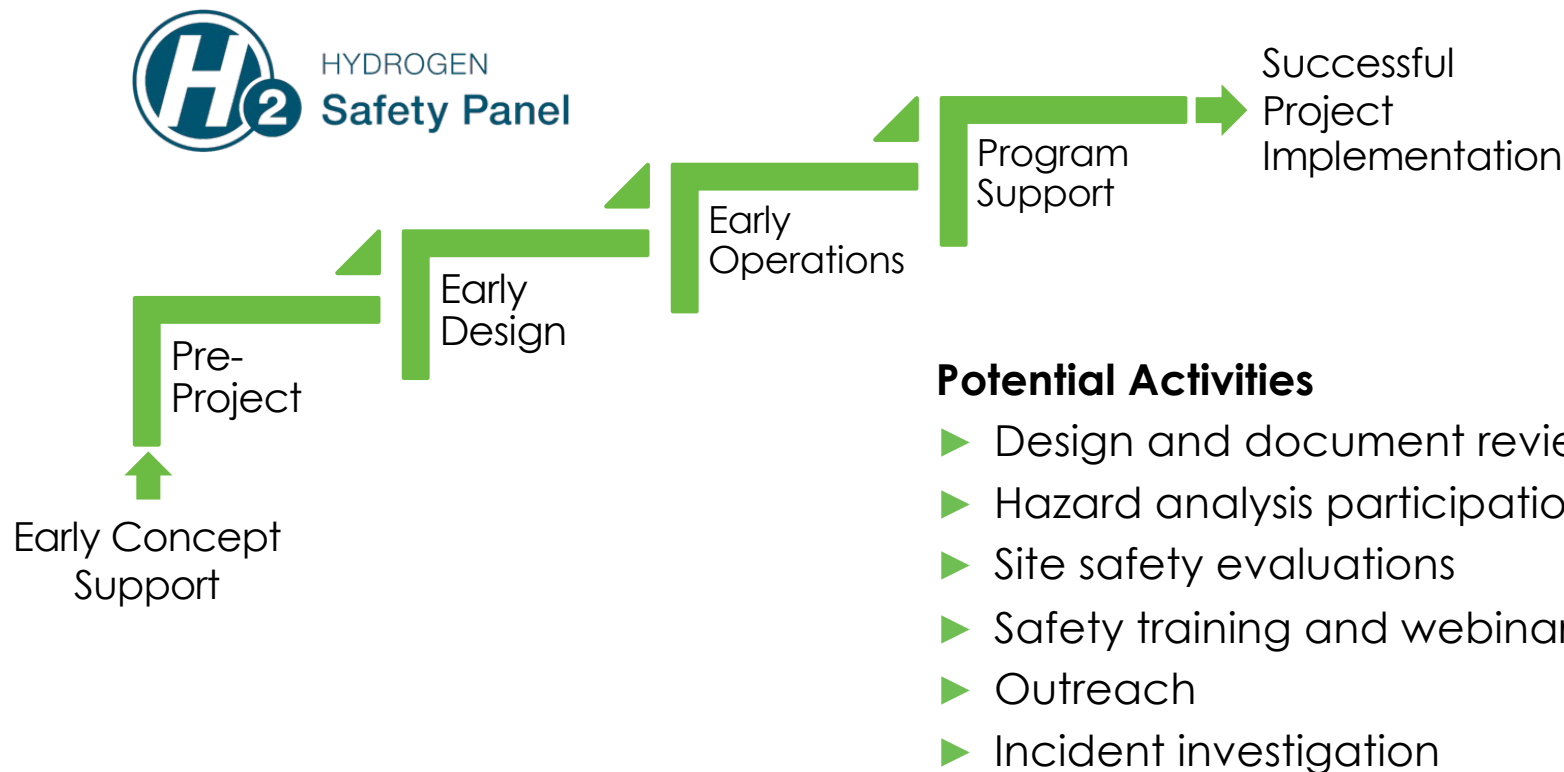
200+ Presentations

15 Guides

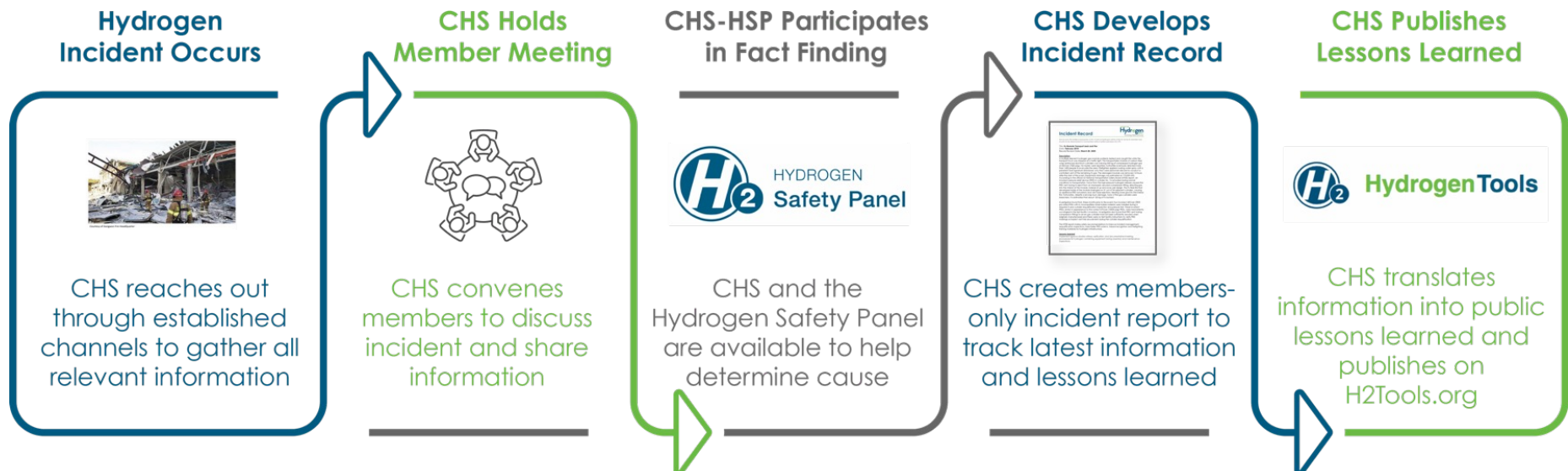
Impact

- ▶ 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

Utilizing the Hydrogen Safety Panel



CHS Hydrogen Incident Response Activities



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

Education and Training



<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

New Free eLearning Course

- Hydrogen Laboratory Safety

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

Committed to Safety

CENTER FOR
Hydrogen[™]
SAFETY
Connecting a Global Community

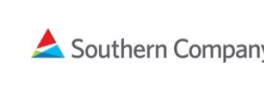
M E M B E R

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



MEMBERS



Thanks for Your Attention!



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<http://h2tools.org>



LinkedIn: www.linkedin.com/showcase/center-for-hydrogen-safety/

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

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November 1, 2023 / 31