CENTER FOR Hydrogen SAFETY
Connecting a Global Community





Hydrogen Safety at Scale and Workforce Development

Presented at the DOE Workshop: Enabling Decarbonization With Clean Hydrogen At Scale

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Hydrogen's Great Potential

The Impact of Incidents

- On 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Did Outdated System Kill 128?--Col. 6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

- On December 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**.

- On January 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**
  - An incompatible pressure relief device installed

Courtesy of Gangwon Fire HeadQuarter

Damage from Electrolyzer Incident

Common Fuels Incidents

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)
  - ~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

2019 Gasoline Station Fire

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)

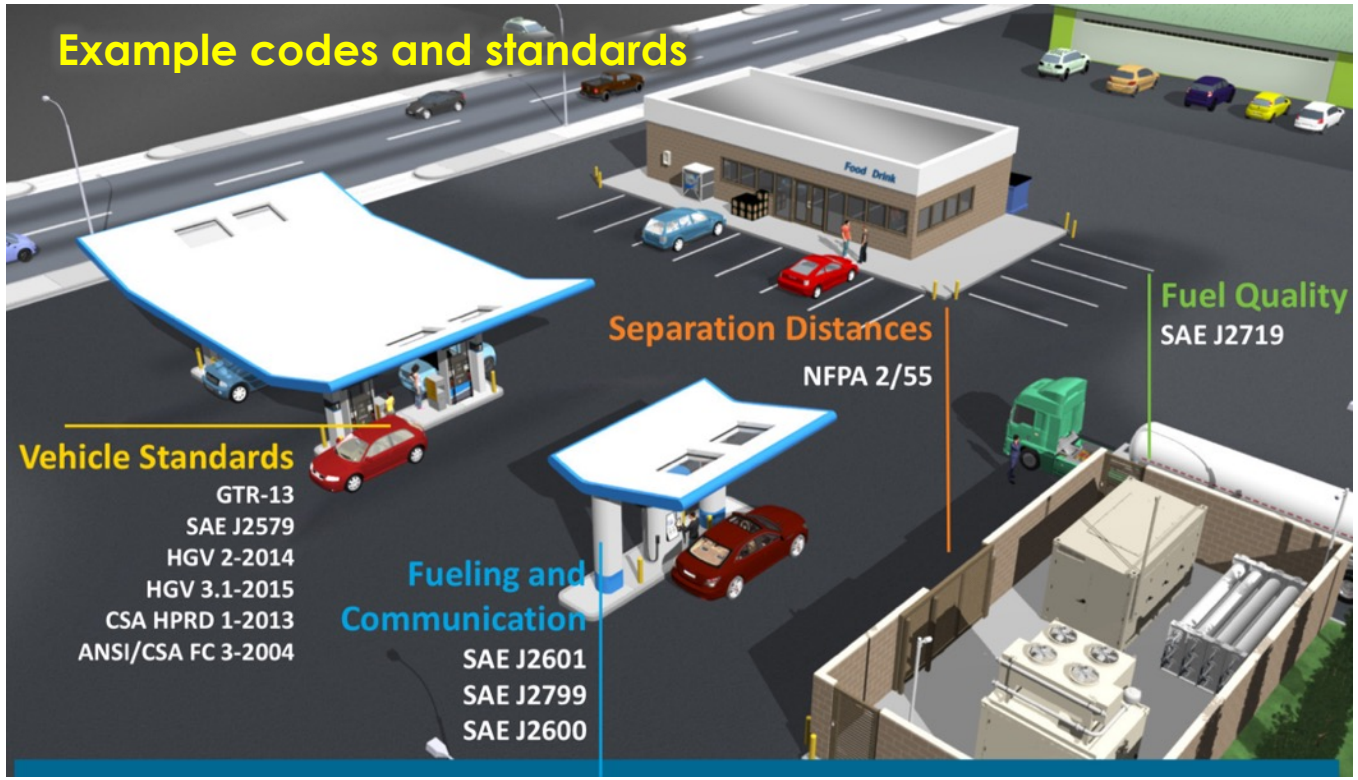
Failing to address the knowledge gaps can result in impactful incidents and industry setbacks

Safety Elements for Hydrogen Project Success

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

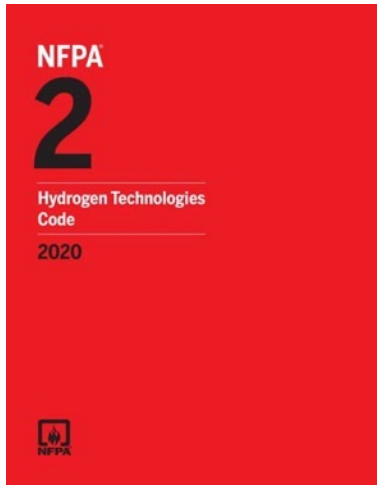


Did you know? Many codes and standards were developed using industry best practices.

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

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)

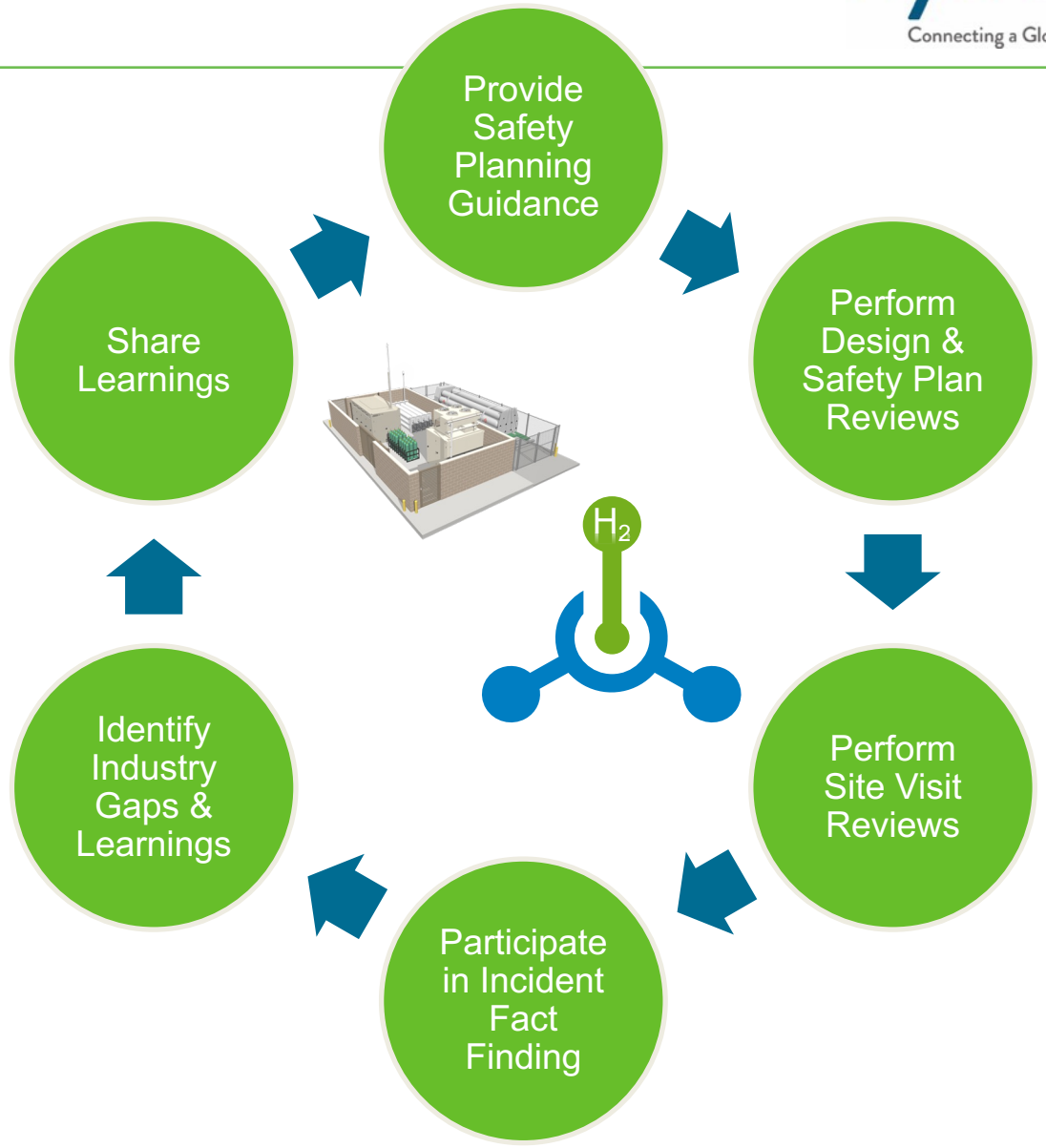
- SAE J2601–Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles[80]
- SAE J2799–Hydrogen Surface Vehicle to Station Communications Hardware and Software
- SAE J2719–Hydrogen Fuel Quality for Fuel Cell Vehicles
- HGV CSA Series Standards (currently being updated)

Hydrogen Safety Panel

Purpose: 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
- Supporting the safe deployment of hydrogen hubs



Hydrogen Safety Panel (HSP)

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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)

20 Years

603 Reviews

433 Projects

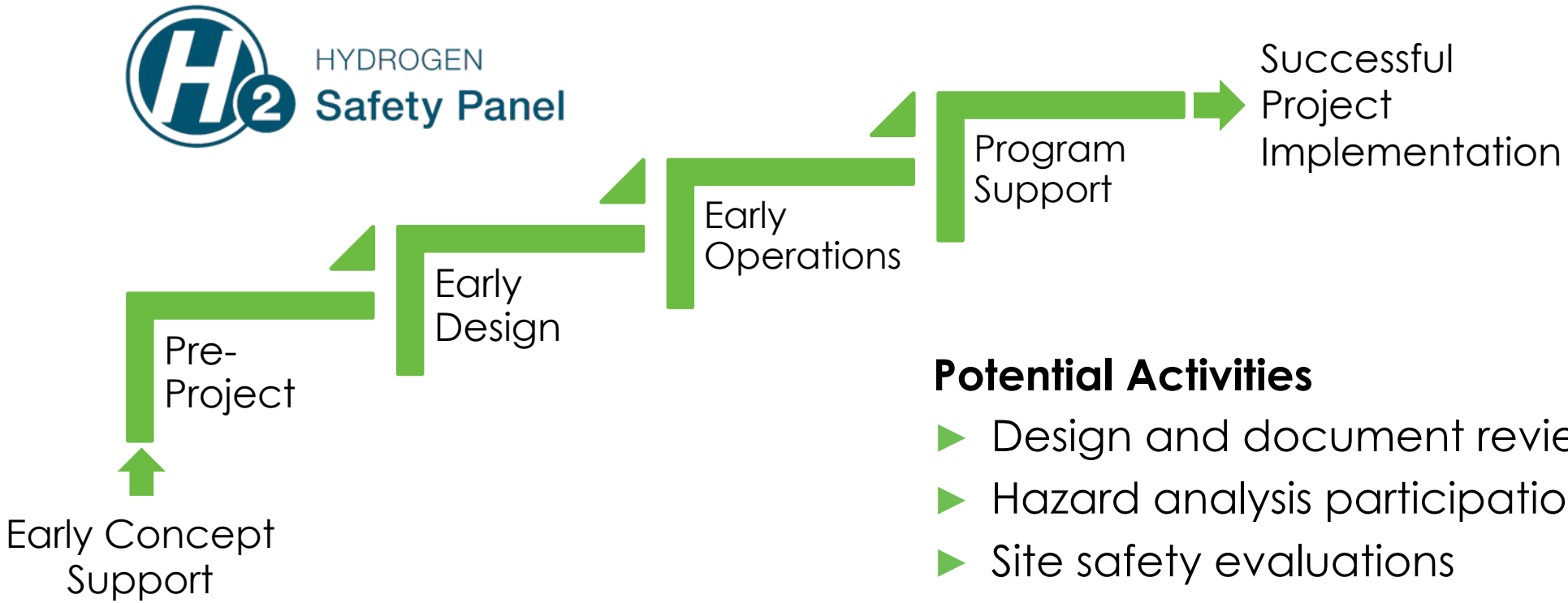
200+ Presentations

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

Hydrogen Safety Panel Support



Potential Activities

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

Streamlined Access to HSP Services

HSP service request form: https://h2tools.org/form/request-for-hydrogen-safety-pane

	DOE HTFO and Some CEC* Funded Projects	Other Projects
Safety Plan Review	Send the plan to hsp@h2tools.org	Submit service request
Document/Design Review	Submit service request	Submit service request
HAZOP Participation or Review	Submit service request	Submit service request
Other reviews	Submit service request	Submit service request
Contract for work needed	No	Yes**
Client funding needed	No	Yes
Time needed for contract disposition	N/A	1-2 weeks
Review time	6-8 weeks	6-8 weeks
Time to process an NDA with the HSP, if one is needed	4 weeks	4 weeks

* Check with the CEC or contact us direct to determine if Client funding is needed.

**A signed AIChE/CHS contract and a deposit are needed to initiate the review activity. Client contracts and substantial revisions of the AIChE contract cannot be accommodated.

HSP Service Request Form

Requesting Organization

Contact Name

Position

Phone

Email

Project Title

Scope/Summary of Project:

Select HSP services requested and specify the expected need by date for ea

Some reviews and associated reports may take 6-8 weeks to complete.

Service Requested	Need By Date
Safety Plan Review	mm/dd/yyyy
Preliminary Design/Information Review	mm/dd/yyyy
30% Design Review	mm/dd/yyyy

Resources to Help You Navigate to Safety

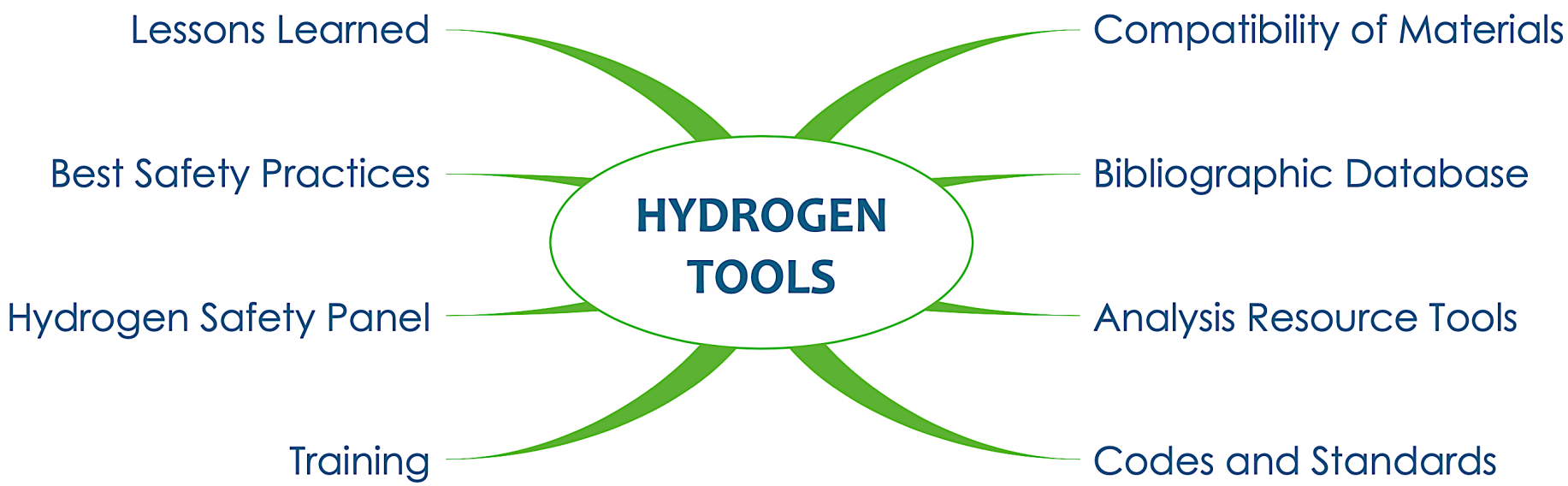
HydrogenTools

An online hydrogen information portal

CENTER FOR Hydrogen SAFETY

An international nonprofit focused on applied hydrogen safety

Significant hydrogen safety resources in one location

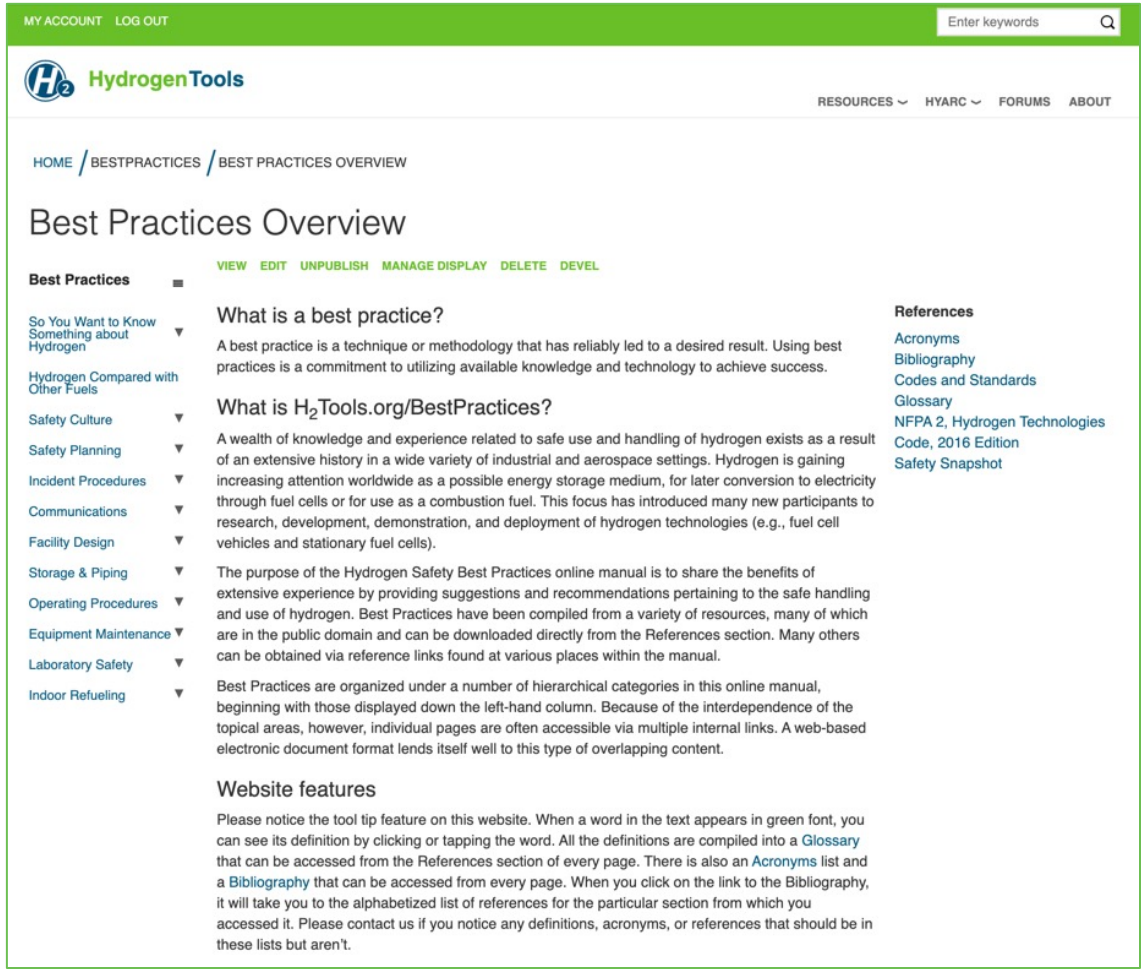


- Supports implementation of the safe handling practices and procedures
- Brings together a variety of tools and web-based content on safety of hydrogen
- Informs designers, stakeholders and first responders

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



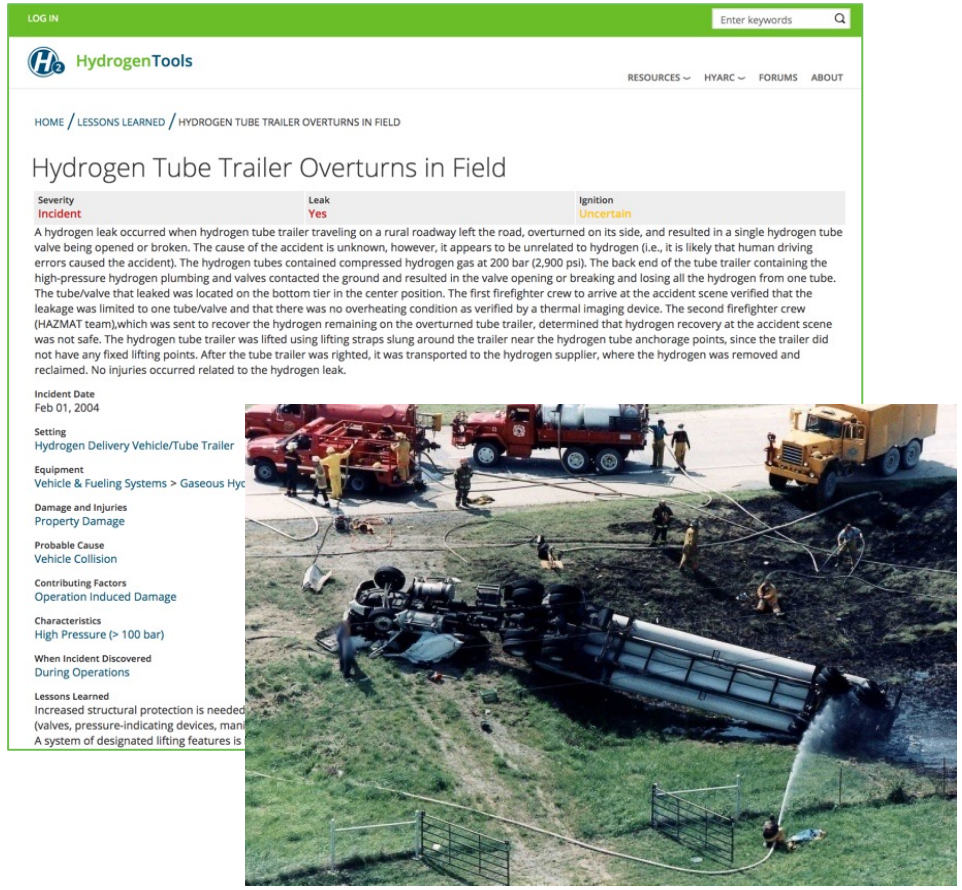
URL: https://h2tools.org/bestpractices/best-practices-overview

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

Center for Hydrogen Safety (CHS)

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

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

CHS Mission and Activities

- **Collaborate** in a global hydrogen safety community
  - Demonstrate commitment to safety - "License to do business"
  - Participate in member meetings
  - Contribute to working groups and conferences

- Access resources to **remove barriers** and manage risk
  - Hydrogen Safety Panel
  - Hazard analysis, site evaluation, custom training
  - Outreach, incident investigation

- **Increase knowledge** and expertise
  - Training courses, credentialing, and webinars
  - Conferences and workshops
  - Best practices and incident resources
  - Technical bulletins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MEMBERS
AcuTech PROCESS RISK MANAGEMENT
Rocket Company ASTRA
Air Liquide
AIR PRODUCTS
Atura Power
bp
BAKERRISK
BayoTech
BLACK & VEATCH
Bloomenergy
BrainDrip Patently True Innovations
Brookhaven National Laboratory
STATE OF CALIFORNIA ENERGY COMMISSION
CATERPILLAR
Pacific Northwest Center of Excellence for Clean Energy
CF
Chevron
Chevron Phillips Chemical Company LP
CHIYODA CORPORATION
ENERGY INSTITUTE COLORADO STATE UNIVERSITY
conEdison
Constellation
CSA GROUP
CSIRO
Cummins
DOUGLAS COUNTY P.U.D.
Dräger
ELECTRIC HYDROGEN
EPRI ELECTRIC POWER RESEARCH INSTITUTE
EMCARA
ENEOS
ENGIE
equinor
EVERSOURCE
ExxonMobil
TRUE ZERO
FuelPositive Fuel For A Mindful World
GEXCON
GTI ENERGY
HTEC FUELING THE DRIVE TO HYDROGEN
HYSTOR ENERGY
HAVRAND Hydro
HYDROGEN RESEARCH INSTITUTE UQTR
HYUNDAI
intertek
Iwatani Group Iwatani Corporation of America
JGC
Kawasaki
PKS Kiewit
한국가스안전공사 KOREA GAS SAFETY CORPORATION
LIFTE H2
Linde Making our world more productive
MACQUARIE University SYDNEY-AUSTRALIA
MITSUBISHI HEAVY INDUSTRIES
MOLLO HYDROGEN (PTY) LTD GREEN IS THE FUTURE!
MYONGJI UNIVERSITY
nationalgrid
NREL NATIONAL RENEWABLE ENERGY LABORATORY
Nebraska Public Power District Always there when you need us
nel
NIKOLA
HySA Infrastructure Hydrogen South Africa
NOVO HYDROGEN
NW Natural
NEW YORK STATE OF OPPORTUNITY. NYSERDA
OAK RIDGE National Laboratory
ohmium
origin
Pacific Northwest NATIONAL LABORATORY
pdc MACHINES.COM
PLUG POWER
RENEWABLE INNOVATIONS renewable-innovations.com Clean Scalable Power
SAN JUAN COLLEGE School of Energy
Sandia National Laboratories
SAPPHIRE GAS SOLUTIONS
aramco
Savannah River National Laboratory
SoCalGas A Sempra Energy utility
Southern Company
STAR SCIENTIFIC
TC Energy
tenova
Chemours
PILOT COMPANY
TOYOTA
UL
UNIVERSITY of HOUSTON
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MISSISSIPPI POLYMER INSTITUTE
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WHA
Williams
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WOODWARD
Xcel Energy
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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

Center for Hydrogen Safety

Connecting a global community to enable the safe and timely transition to hydrogen and fuel cell technologies.

Public Safety · New York, New York · 1,524 followers

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 need 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 Academic Working Group

- Identify Academia's needs for supporting workforce development for hydrogen industries
- Evaluate needs based on worker functions
- Develop outlines to support curriculum development for basic skills and technical knowledge

Participating organizations

- ✓ Centralia College
- ✓ San Juan College
- ✓ Washington State University
- ✓ University of Houston
- ✓ University of Southern Mississippi
- ✓ University of Quebec
- ✓ Colorado State University
- ✓ Myongji University
- ✓ Zhejiang University
- ✓ GTI Energy
- ✓ HyStor
- ✓ Hydrogen Fuel Cell Partnership
- ✓ Star Scientific
- ✓ US Department of Energy

Let us know if you would like to participate in this important activity – email chs@aiche.org.

CHS 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

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

Other Training Resources

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

Outreach

- Outreach will be necessary for community acceptance
  - An uninformed community is less likely to accept or embrace new technology
- Outreach should highlight technology differences and address safety issues
- Key audiences include stakeholders, approval authorities, first responders, and the public
- In-person events offer the best opportunity for a positive impact
- Provide opportunities for questions and interaction (at least half of the time should be reserved for Q&A)

In-person outreach will typically yield a positive experience for most attendees and bolster public confidence.

Safety Culture

Avoid the negative: Incidents will affect all hydrogen organizations

Support the positive: A good safety culture fosters efficiency and productivity

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The UK Health and Safety Executive defines safety culture as "…*the product of the individual and group values, attitudes, competencies and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety programs." (1) A more succinct definition has been suggested: "Safety culture is how the organization behaves when no one is watching."*

- **It's important** because… Investigations of catastrophic events have identified common safety culture weaknesses that are often factors
- Efforts to nurture and sustain a sound safety culture **must occur everywhere**, from the boardroom to the production floor.
- Safety culture **is critical for**:
  - Building a sustainable legacy
  - Maximizing an organization's impact and reaching goals
  - Ensuring long-term acceptance of the hydrogen industry

Safety Culture Framework (IAEA)

- ✓ 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

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

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

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?

Be prepared and avoid having to deal with the consequences of an incident

Thanks for Your Attention!

CENTER FOR Hydrogen SAFETY
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http://h2tools.org

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