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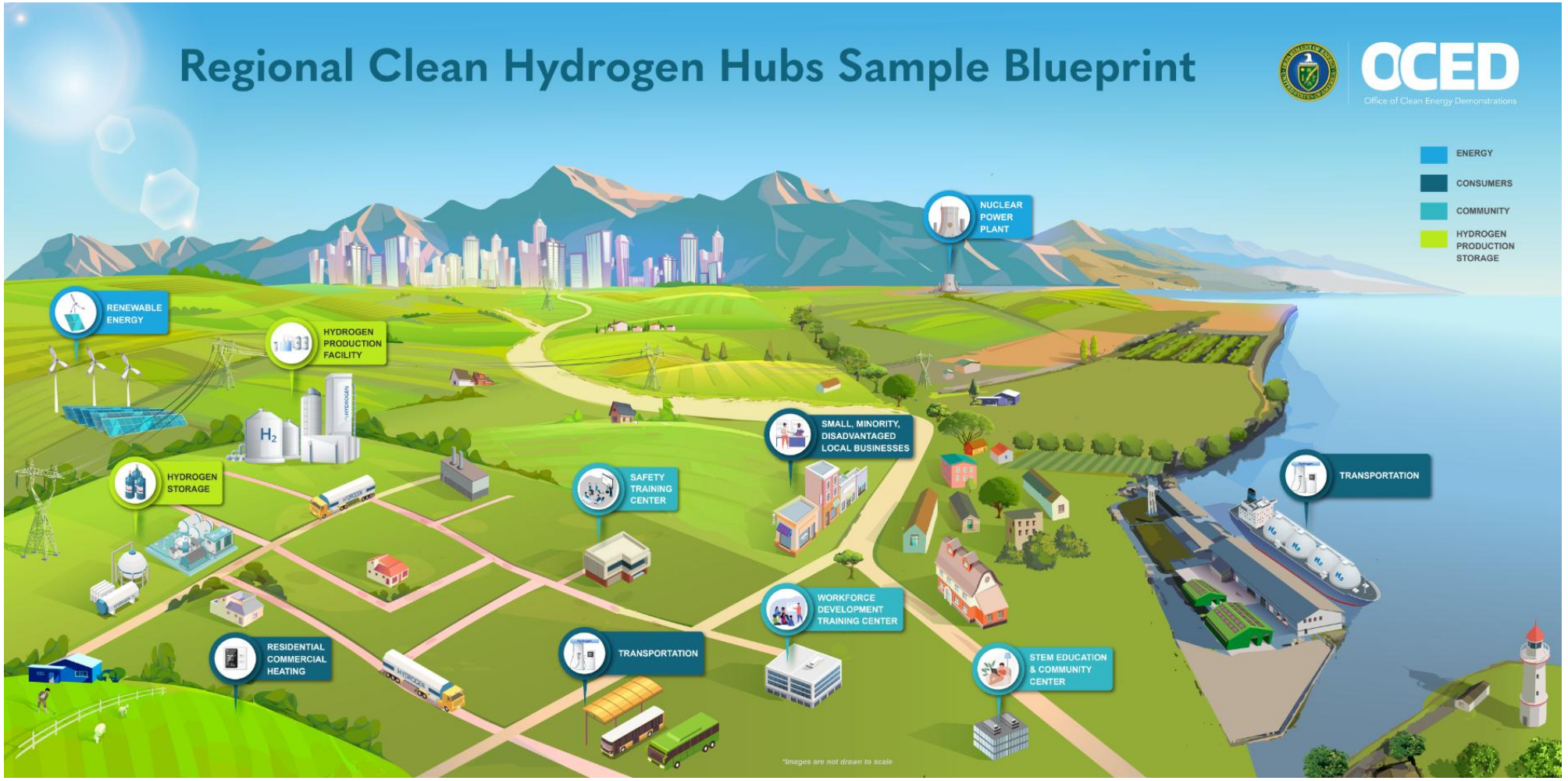
Process Safety Management for Hydrogen as a Fuel

David A. Moore, PE, CSP
President & CEO
AcuTech Group, Inc.
www.acutech-consulting.com

Keynote Presentation
2026 MARY KAY O'CONNOR PROCESS SAFETY & RISK CONFERENCE, OCTOBER 20-22, 2026
Houston, Texas



The Vision – A Hydrogen Economy

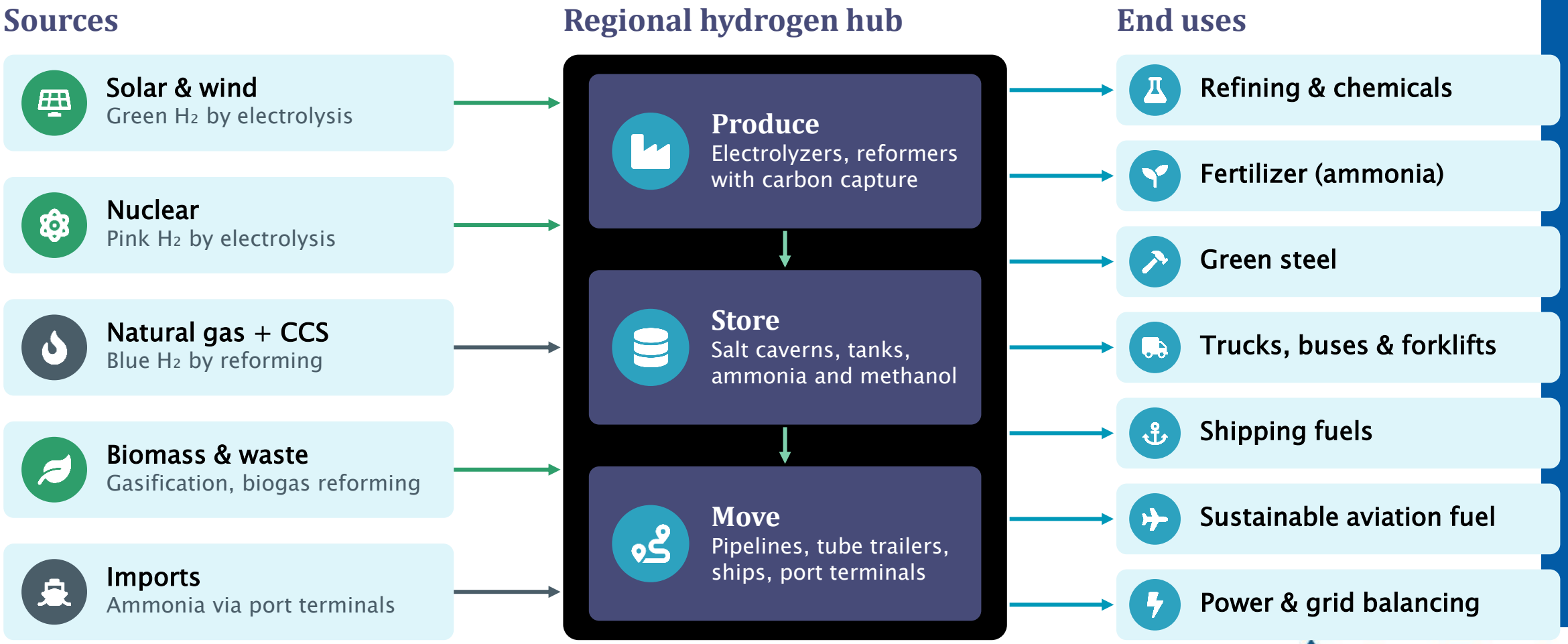


Plans for the hydrogen economy will involve rapidly developing infrastructure *with exposure to the public to hydrogen that is not typical today.*

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The Future Regional Hydrogen Economy

Many clean sources feed a shared hub that produces, stores and moves hydrogen to hard-to-electrify users

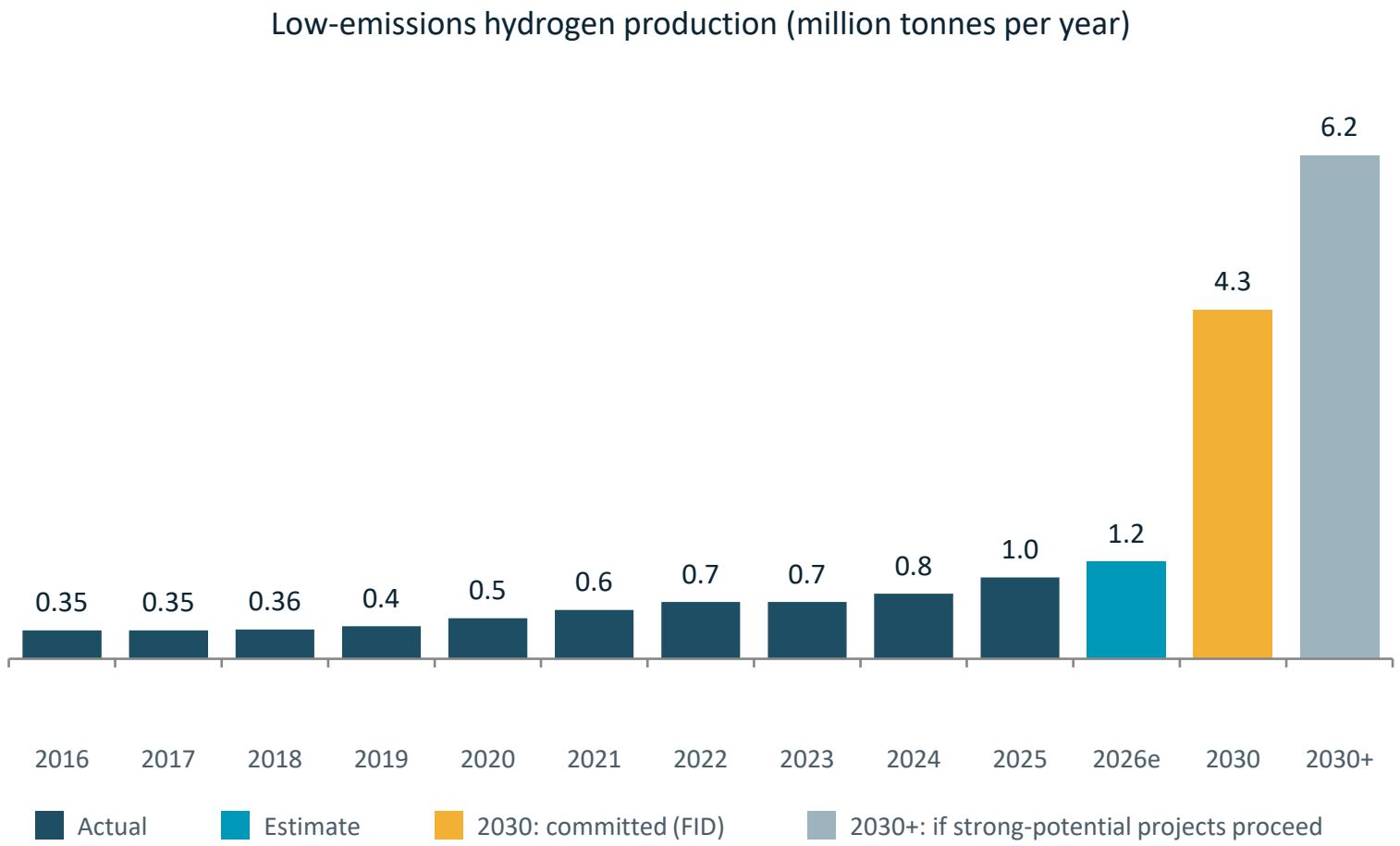


Illustrative regional hydrogen hub. Green icons and arrows = renewable, nuclear or bio-based supply; grey = fossil with carbon capture, or imports.

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Decarbonized Hydrogen Supply is Scaling Up

Low-emissions hydrogen output has roughly tripled in ten years; projects already financed point to ~4x more by 2030



~1 Mt in 2025; under 1% of all hydrogen

~10% a year average growth, 2020–2025

~40% a year from committed projects to 2030

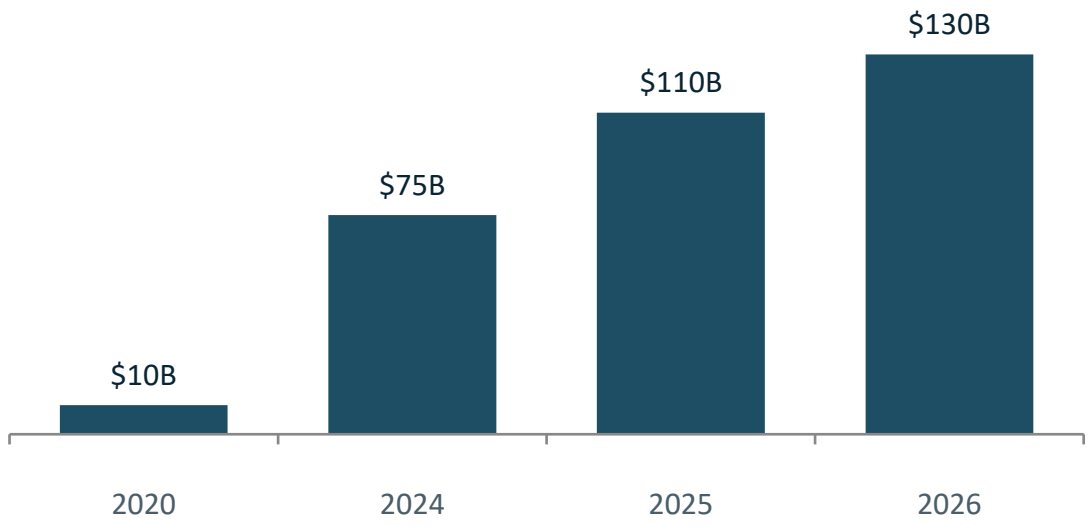
27 Mt announced for 2030, 4x what is committed

Sources: IEA, Global Hydrogen Review 2026 (Jul 2026) and 2024 editions; IEA, The Future of Hydrogen (2019) for 2016–2019, approximate. Low-emissions = electrolysis with low-carbon power, or fossil fuels with carbon capture.

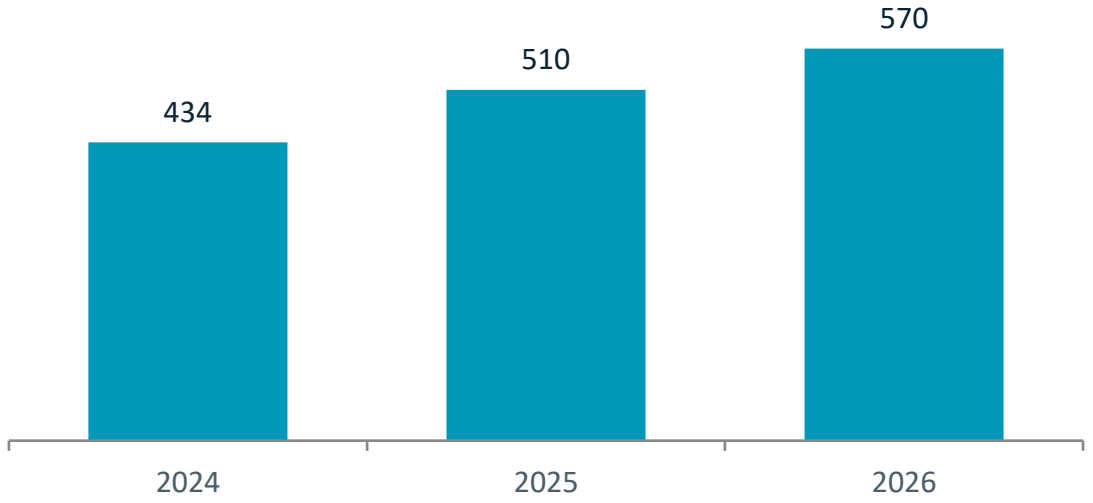
Global Clean Hydrogen Industry is Moving from Concept to Build-out

Projects past final investment decision (FID) and committed capital keep climbing, even as some projects drop out

Committed clean-H_2 investment (USD bn)



Projects past FID, worldwide (count)



1.7 Mt per year of clean H_2 now operating, up 70% in a year

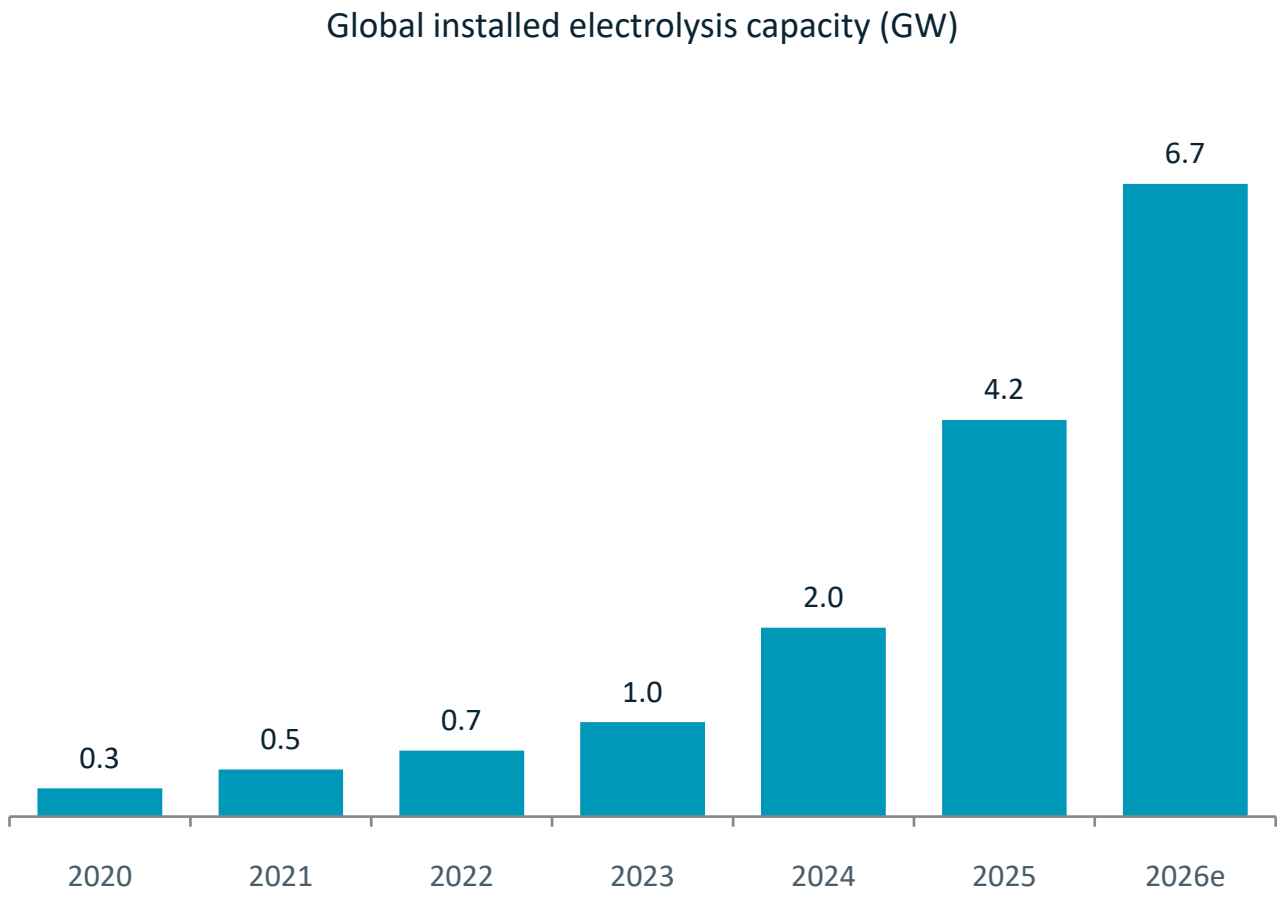
~90% of committed capacity is operating or under construction

~1% of global H_2 output is low-emissions in 2026 (a first)

Sources: Hydrogen Council, Global Hydrogen Compass 2026 (Sep 2026) and Hydrogen Insights 2024; IEA, Global Hydrogen Review 2026. 2026 project count is "570+".

Electrolyzer Capacity Doubled in 2025

Installed electrolysis passed 4 GW, and projects already at FID point to roughly 5x more by 2030



~75% of 2025's new capacity was built in China

2.5+ GW under construction for 2026 start-up, ~2 GW in Europe

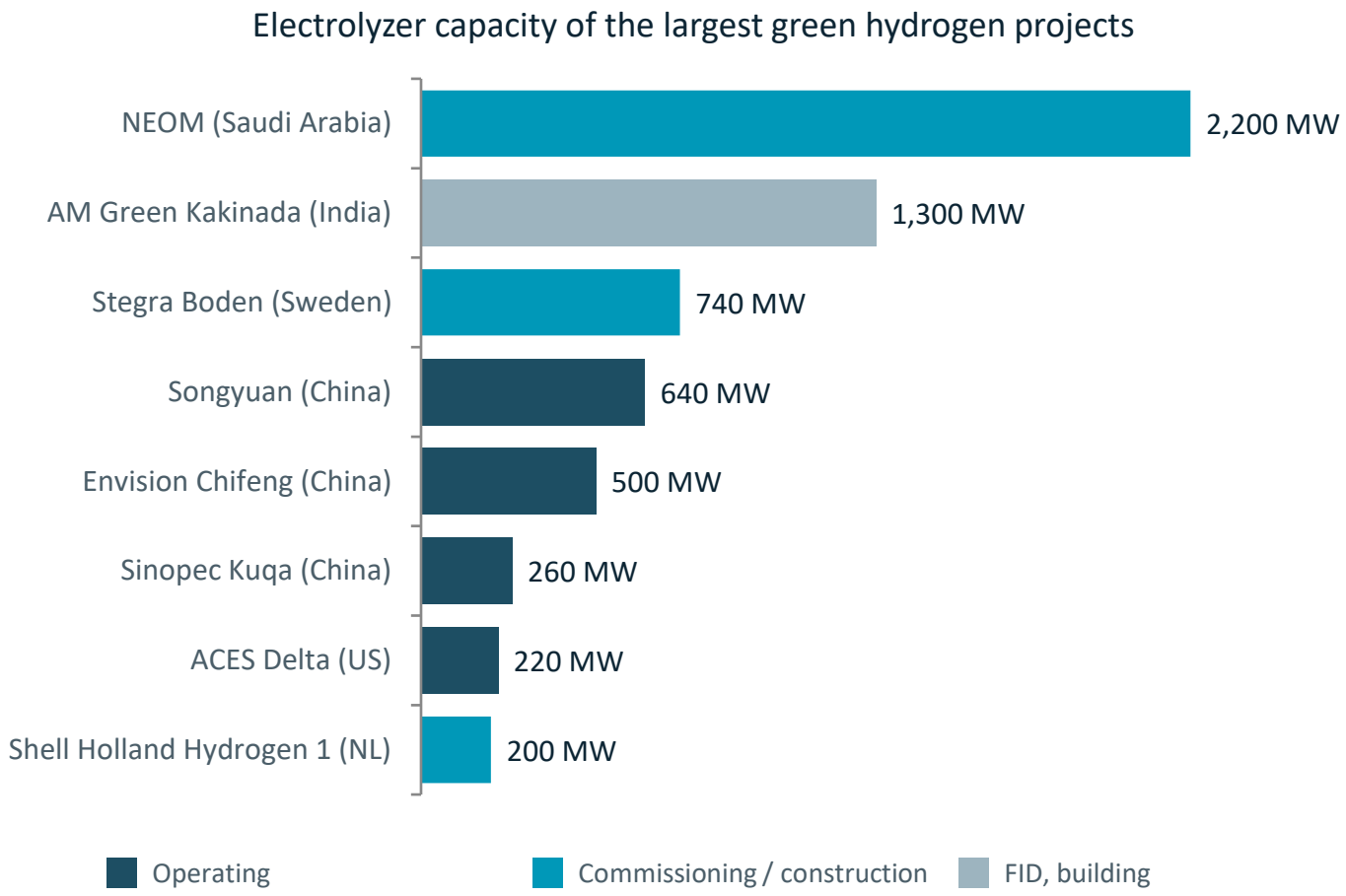
~26 GW by 2030 from projects that have already taken FID

100+ GW of announced projects miss 2030 without FID by end-2027

Sources: IEA, Global Hydrogen Review 2026 (Jul 2026) and Energy Technology Perspectives 2026 (Mar 2026). 2020–2024 values approximate, from earlier IEA editions; 2026e = 2025 base + capacity under construction.

The World's Largest Hydrogen Projects

Flagship plants have jumped from hundreds of megawatts to gigawatt scale, led by Saudi Arabia, India and China



~8x jump in flagship size: 260 MW (2023) to 2.2 GW

3 of 4 operating plants shown here are in China

NH_3 ammonia is the main product, mostly for export

220 MW ACES Delta is the largest US green plant

Sources: pv magazine (NEOM, Aug 2026); gasworld (AM Green FID); Hydrogen Insight (Stegra, Jun 2026; Envision, Jul 2025); SMM (Songyuan phase 1, Dec 2025); Hydrogen Fuel News (ACES Delta, Feb 2026); S&P Global (Shell HH1, Apr 2026). Songyuan shown at full planned size.

End Use for Green Hydrogen Projects

Most mega-projects make ammonia or supply heavy industry; several equally large ones have been paused or cancelled

Project	Country	Use	Scale	Status
NEOM Green Hydrogen	Saudi Arabia	Green ammonia for export	2.2 GW; up to 600 t H_2/day	Commissioning; product 2027
AM Green Kakinada	India	Green ammonia for export	1.3 GW; ~1 Mt NH_3/yr	FID taken; building
Stegra Boden	Sweden	Green steel	740 MW	Under construction
Songyuan (CEEC)	China	Ammonia and methanol	640 MW planned	Phase 1 operating (Dec 2025)
Envision Chifeng	China	Green ammonia	500 MW; 320 kt NH_3/yr	Operating since mid-2025
ACES Delta	United States	Seasonal storage for power	220 MW; ~100 t H_2/day	Full load (early 2026)
Shell Holland Hydrogen 1	Netherlands	Refinery supply	200 MW; 60 t H_2/day	Start-up due 2026
CF Donaldsonville (blue)	United States	Ammonia with carbon capture	~300 kt H_2/yr	Operating since Jul 2025

Paused or cancelled giants: ExxonMobil Baytown, US (blue, ~900 kt/yr; paused 2025); HyScale 100, Germany (2.1 GW; cancelled 2026); Air Products Louisiana, US (blue ammonia; halted 2025).

Sources: as previous slide; GlobalData (CF Donaldsonville, Baytown capacities); The Energy Year (Baytown pause, Nov 2025); pv magazine (HyScale 100, Aug 2026); EnkiAI (Air Products Louisiana).

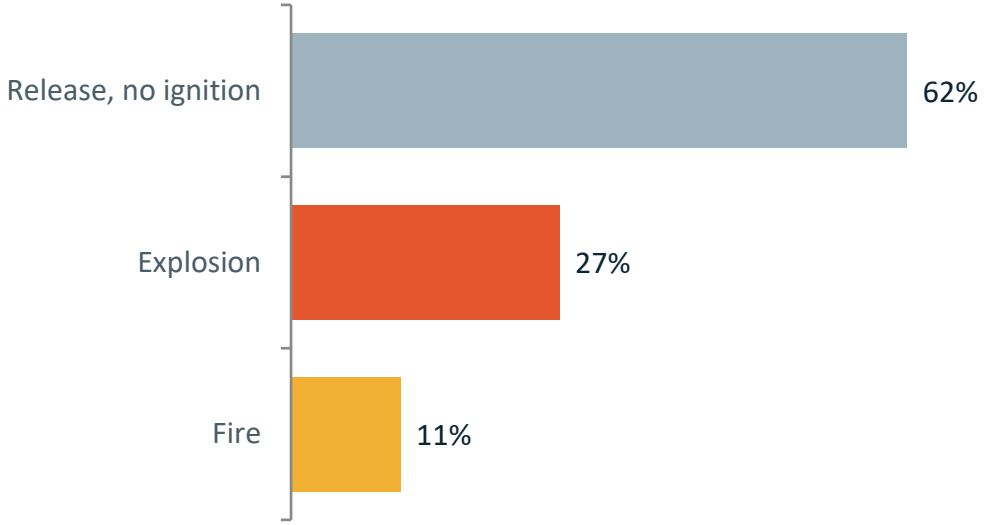
Hydrogen Safety Challenges

- Scaling at a rapid pace
- Propensity for hydrogen to leak and high potential for ignition; oxygen hazards
- Overpressure explosion hazards when hydrogen is released into confined or congested areas or internal explosions where hydrogen and oxygen may interface
- Lack of operating experience
- Unfamiliar technology to many engineers and operators
- Range of operating parameters (P, T, power density, lifespan)
- Novel technology developments expected as the industry evolves
  - Operating history and safety and reliability data is lacking
- Balance of plant (BOP) components can differ across electrolyzer stack designs
- Design codes and standards are developing

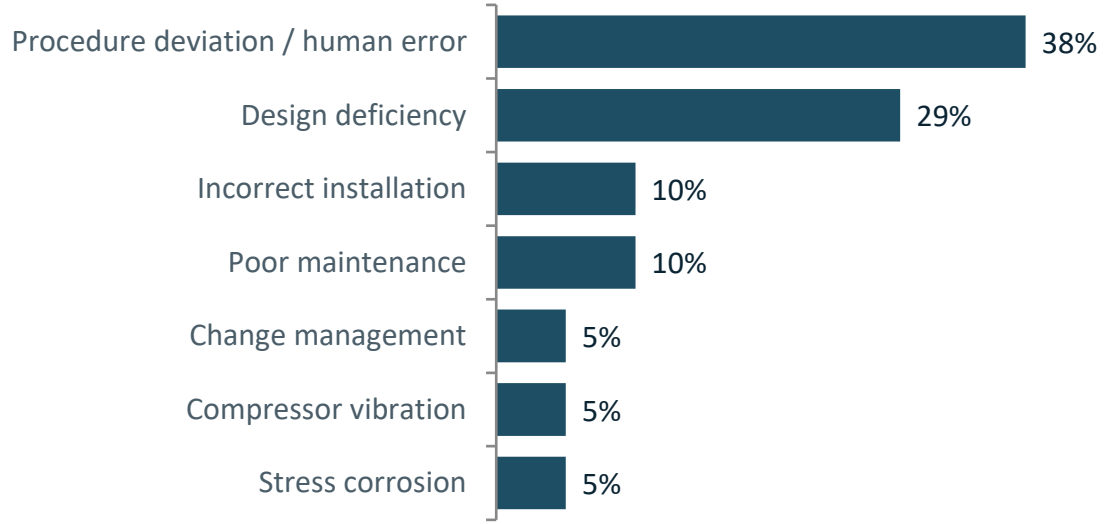
Safety Record at New Hydrogen Energy Sites

Refuelling stations, electrolysis plants, hydrogen storage and supply only; refineries and industrial users are excluded

Consequences of station incidents (45 events)



Causes of station storage-tank incidents



45 refuelling-station incidents recorded worldwide, 1990–2024

3 / 12 deaths / injuries at stations, all from storage-tank failures

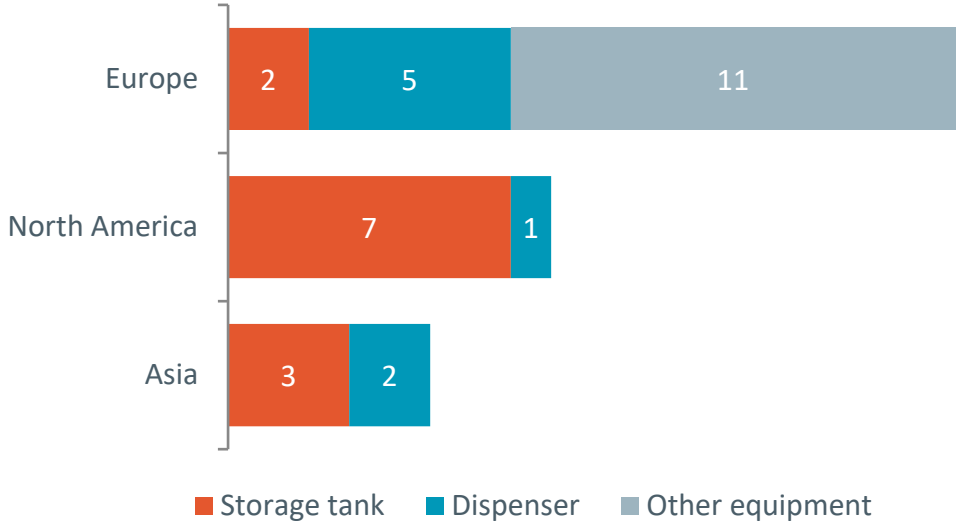
11 electrolyzer accidents logged (1975–2021): 5 explosions, 1 fire

Sources: Nekhwevha et al., "Analysis of Equipment Failures as a Contributor to Hydrogen Refuelling Stations Incidents", Hydrogen 6(4):79 (Oct 2025; HIAD, H2Tools, media); Tuhi et al., ESREL 2024 (NTNU/SINTEF; HIAD 2.1 + literature).

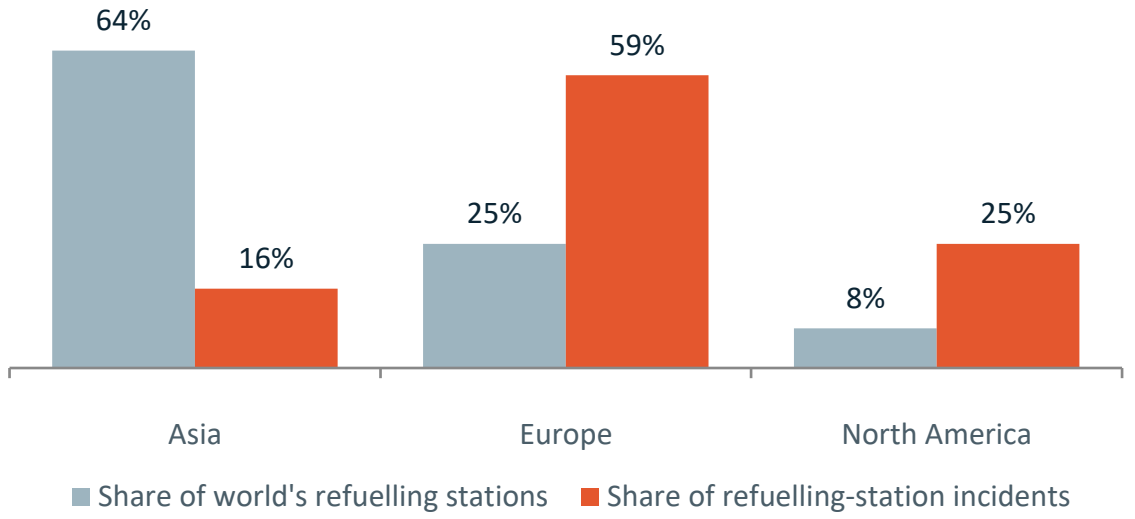
Our Knowledge of Incidents Follows Reporting

Asia has most of the world's refuelling stations but few reported incidents; Europe reports the most

Station incidents by region and equipment



Refuelling stations vs. their incidents, by region



Europe — France, UK, Sweden and Germany lead reported station incidents

US — 7 of its 8 station incidents were storage-tank failures

Japan — 2 of 11 electrolyzer accidents; UK, France, Korea, Germany 1 each

Sources: Nekhwevha et al., Hydrogen 6(4):79 (Oct 2025; 1,160 stations operating end-2024); Tuhi et al., ESREL 2024. Country detail for station incidents is by region only in the source study.

Hydrogen Incidents – www.h2tools.com

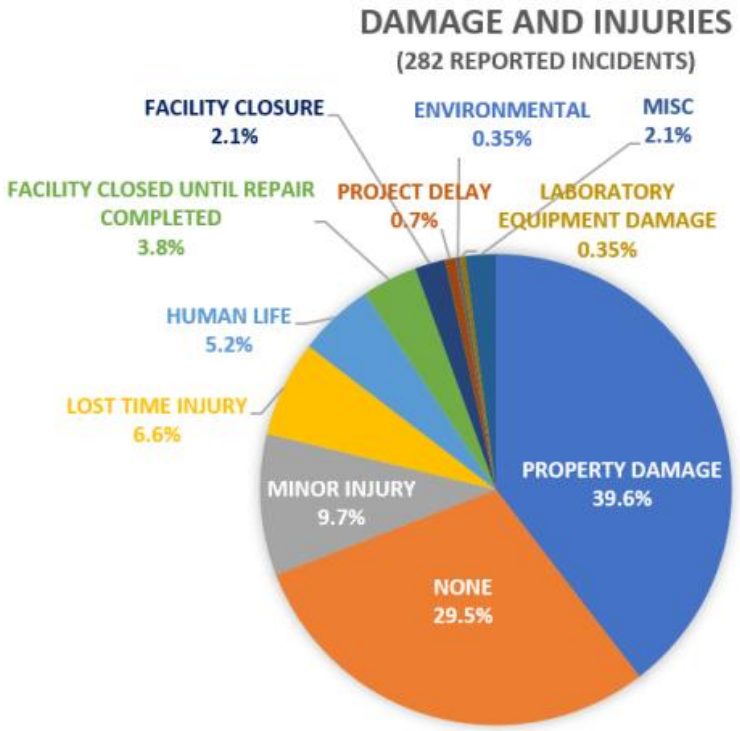


Figure 3: Reported damage and injury categories resulting from hydrogen related incidents reported to h2tools.org.

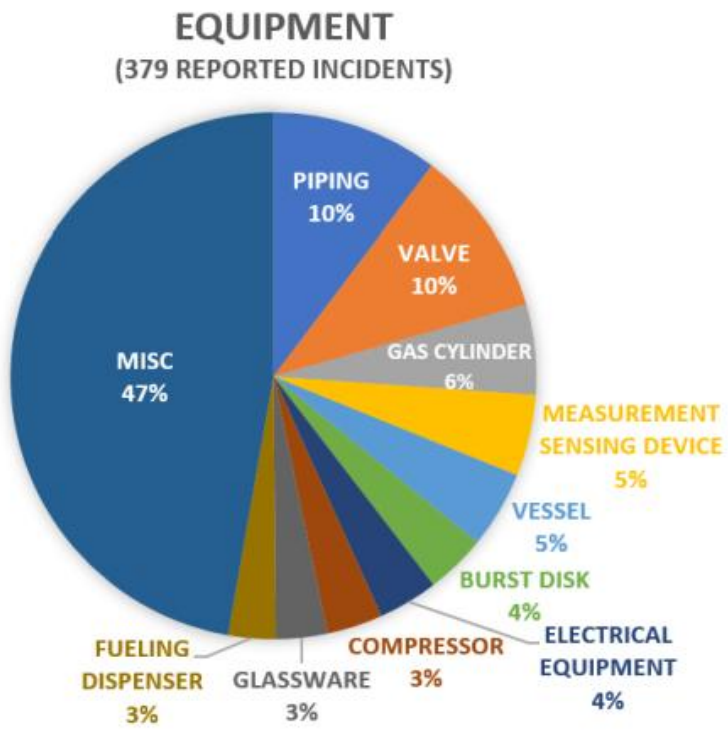


Figure 4: Reported categories for equipment involved in hydrogen incidents reported to h2tools.org. (The primary causes for the equipment-related incidents include component failure, operation error, installation/maintenance, etc.).

Weiner and Fassbender (2012) – Reference: Hydrogen Safety Review for Gas Turbines, SOFC, and High Temperature Hydrogen Production 30 March 2023 Office of Fossil Energy and Carbon Management DOE/NETL-2022/3329

Hydrogen Incidents – www.h2tools.com

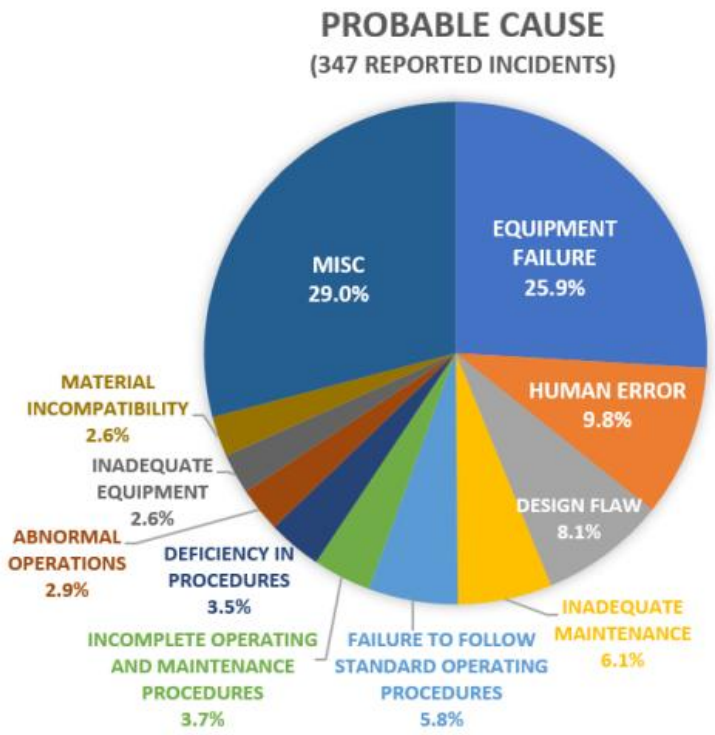


Figure 5: Probable cause categories for hydrogen incidents reported to h2tools.org.

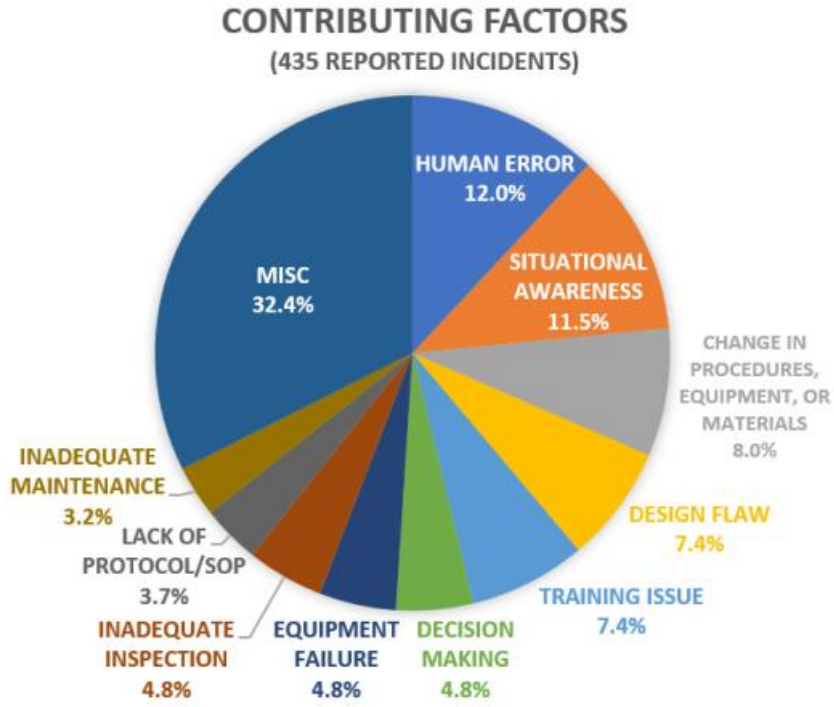


Figure 6: Contributing factors categories for hydrogen incidents reported to h2tools.org.

Weiner and Fassbender (2012) – Reference: Hydrogen Safety Review for Gas Turbines, SOFC, and High Temperature Hydrogen Production 30 March 2023 Office of Fossil Energy and Carbon Management DOE/NETL-2022/3329

US DOE Hydrogen Safety Panel – Hydrogen Incident Examples

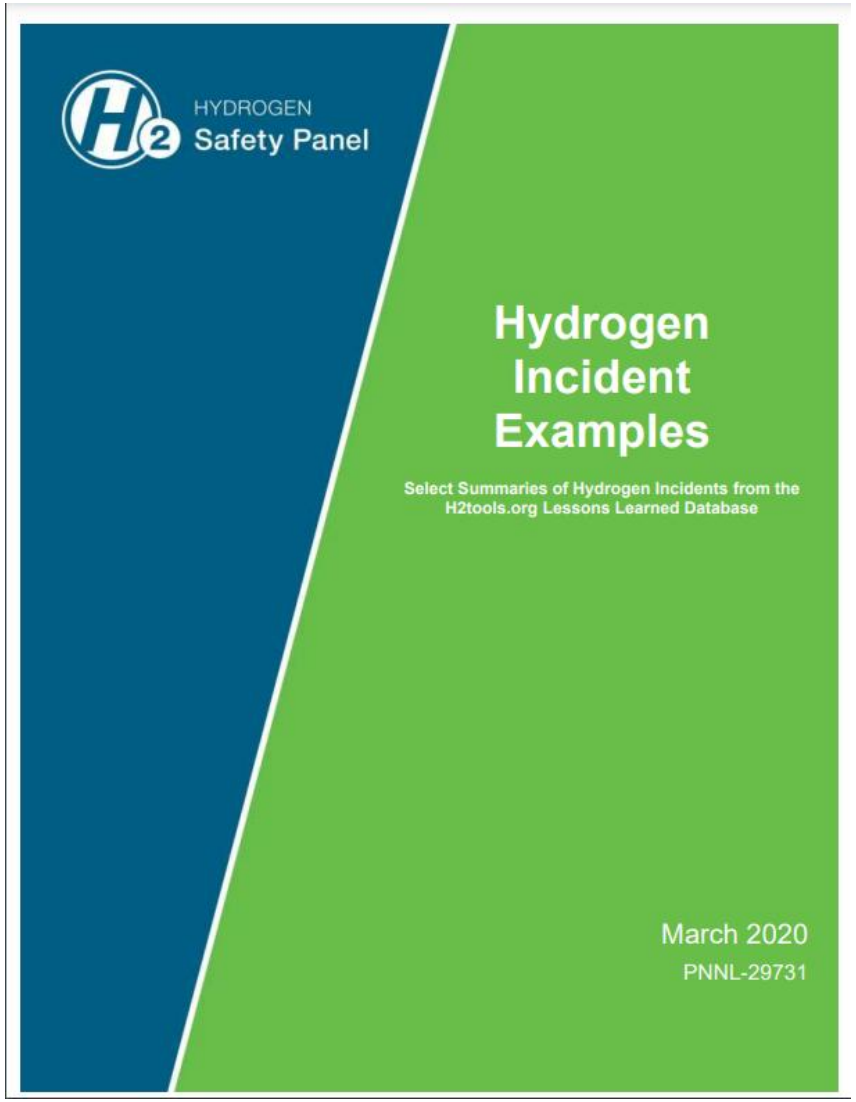


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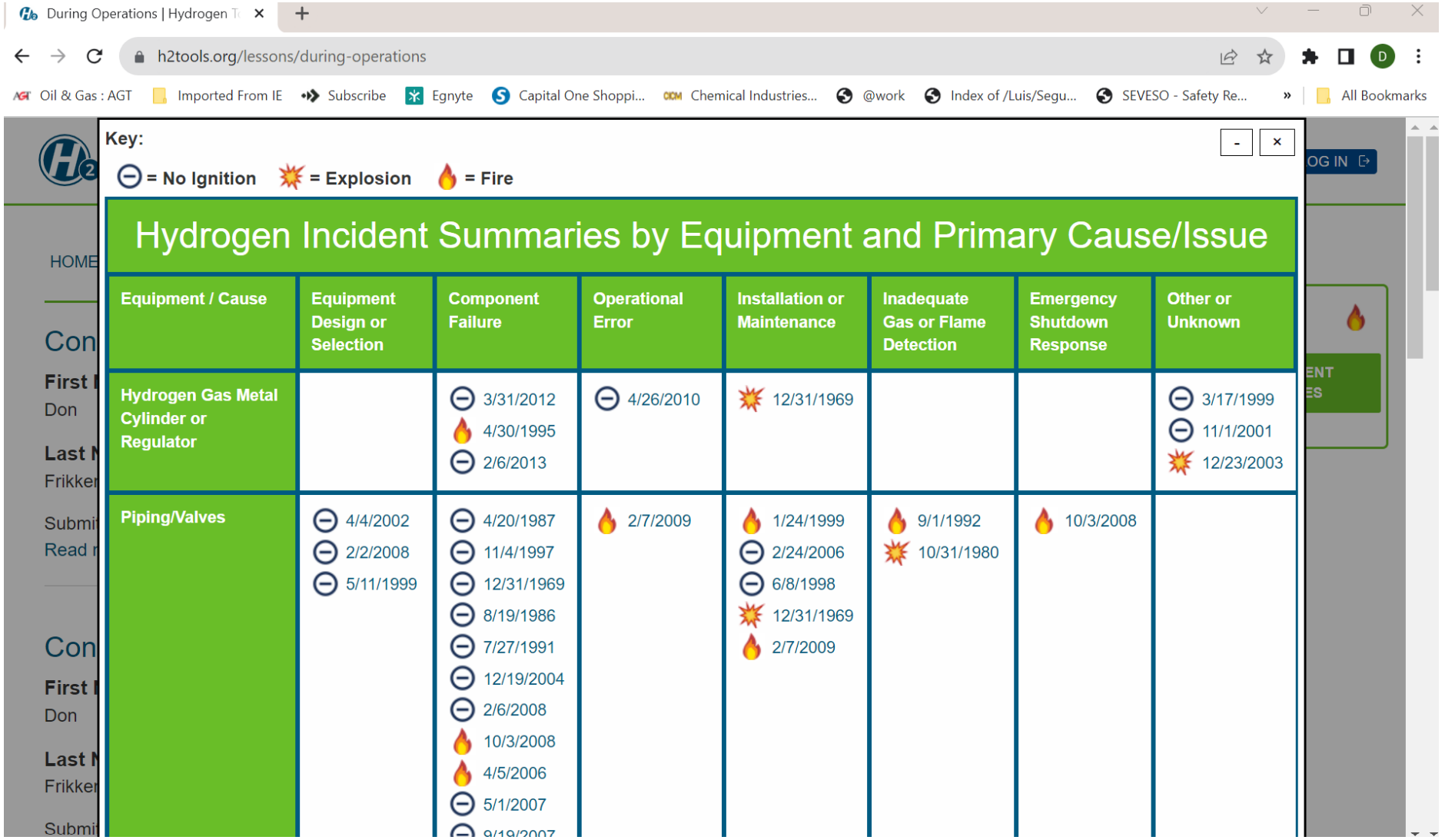
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https://h2tools.org/sites/default/files/Hydrogen_Incident_Examples.pdf

US DOE H2Tools Website Incident Summaries



https://h2tools.org/

US DOE H2Tools Website Incident Summaries

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

Courtesy of Nick Barilo, Director, Center for Hydrogen Safety

Incidents Have Not Scaled With the Build-out

Capacity and station counts have multiplied since 2019, yet serious incidents at energy sites remain low in number to date

Notable energy-site incidents

- **May 2019** — **Gangneung, South Korea**
  Electrolysis pilot plant tank explosion; 2 killed, 6 injured
- **Jun 2019** — **Santa Clara, US**
  Tanker leak and explosion at H_2 supply plant; 11 stations shut
- **Jun 2019** — **Sandvika, Norway**
  Station explosion; minor injuries; all 10 Norway stations closed
- **Jun 2024** — **Gersthofen, Germany**
  New station explodes and burns; no injuries reported
- **Dec 2024** — **South Korea**
  Fuel-cell bus explodes at refuelling station; 1 seriously hurt
- **Dec 2025** — **Leuna, Germany**
  Leak and fire at Linde electrolyzer restart; no injuries reported

Sources: ISPT Hydrohub safety report (2023); CCJ (Jun 2019); Hydrogen Insight (Jun 2024, Dec 2024); Industry Decarbonization (Linde Leuna); IEA GHR 2026 for capacity growth. Red marker = injury or death; dark marker = no serious injury.

Linde explosion | A quarter of Germany's hydrogen filling stations out of action as supply problem enters eighth week

At least 23 of the country's 83 H2 fuelling stops are currently out of operation, largely due to a lack of H2 as investigation continues into August truck trailer explosion



The charred truck trailer and hydrogen cylinders damaged in the explosion being doused with water by Leuna Chemical Park's own firefighters on 26 August. No-one was injured in the accident. **(Photo: InfraLeuna)**

Explosion at filling plant causes nationwide hydrogen crisis

Germany is currently experiencing a massive hydrogen crisis. The trigger was an explosion at a filling plant. Now there are major supply problems.

Quoted from: Linde explosion | A quarter of Germany's hydrogen filling stations out of action as supply problem enters eighth week | Hydrogen Insight

A hydrogen fuel supply problem in Germany is **continuing into its eighth week** following an H_2 truck trailer explosion back in August, with at least 23 of the country's 83 filling stations out of action yesterday evening.

A truck trailer carrying hydrogen cylinders exploded on 26 August at industrial gases giant Linde's facility at the Leuna Chemical Park in eastern Germany due to a suspected, unexplained H_2 leak.

Although no-one was hurt in the deflagration, **all trailers of the same type have been taken out of circulation until the cause of the leak has been unidentified and a potential remedy deployed** — which means that there is currently no way of getting hydrogen to many filling stations across Germany.

California, Golden Energy Transit H2 Bus Fueling Fire, 2023

GET said in a release a portion of the new hydrogen fueling station and a hydrogen fuel cell bus was engulfed in flames.



A GET hydrogen bus, valued at $1.1 million, was destroyed and part of the fueling station was damaged during an early morning fire on Golden State Highway. PHOTO: Brandon A. Barraza

"It is too early to speculate what happened and the Bakersfield Fire Department is conducting an investigation," said Karen King CEO of Golden Empire Transit.

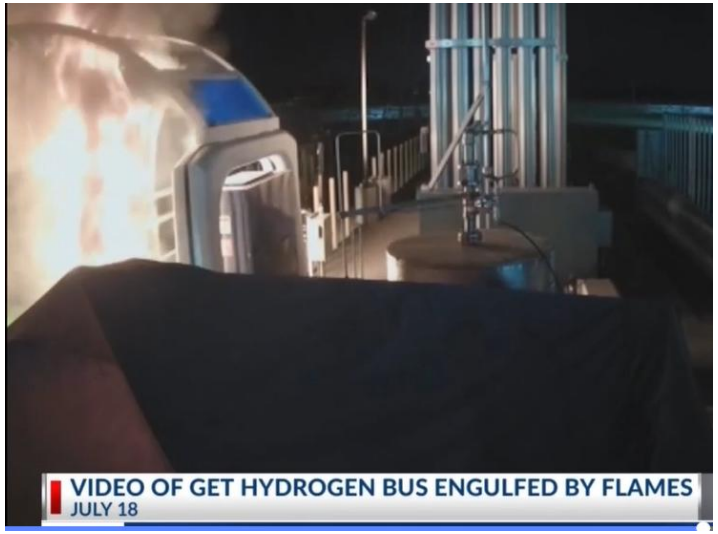
The hydrogen buses were being fueled at the time of the fire.

According to the release, one bus was destroyed and only the dispensing portion of the hydrogen fueling station was damaged.

Video Link: https://youtu.be/-kxnjB7l3bE?si=pmhm8az0_nWltKhM













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Hydrogen explosion shakes Santa Clara neighborhood

By Luz Pena
Sunday, June 2, 2019



An explosion at a chemical plant in Santa Clara caused a shelter in place for residents and businesses in the area.

Hydrogen stations in SF Bay Area still offline, 4 months after explosion

David Herron | September 20, 2019 | Fuel Cells

After the incident, Air Products curtailed hydrogen module cylinder trailer deliveries to allow for inspection of the trailers and a review of the implications of the Santa Clara incident. The suspension of hydrogen deliveries caused interruption or shutdown of nine of the eleven hydrogen vehicle refueling stations in the San Francisco Bay area.[21] These stations were impacted for approximately four months.[22] There were also shortages of hydrogen supplies for several months at other California refueling stations.[23] Air Products did not resume operation until authorized by the Santa Clara Fire Department.

Hydrogen Quantity:
4-5 kg prior to ignition
Tube trailer inventory burned after ignition.



Hydrogen Fueling Station Explodes: Toyota & Hyundai Halt Fuel Cell Car Sales

Blast was so big it set off airbags in nearby cars.



Hydrogen Quantity: 3.5 kg prior to ignition

Norway fines Nel units $3 million over 2019 blast at hydrogen fuel station

By **Reuters**

February 16, 2021 5:33 PM EST · Updated 4 years ago

Aa

OSLO (Reuters) - Nel, a Norwegian maker of zero-emission hydrogen technology, said on Tuesday the authorities had fined two of its units a total of 25 million crowns ($2.97 million) for an incident at a hydrogen fuel station in 2019.

Hydrogen gas leaked from a tank at the station near Oslo in June 2019 and exploded, injuring three people when a pressure wave triggered airbags in their cars nearby, according to Nel and police reports.

Current status

The root cause of the incident has been identified as an assembly error of a specific plug in a hydrogen tank in the high-pressure storage unit. This led to a hydrogen leak, creating a mixture of hydrogen and air that ignited. The investigations will continue into the specific source of ignition.

Nel held press and investor conferences on Friday, 28 June, to share all relevant information publicly. Both events were live-streamed and available as recordings for the remainder of the day for anyone who wasn't able to join at the time.

We will continue to assist our customers in getting stations safely back into operation as quickly as possible.

Q: What is the likely source of ignition?

The source of ignition is still being investigated and it is possible it will never be known with certainty. However, the investigations by Gexcon have indicated that either auto-ignition and/or the movement of the gravel underneath the unit are the most likely sources.

(Published: 28 June, 2019)



1. **A somber scene.** A hydrogen delivery truck is surrounded by debris from the explosion at Muskingum River Power Plant's Unit 5. During delivery, a hydrogen relief device failed, permitting the contents of the hydrogen tank in question to relieve and be ignited by an unknown source. *Courtesy: American Electric Power*

Hydrogen Explosion at Power Plant Results in a $6.9M Verdict

Posted by *msch* on Sep 9, 2011 11:00:00 AM

X Post Share Share 1

Geoffrey Brown and Brian Swiger Attorneys Hydrogen Explosion Trial **Timmons v. Ohio Power Company and American Electri**

Power Service Corporation (Marshall County, West Virginia)

A Marshall County, West Virginia jury awarded a verdict of $6,998,940 to the family of Lewis Timmons, a 61-year old resident of Tyler County, West Virginia, who was killed as a result of an explosion in the hydrogen storage area of the Muskingum River power plant owned by the American Electric Power Services Corporation. The jury awarded the family of Lewis Timmons nearly $2,000,000 in compensatory damages, and $5,000,000 in punitive damages. The jury also declared that the estate was entitled to attorney fees.

Hydrogen Quantity: 18 kg

Explosion and fire severely damages hydrogen refuelling station in Germany just days after it opened to the public

The facility, which received €2m of state funding, is now 'closed until further notice'



The local fire brigade pouring water onto the source of the fire at the hydrogen refuelling station in Gersthofen, Bavaria. (Photo: Gersthofen Fire Brigade)

Quoted from: [Fire brigade extinguishes fire at new hydrogen refueling station in Germany – pv magazine International]

The fire brigade in Gersthofen, Germany, has extinguished a fire at a new hydrogen filling station and prevented it from spreading, the organization said on social media. Gersthofen is a town in Bavaria, near Augsburg.

“According to current information, there was also a loud bang when the fire broke out. The fire department quickly brought the fire under control,” said the local police.

Tyczka Hydrogen inaugurated the station on June 17. The German company operates the filling station and supplies the green hydrogen. The station took nine months to construct.

“With hydrogen dispensers at 350 and 700 bar pressure, the filling station can refuel a wide range of vehicles – from cars, buses, and special vehicles to heavy trucks,” Tyczka Hydrogen said in a press release. “At the current stage of expansion, it can provide around 500 kg of hydrogen per day.”

California, Golden Energy Transit H2 Bus Fueling Fire, Bakersfield, CA, 2023

Video Link: https://youtu.be/-kxnjB7l3bE?si=pmhm8az0_nWltKhM

GET said in a release a portion of the new hydrogen fueling station and a hydrogen fuel cell bus was engulfed in flames.



A GET hydrogen bus, valued at $1.1 million, was destroyed and part of the fueling station was damaged during an early morning fire on Golden State Highway. PHOTO: Brandon A. Barraza

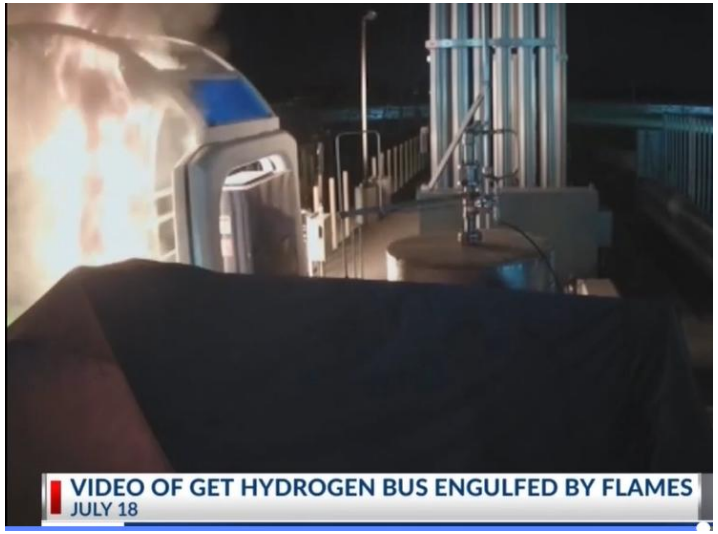
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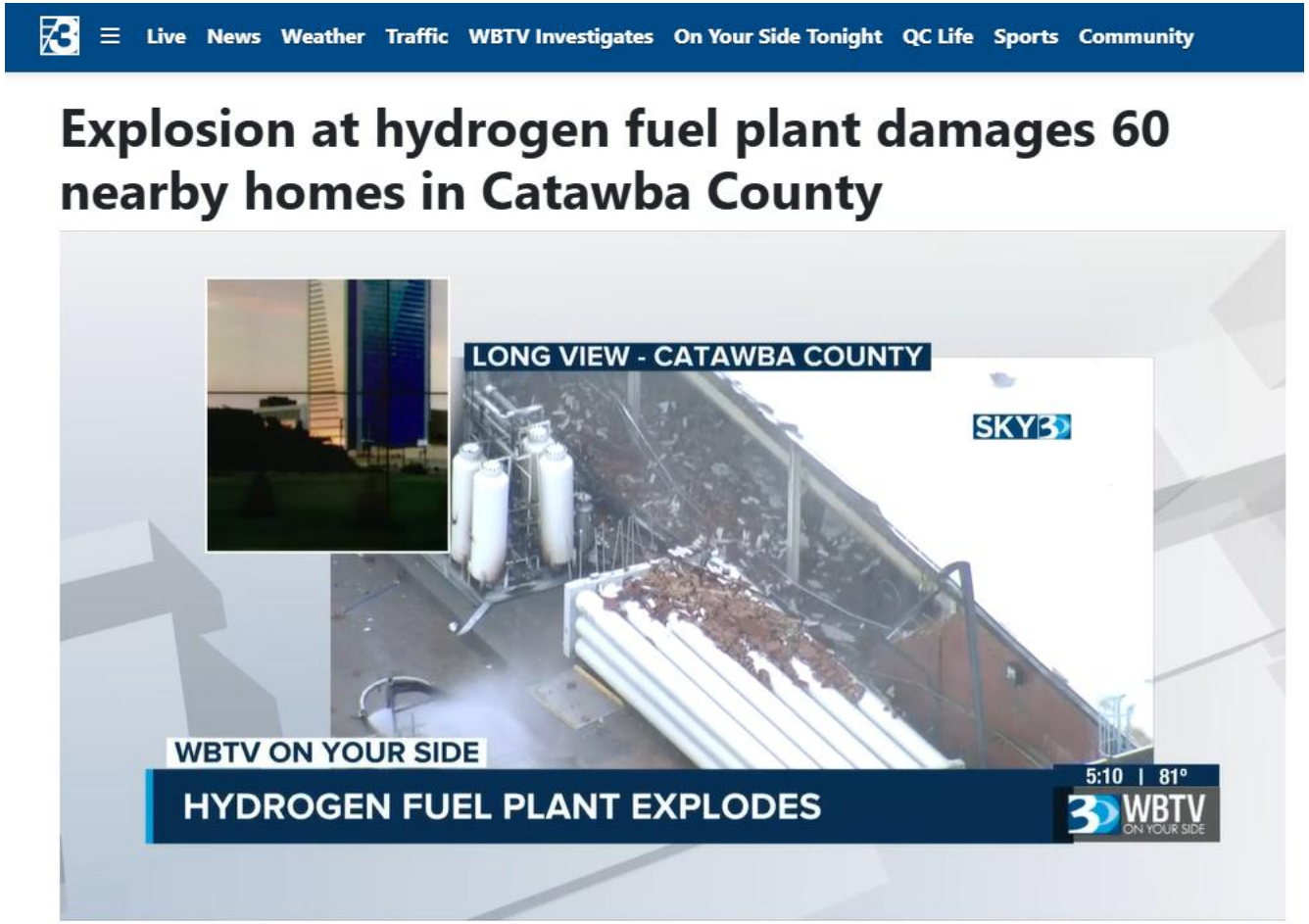
According to the release, one bus was destroyed and only the dispensing portion of the hydrogen fueling station was damaged.











Hydrogen Quantity: 50-60kg

Quoted from: [Explosion at hydrogen fuel plant damages 60 nearby homes in Catawba County]

Officials say all 44 OneH2 employees have been accounted for. It's unclear how many, if any, employees were inside the facility at the time of the explosion.

It appears the explosion happened near the back, outside part of the building, according to officials. **Damage was reported to the building and about 60 surrounding homes.**

Fire officials say **the homes were inspected and one was deemed uninhabitable**. All the other homes suffered "mostly minor damage from the explosion."

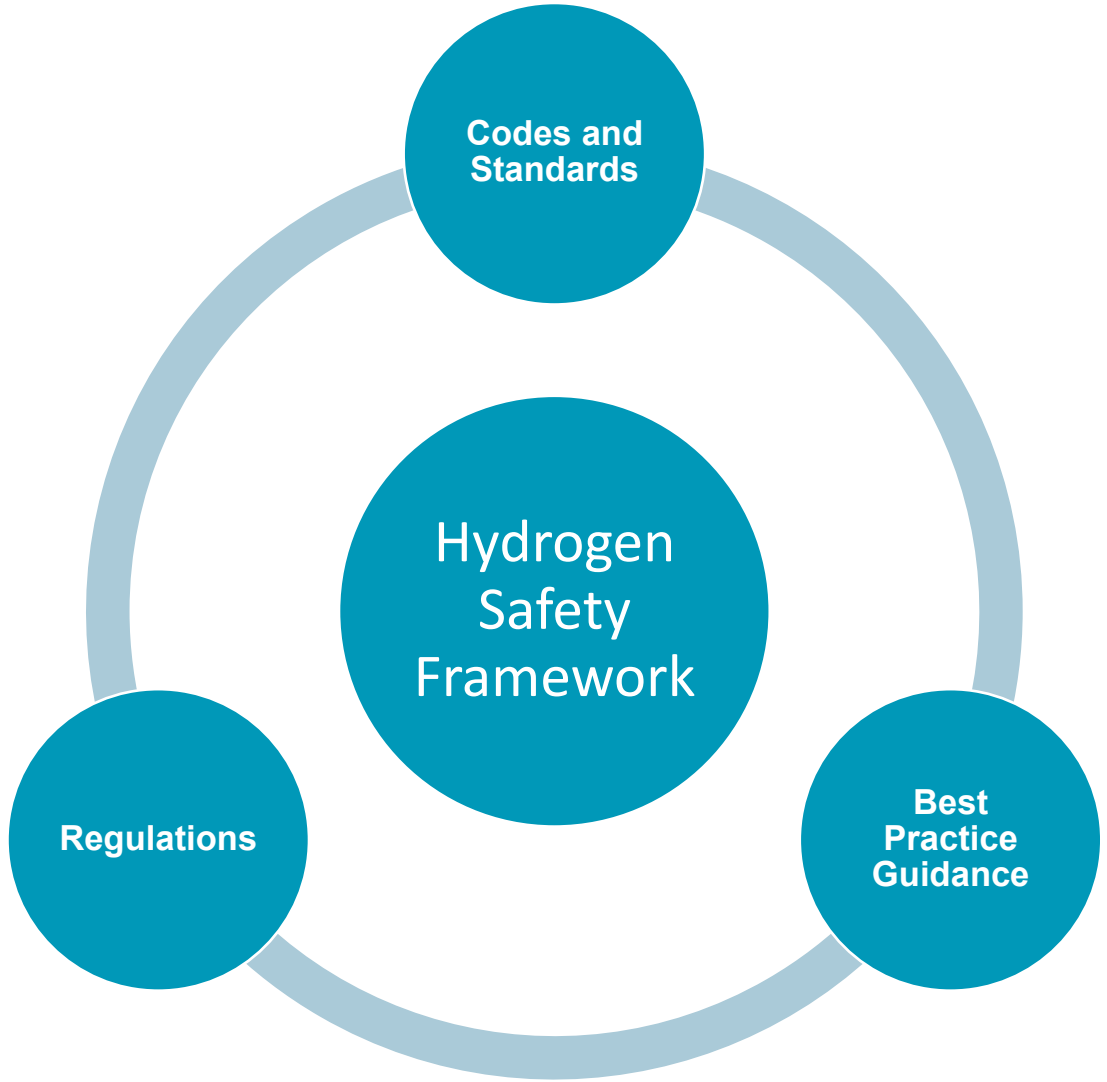
Lynn Brigsbee's home was the one heavily damaged. by the explosion.

"95 percent of my windows are gone," she said.

Lynn was on the sofa when the blast happened less than 100 yards away.

Hydrogen Industry Safety Approach

- As we build out the hydrogen industry applications there will be an unprecedented integration of hydrogen into many aspects of industrial and non-industrial uses.
- There is a network of global regulations, engineering standards, codes, and guidance for best practices for hydrogen safety.
- Following good design codes and standards is not considered best practice for good safe plants and operations.



Hydrogen Industry Safety Approach

- Process safety in addition is the “gold standard” for safety management of hazardous chemical processes
- PSM regulations v voluntary mgmt system
- Vary depending on the country of operation and their regulatory frameworks.
- **Gaps?** –
  - Others may operate in countries that do not have a PSM regulation or they may be excepted by threshold quantitates or exemptions as fuel.
- **Recommendation** - Producers, suppliers, facility operators, users, and their contractors and employees would all benefit from an industry approach to voluntary PSM



Process Safety Management Is The Backbone

Build safety in from concept to operations; PSM keeps those gains from eroding once the site is running

PHASE 1 Concept & design	PHASE 2 Expert review	PHASE 3 Build & commission	PHASE 4 Operate	PHASE 5 Measure & learn
• HAZID and HAZOP • Quantitative risk assessment • ISO 19880-1, ISO 22734, NFPA 2	• Hydrogen Safety Panel (US) or notified body (EU) • Fire service sign-off	• Acceptance tests • Pre-startup safety review • Operators certified first	• Inspection and trip testing • Management of change • Regular audits	• Leading indicators • Report to HIAD or H2Tools • Share lessons

PSM is critical across every phase: hazard analysis, operating procedures, training, mechanical integrity, management of change, pre-startup review, contractor control, incident investigation, emergency planning and audits. Required by OSHA above 10,000 lb of H_2; apply it at every site regardless of size.

Target: zero serious losses of containment (API RP 754 Tier 1–2), 100% of safety-critical inspections and trip tests on time, and near-miss reports rising in early years, a sign that people are reporting.

Standards and programmes: ISO 19880-1; ISO 22734; NFPA 2 and 55; ASME B31.12; IEC 61511; OSHA PSM (29 CFR 1910.119); API RP 754; AIChE Center for Hydrogen Safety; EU HIAD; PNNL H2Tools.

CCPS
Mining, Minerals, & Metals Subcommittee

An AIChE Technology Alliance
CCPS
Center for Chemical Process Safety



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Process Safety Management Systems – License to Operate

- There is a strong business case for implementing process safety management systems – the value is in preventing the loss of lives, preserving the integrity of operations and protecting the environment.
- Safety management systems are well developed over the past 50+ years
- It takes years of development to make a PSM system effective and diligence to sustain that level



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Safety Culture for Hydrogen Industry

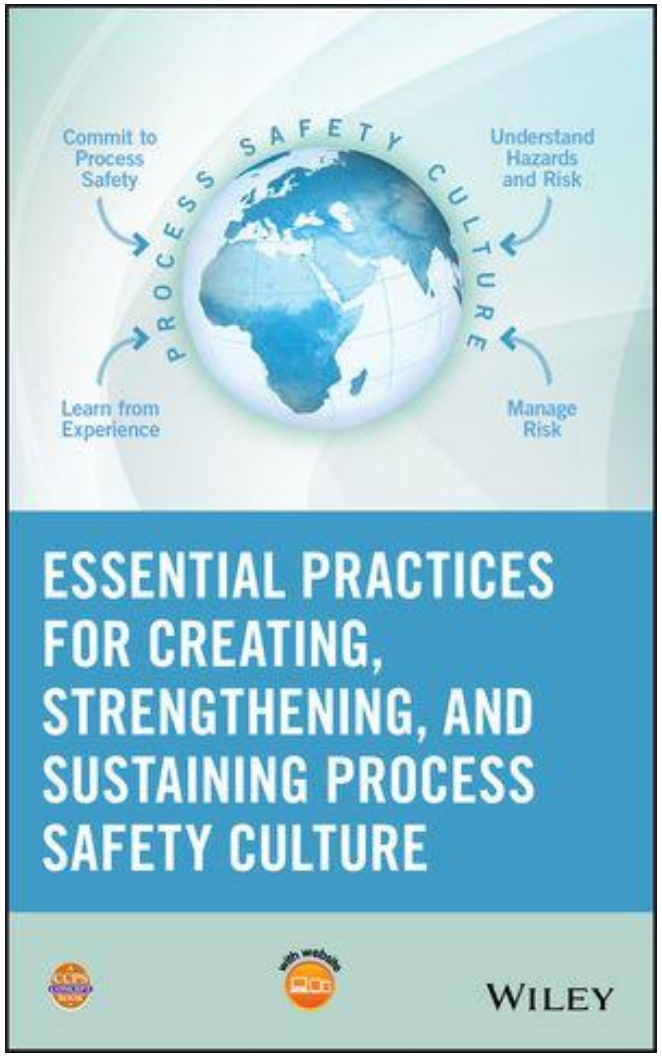
- ***There is a need for continuously diligent hydrogen safety culture*** to improve overall performance
- It must be the foundation of the operating philosophy
- We believe enhancing culture is key to a potential breakthrough in more effective program results.



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Core Principles of Process Safety Culture

- Establish an Imperative for Safety
- Provide Strong Leadership
- Maintain a Sense of Vulnerability
- Understand and Act Upon Hazards/Risks
- Empower Individuals to Successfully Fulfill their Safety Responsibilities
- Defer to Expertise
- Ensure Open and Frank Communications
- Foster Mutual Trust
- Combat the Normalization of Deviance
- Learn to Assess and Advance the Culture



CCPS Guidelines PSM Culture (2017)

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Conduct of Operations – Principles

- Conduct of Operations (COO) is the embodiment of an organization's values and principles in management systems that are developed, implemented, and maintained to:
  - 1) structure operational tasks in a manner consistent with the organization’s risk tolerance
  - 2) ensure that every task is performed deliberately and correctly
  - 3) minimize variations in performance



1 “Conduct of Operations and Operational Discipline – For Improving Process Safety in Industry”, CCPS, Wiley, 2011

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Conduct of Operations and Operational Discipline Contribution to Major CSB Incidents

Conduct of Operations and Operational Discipline – Primary Findings
A2, A5, A10 C3, C11, C12, C18, C26, C43, C50, C57, C58 D9 J2, J19, J28, J38, J49, J50, J51, J52, J53, J54, J55, J56, J57, J58, J61, J63, J67, J70, J72, J73, J114, J127, J130, J147, J151, J165, J171, J174, J178, J180, J182, J183, J188, J190, J192, J208, J209, J211, J217, J243, J247, J248, J259, J262, J270, J271 S3, S4, S5, S13, S14
Conduct of Operations and Operational Discipline – Secondary Findings
A6, A7 C13, C15, C20, C24, C27, C28, C60, C76 D7, D19 J21, J22, J24, J25, J32, J35, J40, J64, J65, J75, J76, J91, J108, J109, J116, J119, J128, J129, J131, J133, J162, J163, J170, J176, J181, J184, J185, J186, J212, J237, J253, J261 S1, S10, S12, S15

	Investigation
C1.	Arkema Inc. Chemical Plant Fire
C2.	Acetylene Service Company Gas Explosion
C3.	AirGas Facility Fatal Explosion
C4.	AL Solutions Fatal Dust Explosion
C5.	Allied Terminals Fertilizer Tank Collapse
C6.	Barton Solvents Explosions and Fire
C7.	Bayer CropScience Pesticide Waste Tank Explosion
C8.	Bethlehem Steel Corporation Gas Condensate Fire
C9.	Bethune Point Wastewater Plant Explosion
C10.	BLSR Operating Ltd. Vapor Cloud Fire
C11.	BP America Refinery Explosion
C12.	BP Amoco Thermal Decomposition Incident
C13.	CAI / Arnel Chemical Plant Explosion
C14.	Carbide Industries Fire and Explosion
C15.	Caribbean Petroleum Refining Tank Explosion and Fire
C16.	Chevron Refinery Fire
C17.	CITGO Refinery Hydrofluoric Acid Release and Fire
C18.	Combustible Dust Hazard Investigation
C19.	ConAgra Natural Gas Explosion and Ammonia Release
C20.	CTA Acoustics Dust Explosion and Fire
C21.	D.D. Williamson & Co. Catastrophic Vessel Failure
C22.	Donaldson Enterprises, Inc. Fatal Fireworks Disassembly Explosion and Fire
C23.	DPC Enterprises Festus Chlorine Release
C24.	DPC Enterprises Glendale Chlorine Release
C25.	DuPont Corporation Toxic Chemical Releases
C26.	DuPont La Porte Facility Toxic Chemical Release
C27.	E. I. DuPont De Nemours Co. Fatal Hotwork Explosion
C28.	Emergency Shutdown Systems for Chlorine Transfer
C29.	Enterprise Pascagoula Gas Plant Explosion and Fire
C30.	EQ Hazardous Waste Plant Explosions and Fire
C31.	ExxonMobil Refinery Explosion
C32.	First Chemical Corp. Reactive Chemical Explosion
C33.	Formosa Plastics Propylene Explosion
C34.	Formosa Plastics Vinyl Chloride Explosion
C35.	Freedom Industries Chemical Release
C36.	Georgia-Pacific Corp. Hydrogen Sulfide Poisoning
C37.	Hayes Lemmerz Dust Explosions and Fire
C38.	Herrig Brothers Farm Propane Tank Explosion
C39.	Hoeganaes Corporation Fatal Flash Fires
C40.	Honeywell Chemical Incidents
C41.	Imperial Sugar Company Dust Explosion and Fire
C42.	Improving Reactive Hazard Management
C43.	Kaltech Industries Waste Mixing Explosion
C44.	Kleen Energy Natural Gas Explosion
C45.	Little General Store Propane Explosion
C46.	Macondo Blowout and Explosion
C47.	Marcus Oil and Chemical Tank Explosion
C48.	MFG Chemical Inc. Toxic Gas Release
C49.	MGPI Processing, Inc. Toxic Chemical Release
C50.	Morton International Inc. Runaway Chemical Reaction
C51.	Motiva Enterprises Sulfuric Acid Tank Explosion
C52.	NDK Crystal Inc. Explosion with Offsite Fatality
C53.	Oil Site Safety
C54.	Packaging Corporation of America Hot Work Explosion
C55.	Partridge Raleigh Oilfield Explosion and Fire
C56.	Praxair Flammable Gas Cylinder Fire
C57.	Pryor Trust Fatal Gas Well Blowout and Fire
C58.	Sierra Chemical Co. High Explosives Accident
C59.	Sonat Exploration Co. Catastrophic Vessel Overpressurization

See www.csb.gov for incident investigation reports

1 "Driving Continuous Process Safety Improvement from Investigated Incidents", CCPS, Wiley, 2021

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Five Priorities For Safer Hydrogen Energy Sites

Each targets a failure mode in the incident record; all five are delivered and sustained through process safety management

1 Design out failures

- Auto-trip electrolyzers on O_2-in-H_2
- H_2-rated materials, fire-sized relief
- Scheduled hose replacement

2 Detect and isolate fast

- H_2 gas and UV/IR flame detectors
- Auto shutdown and isolation
- Trips to IEC 61511 integrity

3 Control start-up

- Pre-startup safety review
- Inert-gas leak test and purge
- Staged ramp-up; restarts too

4 Fix the human factors

- Hydrogen-specific hazard training
- Permit-to-work, contractor control
- Management of change

5 Plan for emergencies

- Train local fire services first
- Redundant supply for stations
- Drills with responders

Why these five

- Storage tanks: 40% of station incidents, all 3 deaths
- Human error 38%, design 29%
- H_2/O_2 mixing: top electrolyzer cause

Sources: incident analysis on slides 4–6 (Nekhwevha et al. 2025; Tuhi et al., ESREL 2024; ISPT 2023; Wen et al. 2022); NFPA 2; ISO 19880-1; ISO 22734; IEC 60079; IEC 61511.

Presentation Summary

- Hydrogen incidents are occurring due to preventable causes and contributing factors that speak to the need for process safety frameworks
- Industry experience of over 40 years of PSM has shown that it has positively changed the way safety is managed
- The application of a PSM framework to hydrogen operations can apply throughout the lifecycle and ecosystem
  - Manufacturing of hydrogen.
  - Transportation.
  - Use of hydrogen as a fuel
- It is recommended to influence the industry for to ensure hydrogen safety through a modern process safety framework

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PROCESS RISK MANAGEMENT

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