CENTER FOR Hydrogen™ SAFETY
Connecting a Global Community

Hydrogen Safety Considerations

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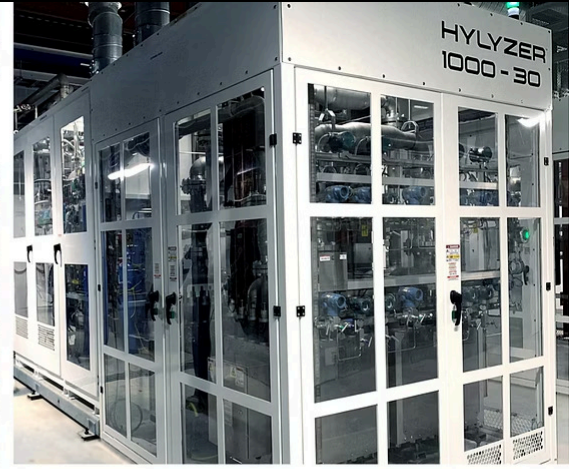
Nick Barilo is Executive Director of the Center for Hydrogen Safety (AIChE) and Hydrogen Safety Program Manager at Pacific Northwest National Laboratory. A licensed fire protection engineer with 40+ years of experience, he leads global efforts to advance hydrogen safety through best practices, collaboration, and knowledge sharing. He also oversees the U.S. Hydrogen Safety Panel and supports risk-informed decision-making, safety education, and first responder readiness worldwide.

The Center for Hydrogen Safety is an international nonprofit dedicated to promoting hydrogen safety and best practices across the global hydrogen community



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

See www.aiche.org/chs for more info

Rich in Resources

Strong in Collaboration

Focused on Impact

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

CENTER FOR Hydrogen SAFETY

EXECUTIVE MEMBERS

AcuTech PROCESS RISK MANAGEMENT · BLACK & VEATCH · Cummins · Shell

CENTER FOR Hydrogen SAFETY
Connecting a Global Community

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What We'll Cover Today

This briefing is designed to give state energy officials the foundational knowledge needed to evaluate hydrogen fueling station investments with confidence—understanding the hazards, the strategies to manage them, and the resources available to support safe deployment.

1. **Background on Hydrogen Safety Hazards**

   What makes hydrogen unique and what risks are specific to fueling stations

2. **Strategies to Address These Hazards**

   Codes, standards, design principles, and safety management approaches

3. **Lessons Learned**

   Real-world examples demonstrating best practices and what can go wrong

4. **Resources, Tools & Training**

   What's available to support your state's hydrogen fueling programs

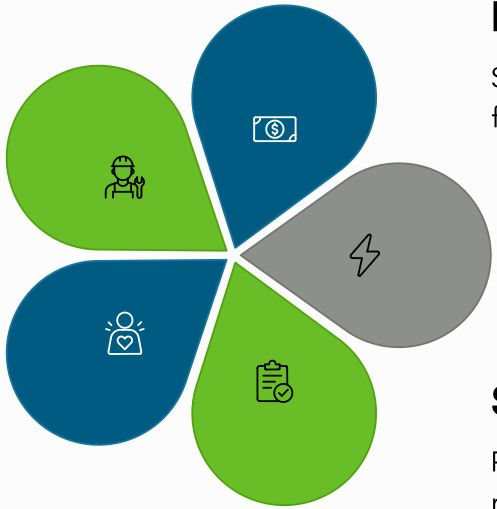
Why Safety?

Protects Workers & Communities

Safe operations keep the people who build, run, and use hydrogen infrastructure out of harm's way.

Builds Public Confidence

Public trust is earned through demonstrated safety — and lost quickly after a single incident.



Ensures Beneficial Use of Public Funds

Safety failures waste public investment. Getting it right the first time protects taxpayer dollars.

Enables Clean Energy Deployment

A strong safety record clears the path for broader hydrogen adoption across the state.

Supports Regulatory Compliance

Proactive safety practices make permitting smoother and reduce the risk of costly retrofits.

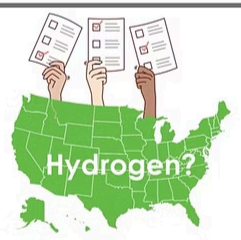
Hydrogen is Not New

Safety knowledge and best practices exist — and the industrial track record is substantial. From the Haber-Bosch process (1913) to refinery hydroprocessing and aerospace applications, hydrogen has been managed safely at massive scale every single day. Global production today stands at approximately **95 million tonnes per year**.

1913
Haber-Bosch Process
Industrial hydrogen at scale begins

95M
Tonnes/Year
Global hydrogen production today

100+
Years of Use
Refinery, aerospace, and chemical applications



2024 US Public Poll

65% Low awareness

62% Open to hydrogen

2.4% Hindenburg effect

79% Want more info

Most people need the basics first | Trust grows when safety is clear | Interest rises with better understanding

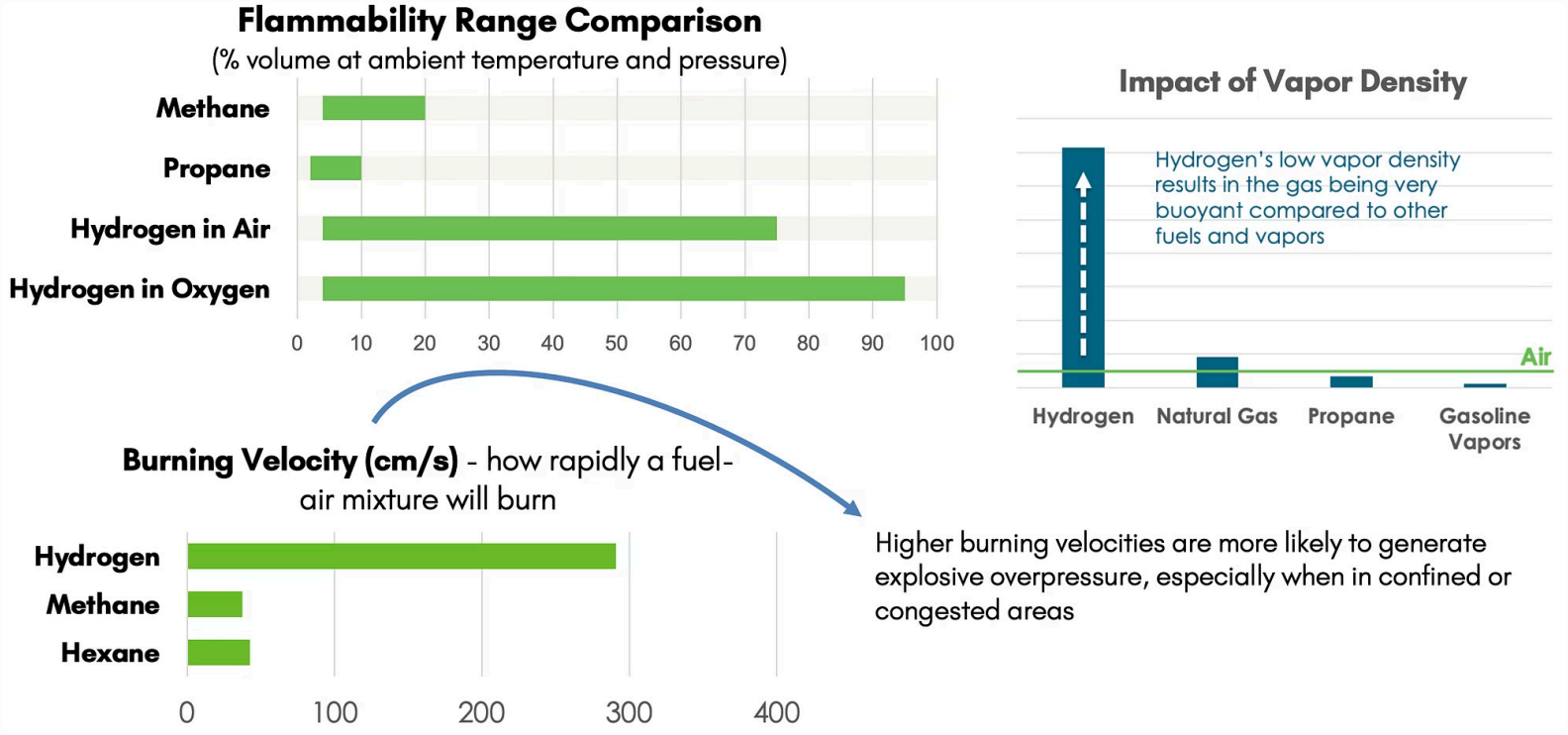
Key message: We are not starting from zero — but we *are* entering new territory. The applications emerging now differ fundamentally from the controlled industrial environments where most experience was built.

Hydrogen's Unique Hazard Profile

Every hydrogen application presents a unique combination of these six primary hazard categories. This matrix should inform where current safety assessments require hydrogen-specific augmentation — above and beyond generic flammable gas protocols.

Hazard	Key Concern
🔥 **Combustion**	Fire & explosion — extremely wide flammability range (4-75% in air); nearly invisible flames
💨 **Pressure**	High-pressure gaseous storage and transport; rapid release and jet fire potential
🔩 **Embrittlement**	Hydrogen-induced material degradation in steels, welds, and pressure components
🫁 **Asphyxiation**	Rare but possible in confined spaces; colorless and odorless — no sensory warning
❄️ **Cryogenic**	Liquid hydrogen applications — cryogenic burns, condensation of oxygen, rapid phase change
⚗️ **Oxygen Enrichment**	Electrolyzer environments — O_2 co-production dramatically increases ignition risk

Comparing Properties



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
  - 345 deaths
  - 1,300 injuries
  - $1.1 billion USD in property loss
- **Natural Gas** – average/year
  - 13,730 fires
  - 35 deaths
  - 254 injuries
  - $303 million USD property damage

Source: NFPA

2019 Gasoline Station Fire

However, new fuels face a challenge for public acceptance

Engineering Principles That Govern Design

A hydrogen-specific design philosophy applies at every stage — from concept to commissioning. These four principles are the non-negotiable baseline for any hydrogen facility design or modification.

1 — **Keep H_2 in Its Pipe**

System integrity is the first barrier. Validate all materials for H_2 service; minimize flanged connections; eliminate unnecessary leak paths at design stage

2 — **If It Leaks, Dilute It Quickly**

Engineered ventilation — air intake low, exhaust high. Ceiling geometry matters: flat ceilings trap H_2; peaked and vented ceilings disperse it

3 — **Shut Gas Off at the Source**

Automated detection linked directly to isolation valves. Do not rely on manual operator response — response time is not sufficient for hydrogen leak scenarios

4 — **Fail-Safe, H_2-Rated Equipment Only**

Every valve, fitting, sensor, and seal must be rated for hydrogen. No substitution from natural gas or air service without formal H_2-specific validation

Separation distances: Hydrogen hazard distances can significantly exceed comparable natural gas facilities — with real implications for plot plans, especially brownfield and space-constrained sites.

Key Risk Areas at Hydrogen Fueling Stations

Hydrogen fueling stations combine high-pressure systems, cryogenic or compressed gas storage, public access, and complex dispensing equipment. Each element introduces distinct hazard categories that must be addressed in design, permitting, and operations.

Leak & Release Events

Fittings, hoses, valves, and connections are the most common failure points. Even small leaks can accumulate in confined spaces and ignite.

Cryogenic Hazards (Liquid H_2)

Liquid hydrogen stations introduce cryogenic burn risks, boil-off management, and additional complexity in emergency response.

High-Pressure System Failures

Compressors, storage vessels, and dispensers operating at 350–700 bar require rigorous materials selection, inspection, and pressure relief design.

Fire & Explosion

Hydrogen jet fires burn invisibly in daylight. Deflagration or detonation risk exists if ignition is delayed after a significant release.

Public Interface Risks

Unlike industrial facilities, fueling stations serve the general public. Dispenser design, signage, training of attendants, and emergency response planning must account for untrained users.

Incidents at Hydrogen Fueling Stations

These real incidents—both at hydrogen fueling stations—illustrate how assembly errors and equipment incompatibility can lead to serious consequences, even when no one is injured.

Bus Fueling Station Fire

What Happened

A pressure relief valve failure released approximately 300 kg (660 lbs.) of hydrogen over 2.5 hours.

Cause

An incompatible pressure relief device had been installed.

Impact

No injuries. Minor equipment damage. Extensive evacuation of nearby residents and businesses.

Lessons Learned

Replace with correct PRD and higher vent stacks; improve emergency communication procedures; train personnel on response coordination with first responders and suppliers.

Fueling Station Tank Leak, Fire & Explosion

What Happened

A leak from a high-pressure hydrogen storage tank caused a jet fire and open-air deflagration.

Cause

An assembly error — inner bolts on a sealing end plug were not adequately torqued, allowing seal failure to escalate into an explosion.

Impact

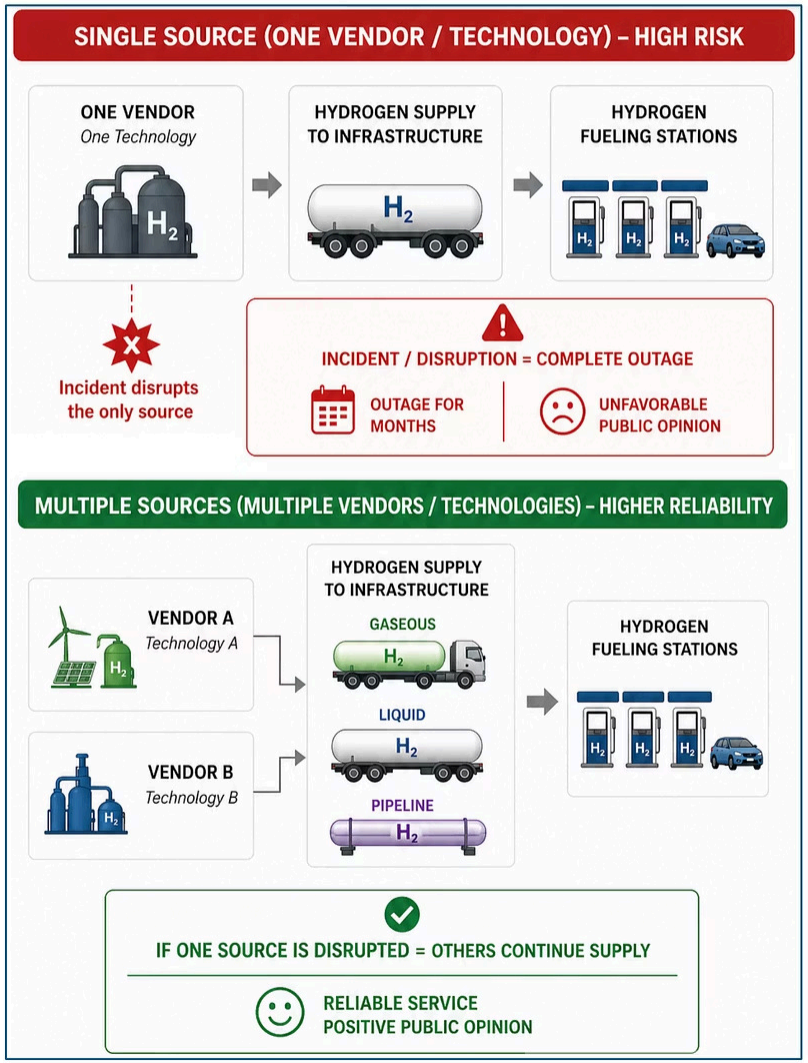
No injuries. Station damage. Airbag activated in a nearby vehicle.

Lesson Learned

Implement rigorous assembly procedures, double-witness verification, and documentation/marking for all hydrogen-containing equipment.

⚠ Both incidents were preventable. The root causes — an undertorqued bolt and a wrong-spec part — underscore why assembly verification and equipment compatibility checks are non-negotiable.

A Hidden Infrastructure Vulnerability



The Single-Source Problem

If one supplier goes down, the whole network can be disrupted for months.

- One incident can cause widespread station outages

The Solution: Built-In Redundancy

Require supply diversity from the start — multiple suppliers and technologies.

- At least two independent supply sources
- Diverse production technologies
- Prevent cascading outages

Plan for Hydrogen Project Success

- **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

Navigating the Regulatory Landscape

Hydrogen fueling stations must comply with a complex and still-evolving set of codes and standards. State energy officials play a critical role in ensuring that funded projects meet—and ideally exceed—these requirements. Understanding the key standards helps states set appropriate grant conditions and technical review criteria.

IFC / IBC

International Fire Code and Building Code: Adopted by most jurisdictions; addresses separation distances, ventilation, and emergency access

NFPA 2

Hydrogen Technologies Code: The primary U.S. model code covering hydrogen fueling stations, including siting, design, installation, and operations

ASME & CGA Standards

Pressure vessel, piping, and compressed gas standards critical for high-pressure storage and dispensing equipment

SAE J2601

Fueling Protocol Standard: Governs the hydrogen fueling process for light-duty vehicles, ensuring safe and consistent dispensing

⚠ Codes are a floor, not a ceiling. Many hydrogen incidents have occurred in facilities that were technically code-compliant. Best practices go beyond minimum requirements.

YOUR SUCCESS, OUR MISSION

H_2 SAFETY RESOURCES FOR EVERY NEED

H2tools.org

Over 3,500 online pages of hydrogen safety resources

PUBLIC & FREE

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Technicql webinars on timely topics free the day of the webinar

LIMITED FREE

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Online and in-person training learning to strengthen your knowledge

FREE & PAY

Expert Reviews

Engage top experts to access to authoritative guidance and best practices

PAY

CHS Membership

Access to a global community and world class resources

BEST VALUE PROPOSITION

https://tinyurl.com/H2-Safety-Resources

H2Tools.org - Your Safety Knowledge Hub

Every incident in the hydrogen industry leaves behind a lesson. CHS captures lessons—systematically, rigorously—and makes them available to members before they face the same situation. The Hydrogen Tools Portal (h2tools.org) is the most comprehensive repository of applied hydrogen safety intelligence available anywhere.

Best Practices Library

Curated, expert-validated guidance covering design, operations, maintenance, and emergency response for hydrogen systems across all scales and applications.

Lessons Learned Database

Structured analyses of real-world incidents and near-misses from across the global hydrogen industry—anonymized and synthesized into actionable insights.

Expert Guidance Documents

Technical guidance authored by the world's leading hydrogen safety professionals, updated continuously as technology and standards evolve.

How CHS Supports the Safe Implementation of Hydrogen Tech

> **"A world committed to hydrogen safety."**

CHS resources are designed to complement existing safety systems — filling gaps, connecting expertise, and accelerating safe deployment across every part of the hydrogen value chain.

Incident Database & Trend Analysis

Informs design decisions and operational risk assessments

Working Groups

Address current issues and develop best practices — including Geologic Hydrogen

Safety Gap Analyses & Best Practices

Reduces project risk and permitting timelines

Training & Competency Programs

Accelerates workforce readiness across contractors and supply chain

Emergency Response Resources

Supports AHJ engagement and community preparedness

Global Community

Connects organizations with peers across the full value chain

Training Programs for Fueling Station Safety

A hydrogen fueling station is only as safe as the people operating it. Training is not a one-time event—it is an ongoing program that must cover operators, maintenance technicians, emergency responders, and management. The following programs are available to support state-funded hydrogen fueling projects.

01

CHS Hydrogen Safety Fundamentals

Online foundational course covering hydrogen properties, hazard identification, and safe handling. Appropriate for all station personnel and a strong baseline requirement for state-funded projects.

02

CHS Professional Certifications

Industry-recognized credentials for engineers, safety professionals, and operators. Validates competency and signals safety commitment to regulators and the public.

03

NFPA 2 Training

Code-specific training on the Hydrogen Technologies Code. Essential for AHJs, project developers, and safety managers navigating permitting and compliance.

04

First Responder Training

Specialized programs for fire departments and emergency services covering hydrogen-specific response tactics, PPE requirements, and station layout familiarization.

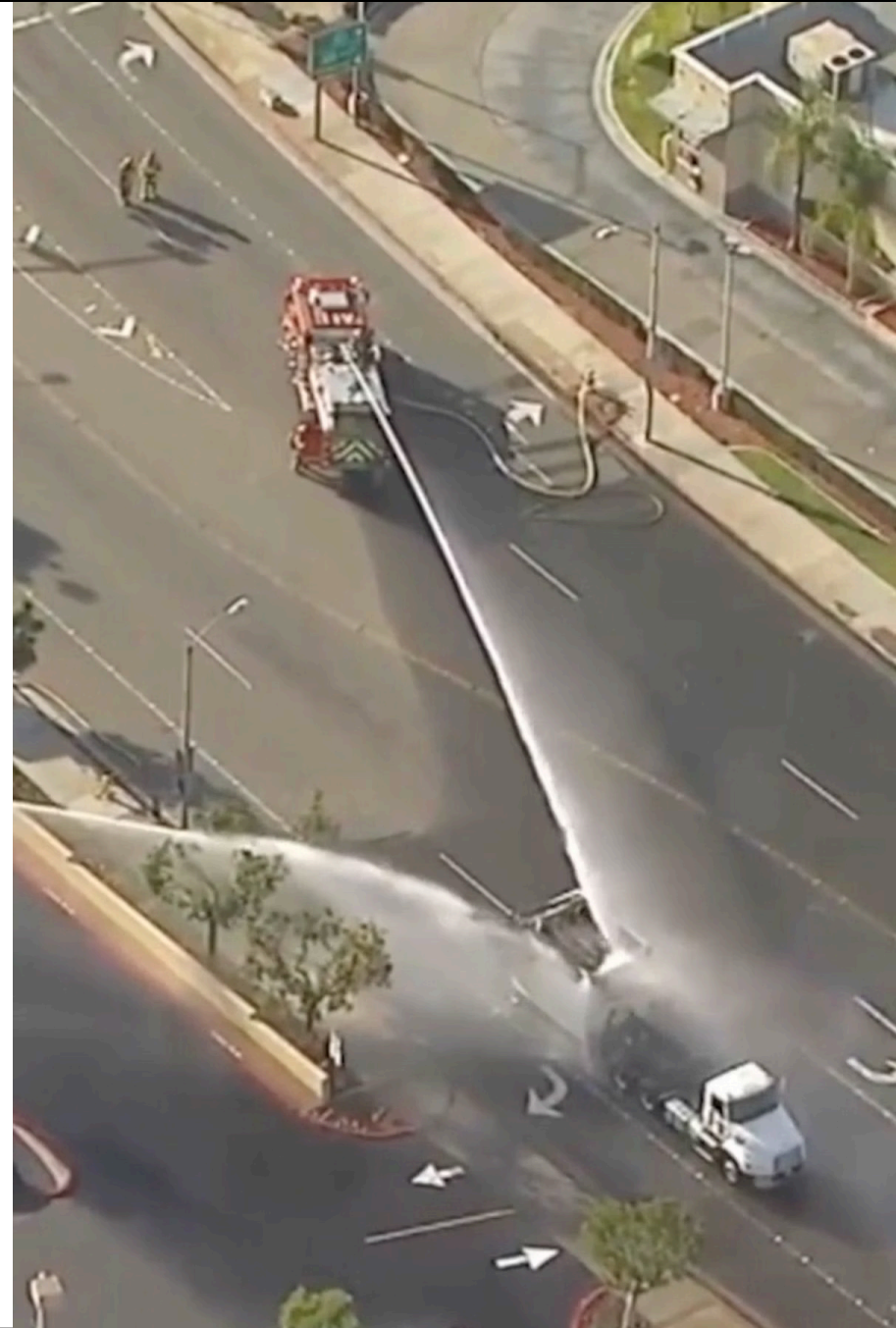
CHS training programs are developed by the same experts who investigate real incidents—ensuring every lesson is grounded in operational reality, not classroom theory.

Emergency Response Preparedness

Hydrogen requires a fundamentally different emergency response mindset. Community and stakeholder confidence depends on proven preparedness — and permitting authorities require hydrogen-specific response plans before project approval.

Key Differences from Hydrocarbon Response

- **Invisible flames** — Hydrogen fires emit very little visible light; daylight fires can be completely undetected by responders
- **Responder training gaps** — First responders trained on hydrocarbons may not recognize a hydrogen fire scenario
- **No odor** — Hydrogen is colorless and odorless
- **Different fuels in transport** — Requiring different attack methods and increasing the hazards of a misdiagnosed fuel source



How CHS Supports State Energy Officials

State energy offices are uniquely positioned to shape how hydrogen fueling infrastructure is built in their states—through grant conditions, technical review requirements, and stakeholder convening. CHS provides the independent expertise and resources to make that role effective.

Technical Review Support

The Hydrogen Safety Panel can provide independent safety reviews of proposed fueling station designs, helping states ensure that funded projects meet best-practice standards—not just code minimums.

Grant Condition Guidance

CHS can help states develop safety-focused grant conditions and evaluation criteria that protect public investment and reduce incident risk across the project portfolio.

Incident Intelligence

Through the CHS Engage platform and lessons learned database, state programs gain access to real-world incident data that informs better project requirements and oversight.

Stakeholder Convening

CHS connects state officials with a global network of hydrogen safety experts, developers, regulators, and researchers—accelerating learning and reducing duplication of effort.

Safety Planning is Essential

CENTER FOR Hydrogen SAFETY
Connecting a Global Community

A proven, systematic approach used in **450+ hydrogen projects** worldwide. Developed by the Hydrogen Safety Panel, this framework has been used by DOE since 2005 and by California hydrogen production and fueling stations since 2016. The most recent update (May 2025) incorporates Process Safety Management concepts and gives increased attention to organizational Safety Culture.

2005

First released by the Hydrogen Safety Panel; adopted by DOE for all funded hydrogen projects

2016

Adopted by California for all hydrogen production and fueling station projects

May 2025

Updated with PSM integration and expanded Safety Culture focus; available to all CHS members

450+ Projects

Applied across single research tasks to complex multi-organization commercial deployments

Strong safety planning builds trust with regulators and communities, saves resources by preventing costly redesigns, and drives mission success from concept through commissioning.

KEY RESOURCES

Free Guide: Hydrogen Safety for California

The **"Hydrogen Safety Considerations for California"** report offers state energy officials crucial insights into safe hydrogen infrastructure development.

Hydrogen isn't the problem—the knowledge gap is. This guide cuts through the complexity, covering production methods, real-world applications, and the safety practices that separate successful deployments from costly failures. The states that get hydrogen right won't be the ones that move fastest. They'll be the ones that knew what to ask.

"*While developed for California, its foundational principles and methodologies are broadly applicable, serving as a vital resource for any state navigating the complexities of hydrogen deployment and ensuring public safety.*"

Attend Our Best Conference Yet!

March 15-18, 2027
Cal State University
Los Angeles, CA, USA

CELEBRATING OUR 10th CONFERENCE

3 Days of Technical Presentations & Panel Discussions
1 Day of Educational Courses

*"The **discussions were incredibly detailed and focused**, and showed that organizations around the world face many of the same challenges."*

- Idil Osmanli, PSRG

*"**This is the place for you to be** if you want to learn hydrogen safety"*

- Rasim Qureshi, Saudi Aramco

*"It's a great place to learn from **real-world technical applications** and connect with others who share a commitment to hydrogen safety."*

- Maggie Lane, Stantec

Next Steps:

Partnering for Safer Hydrogen Fueling Infrastructure

The decisions state energy officials make today—about which projects to fund, what conditions to attach, and what technical support to require—will shape the safety record of hydrogen fueling in the United States for decades. CHS is ready to be your partner in getting this right.

1

Engage CHS for Technical Support

Connect your state's hydrogen fueling projects with independent safety expertise through the Hydrogen Safety Panel. Available for design reviews, grant condition development, and stakeholder briefings.

2

Require Safety Best Practices in Grants

Use CHS guidance to develop grant conditions that go beyond code compliance—requiring pre-commissioning reviews, documented procedures, first responder training, and management of change programs.

3

Join the CHS Network

State energy offices can engage with CHS as members or partners, gaining access to the full knowledge hub, incident database, training programs, and expert network.

Safety is not a barrier to hydrogen deployment. It is the foundation that makes deployment sustainable.

Learn more: www.aiche.org/chs and h2tools.org

Thanks for Your Attention

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