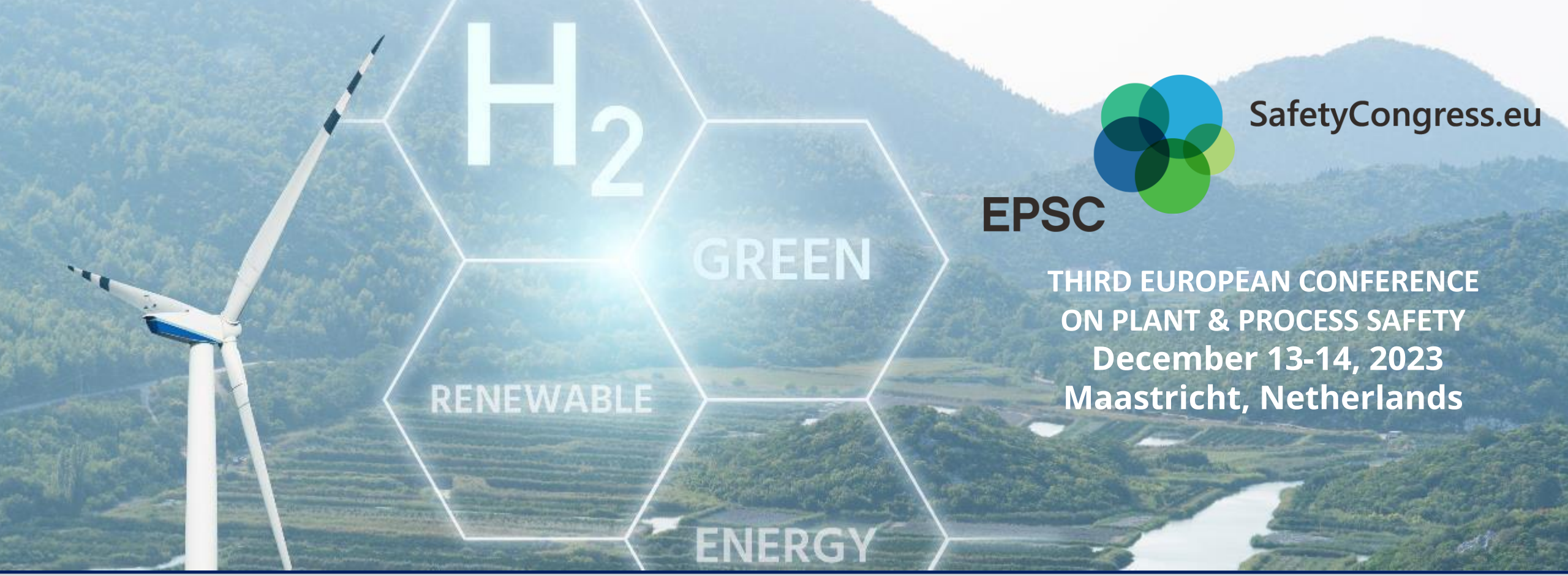

SafetyCongress.eu

EPSC

THIRD EUROPEAN CONFERENCE
ON PLANT & PROCESS SAFETY
December 13-14, 2023
Maastricht, Netherlands

Analysis of Recent Process Safety Incidents in the Hydrogen Industry

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Presentation Overview

- The hydrogen economy and importance of global process safety management implementation as a safety framework
- Available process safety frameworks and gaps
- Data sources for analyzing hydrogen releases and quality of data
- Recent incidents
- Conclusions

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February 23, 1765, Discovery?

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February 23, 1765, Discovery of Hydrogen

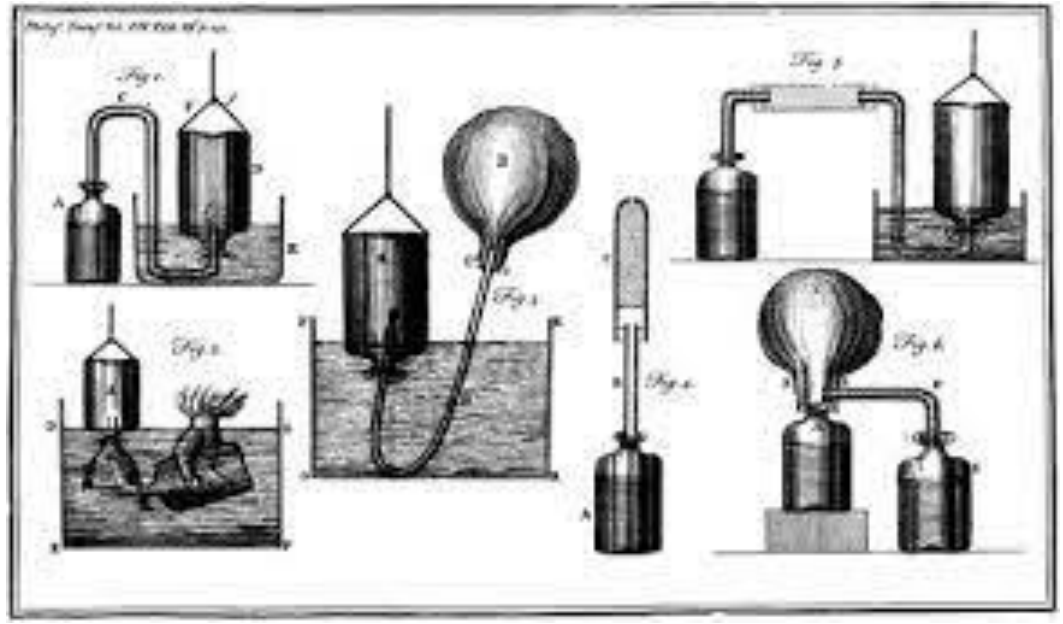
February 23, 1765 - Henry Cavendish discovers hydrogen

To Henry Cavendish, British-French physicist and chemist, considered one of the great precursors of modern chemistry, we owe the discovery of hydrogen, the lightest of the known gases.

On February 23, 1765, he managed to isolate said element and thus discover its properties. To do this, he took zinc particles that he later mixed with chloric acid. This mixture began to bubble, generating a gas, which he called "flammable air" (what we know today as hydrogen).

Cavendish wanted to go a step further and investigate how hydrogen reacted with other elements, such as air. The surprise was the result of this chemical reaction: water! He analyzed it and discovered that it was made up of two parts hydrogen and one part oxygen.

Mes: February
Etiquetas: periodic table - química - science



The proposed widespread use of hydrogen poses new safety hazards that requires careful consideration and stringent management of risk.

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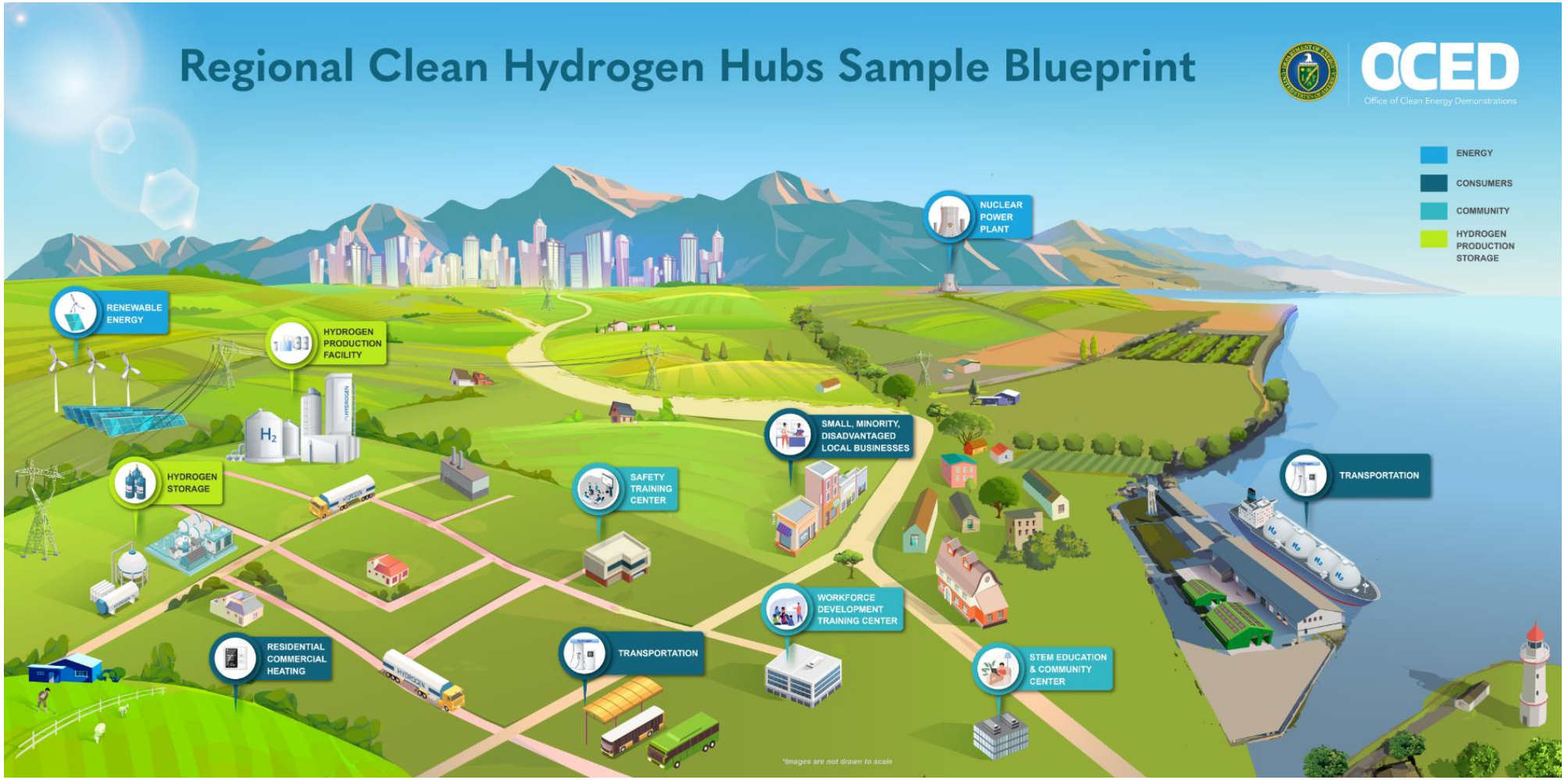
Hydrogen Economy



- 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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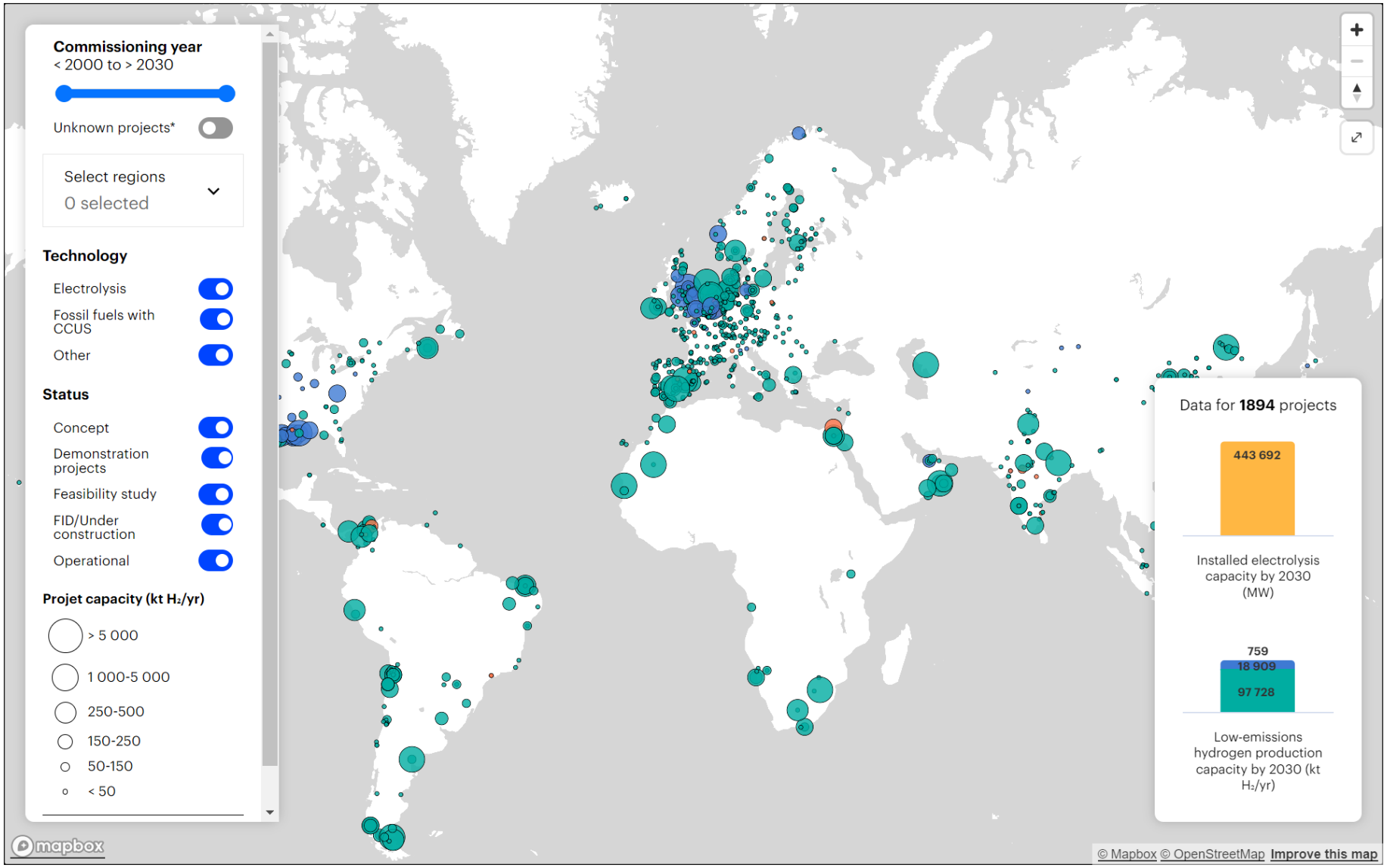
Planned Hydrogen Projects – 2000 to 2030 (as of 12-2023)



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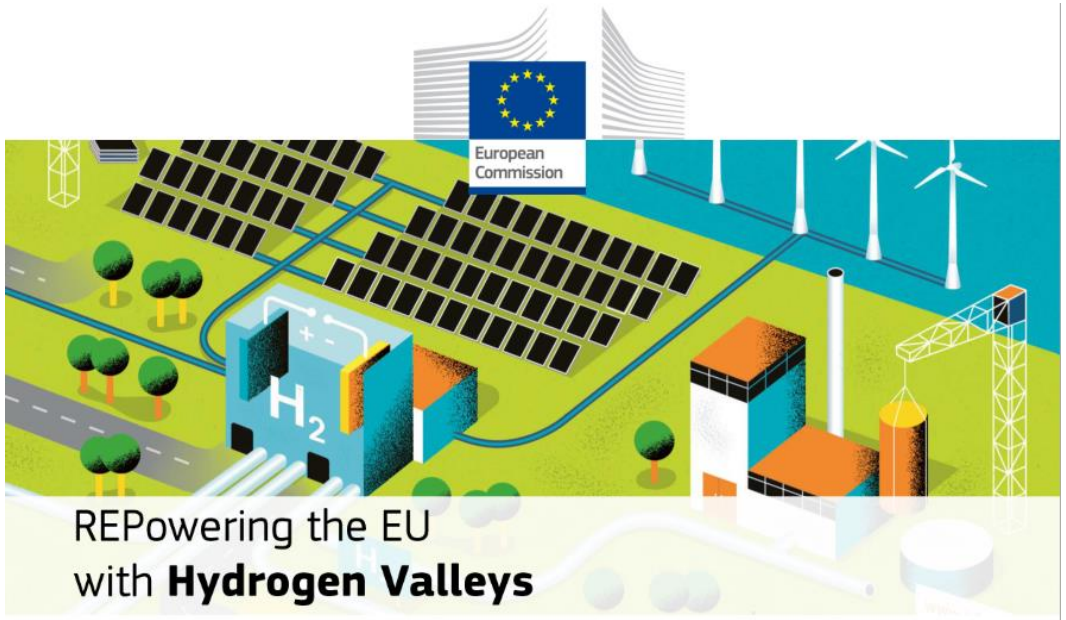
EU Hydrogen Initiatives



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US DOE Sponsored Hydrogen Hubs

- October 2023: DOE competitively selected seven US regional clean hydrogen hubs to catalyze more than $40 billion in private investment bringing the total public and private investment in hydrogen hubs to nearly $50 billion with US Government matching funds

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Importance of a Process Safety Framework for Hydrogen

- The hydrogen industry as it evolves will need to maintain the highest level of safety performance
- Recent incidents challenge the public's confidence in hydrogen safety and illustrate the necessity and value of process safety management
- Full appreciation of the challenges ahead and use of best available methods – get ahead of the issues learned by other industries

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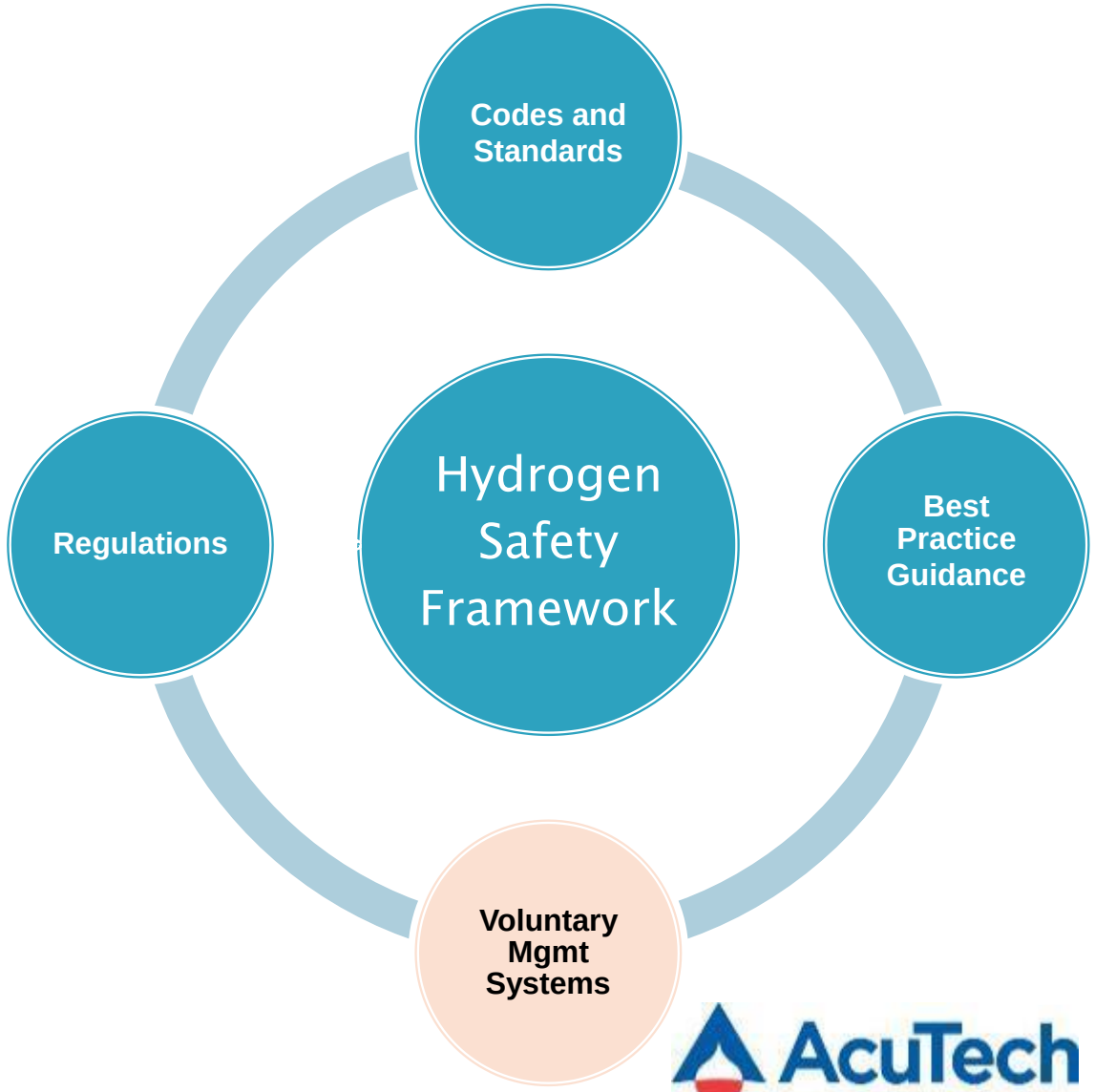
Hydrogen Industry Safety Approach

- Network of global regulations, engineering standards, codes, and guidance for best practices for hydrogen safety.
- Some operations may be subject to PSM regulations, which may 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.
  - If not required by regulation still may follow model approaches and industry codes and standards.
- **Recommendation** - Producers, suppliers, facility operators, users, and their contractors and employees would all benefit from an industry approach to voluntary PSM



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Process Safety Management Regulations v Industry Initiatives

- **PSM regulations:**
- Mandatory but not 100% global coverage and not entirely focused on corporate risk management
  - Reduce the likelihood and intensity of process safety impacts at the national level on workers, the public, and the environment and national economic impacts including loss of industrial manufacturing, supply chain disruptions and related costs.
- **Corporate Initiatives:**
- Voluntary, necessary to complete the gaps as a global enterprise risk management standard, and may exceed regulatory requirements benefitting the corporation
  - Reduce the likelihood and intensity of process safety impacts on site workers, the local public, and the local environment and company economic impacts including capital losses, legal and other administrative costs, process and supply chain disruptions and losses, and reputational damage.

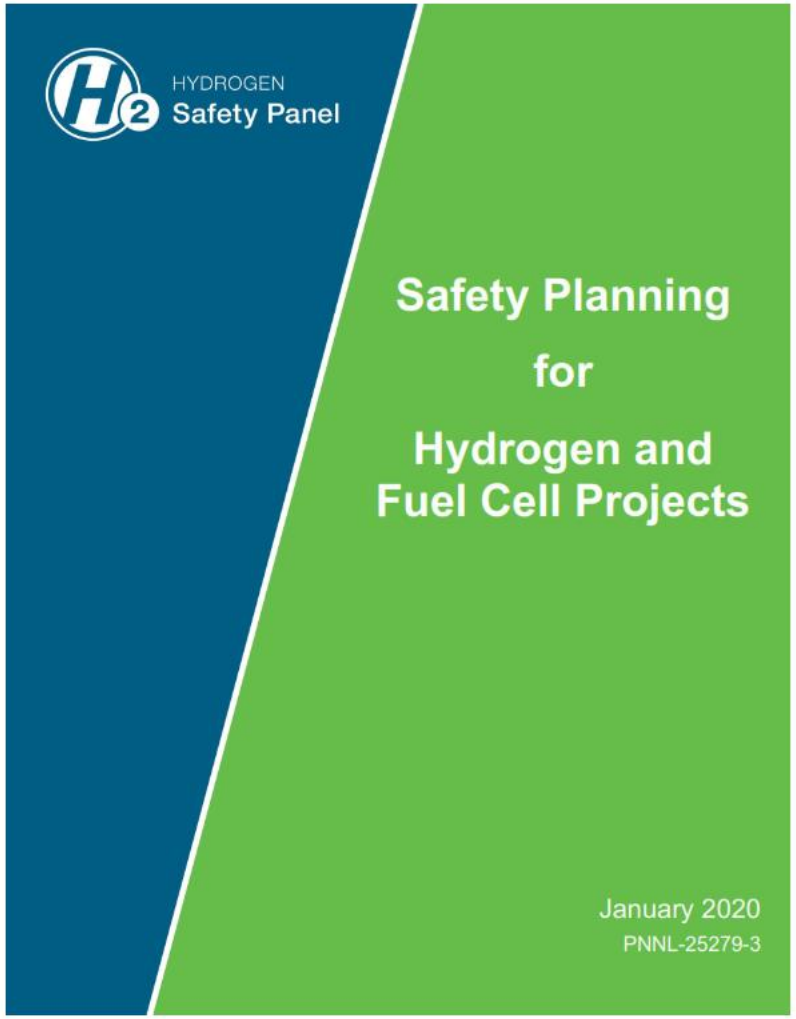
Regulatory Reponses to Bhopal India and Other Incidents

- **Not all hydrogen applications will be covered by current regulations for process safety. For example, in stationary sources the most significant regulations are for major hazard installations:**
  - **The Seveso-III-Directive (2012/18/EU)** aims at the prevention of major accidents involving dangerous substances. However, as accidents may nevertheless occur, it also aims at limiting the consequences of such accidents not only for human health but also for the environment (https://ec.europa.eu/environment/seveso/legislation.htm)
  - **UK Control of Major Incident Hazards (COMAH)** including a MAPP for SMS
  - **OSHA Process Safety Management Regulations** – (29 CFR 1910.119) concerned with accident prevention in the workplace (www.osha.gov) based on a list of certain chemicals above threshold quantities
  - **EPA Risk Management Program Regulations** (40 CFR Part 68) - concerned with accident prevention to protect the public and environment (www.epa.gov/swercepp) based on certain chemicals above threshold quantities

CCPS Risk Based Process Safety v OSHA PSM v HSP Safety Plan

Table 2.1. Comparison of RBPS elements to OSHA PSM elements.

CCPS RBPS Element	*OSHA PSM/EPA RMP Elements*
Commit to Process Safety	
1. Process Safety Culture	
2. Compliance with Standards	Process Safety Information
3. Process Safety Competency	
4. Workforce Involvement	Employee Participation
5. Stakeholder Outreach	Stakeholder Outreach (EPA RMP)
Understand Hazards and Risk	
6. Process Knowledge Management	Process Safety Information
7. Hazard Identification and Risk Analysis	Process Hazard Analysis
Manage Risk	
8. Operating Procedures	Operating Procedures
9. Safe Work Practices	Operating Procedures Hot Work Permits
10. Asset Integrity and Reliability	Mechanical Integrity
11. Contractor Management	Contractors
12. Training and Performance Assurance	Training
13. Management of Change	Management of Change
14. Operational Readiness	Pre-startup Safety Review
15. Conduct of Operations	
16. Emergency Management	Emergency Planning and Response
Learn from Experience	
17. Incident Investigation	Incident Investigation
18. Measurement and Metrics	
19. Auditing	Compliance Audits
20. Management Review and Continuous Improvement	



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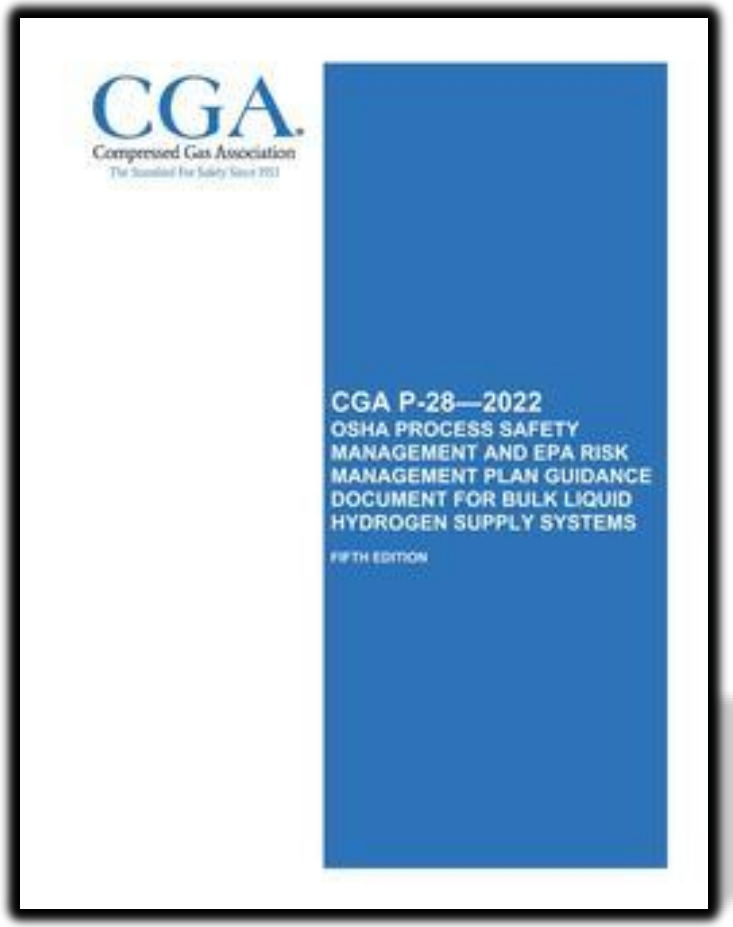
Example – Compressed Gas Association Process Safety Management and EPA Risk Management Guidance Document

- **P-28:** OSHA Process Safety Management and EPA Risk Management Plan Guidance Document for Bulk Liquid Hydrogen Supply Systems
- The U.S. Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) standard and the U.S. Environmental Protection Agency (EPA) Risk Management Program (RMP) rule require that some U.S. industrial gas facilities comply with these regulations".

  This publication is designed to help owners and operators of liquid hydrogen bulk tanks comply with PSM and RMP rules in addition to the requirements of CGA H-5, Standard for Bulk Hydrogen Supply Systems (an American National Standard). CGA H-5 refers to NFPA 55, Compressed Gases and Cryogenic Fluids Code, for the minimum setback distances between bulk hydrogen systems and exposures.
-

  More details about the application of OSHA PSM and EPA RMP to hydrogen supply systems and other compressed gas and cryogenic fluid systems can be found in CGA P-29, Guideline for Application of OSHA PSM and EPA RMP to the Compressed Gas Industry.



CGA's P-86 Publication Guides Process Safety Management in Industrial & Medical Gas Facilities

A Process Safety Management Framework for the Compressed Gas Industry

- The process safety management framework provided in CGA P-86 may be applied to all processes within the industrial and medical gases industry. The intent of this publication is to make process safety management understandable beyond the requirements found in U.S. Occupational Safety and Health Administration (OSHA) PSM regulations.
- CGA P-86 is designed to address process safety hazards and to be equally suitable for processes found across the industry

21 Essential Process Safety Management Elements

•Element 1 – Leadership commitment and responsibility
•Element 2 – Compliance with legislation and industry standards
•Element 3 – Employee selection, training, and competency
•Element 4 – Workforce involvement
•Element 5 – Communication with stakeholders
•Element 6 – Hazard identification and risk assessment
•Element 7 – Documentation, records, and knowledge management
•Element 8 – Process and operational status monitoring and handover
•Element 9 – Operating procedures
•Element 10 – Management of operational interfaces
•Element 11 – Standards and practices
•Element 12 – Management of change
•Element 13 – Operational readiness and process startup
•Element 14 – Emergency and crisis management
•Element 15 – Inspection and maintenance
•Element 16 – Management of safety critical devices
•Element 17 – Work control, permit to work, and task risk management
•Element 18 – Contractors and suppliers – selection and management
•Element 19 – Incident investigation
•Element 20 – Audit, management review, and intervention
•Element 21 – Measures and metrics

RIVM Incident Analysis

Substance, product or solution	Number of victims	Number of incidents
Chlorine	24	14
Hydrogen chloride (hydrochloric acid)	18	11
Hydrochloric acid (solution)	18	6
Oleum	9	1
Caustic soda (solution)	8	7
Ammonia	7	13
Phosphorus	7	5
Phosgene	7	2
Chloroacetaldehyde	7	1
Isoprene	7	1
Ethylidene norbornene	6	1
Hydrogen sulphide	5	9
Toluene	5	3
Acetyl chloride	5	1
Hydrogen	4	21
Ethylene oxide	4	10
Steam/Hot water	4	6
Gasoline	2	7
Ethanol	2	6
Naphtha	2	6
Benzene	1	10
Gasoline (diesel)	1	6
Propene (propylene)	1	6
Methane	0	6

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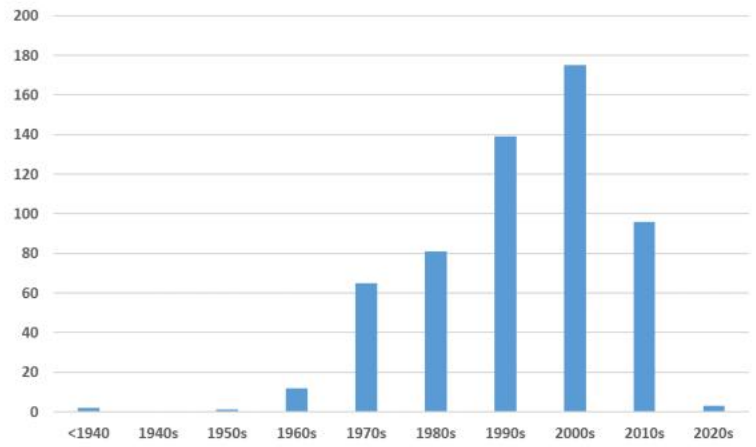
European Hydrogen Safety Panel Incident Analysis

Clean Hydrogen Partnership

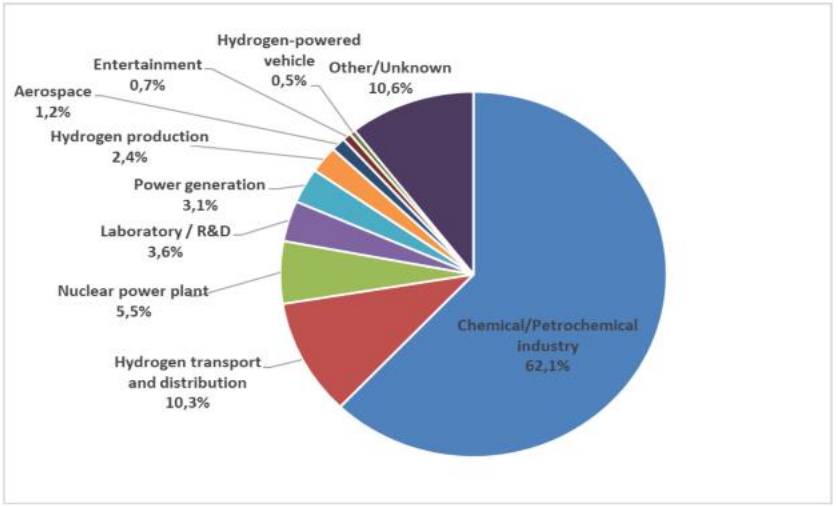
Results from the statistics analysis (1)

The analysis reported here is based on the 706 incidents, which were in the database as of May 2021. A total of 576 of these events were considered to be statistically relevant and formed the basis for the statistical analysis to inform lessons learned and recommendations.

Years



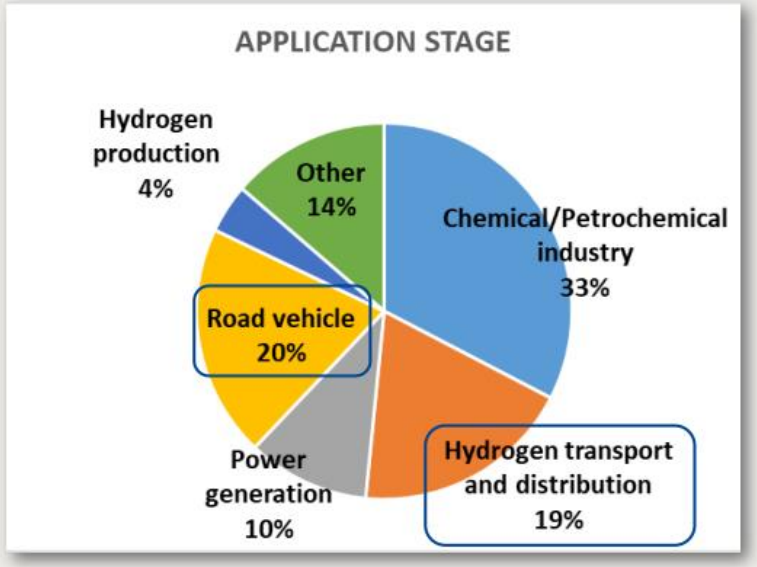
Industrial sectors



HIAD Data

Lessons learnt from safety-related events involving hydrogen storage

Workshop on Safe Storage of Hydrogen



Road vehicle (19 events)

- Incidents involving mainly FCE buses (near misses)
- 1 car incident (with explosion): H2 tube trailer involved
- 1 Hydrogen leak on a fuel cells bus (in confined space)

Hydrogen transport and distribution

- Number of cases: 18
  - ✓ Tube trailers 9
  - ✓ Fuelling station 3
  - ✓ Hydrogen storage 6

4

"Lessons learnt from safety related events involving hydrogen storage", Daniele Melideo , FCH, 2021

EU HyRam/HIAD Data Analysis

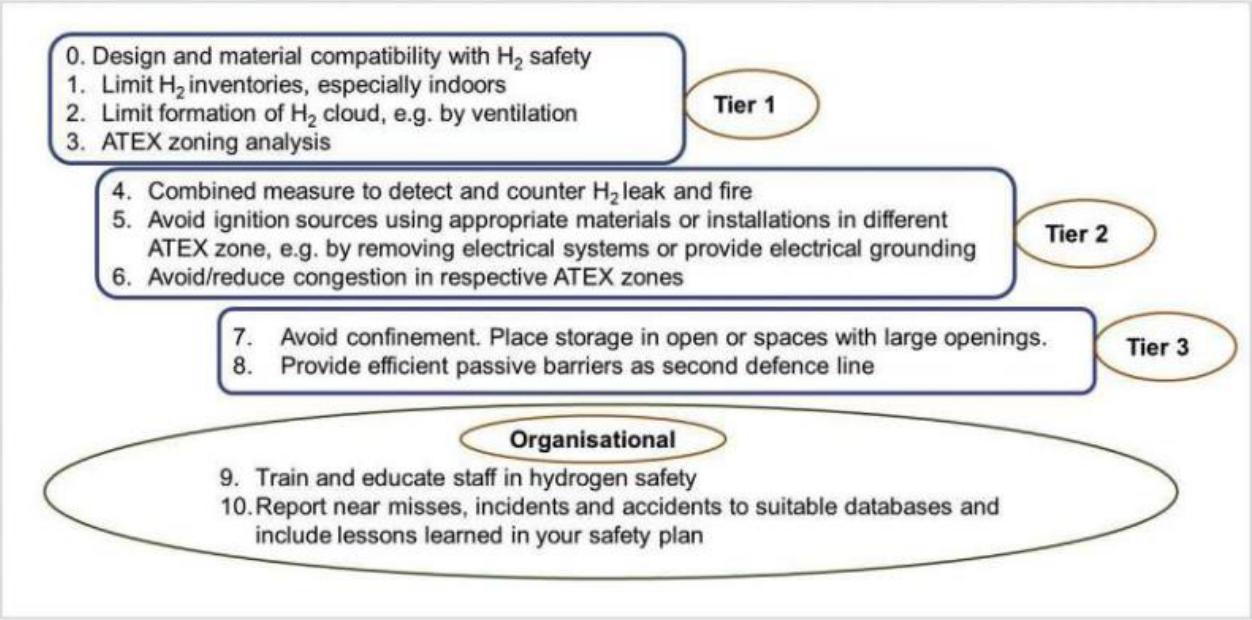


Fig. 7 – Hydrogen safety principles (SP#) (European Hydrogen Safety Panel, 2021).

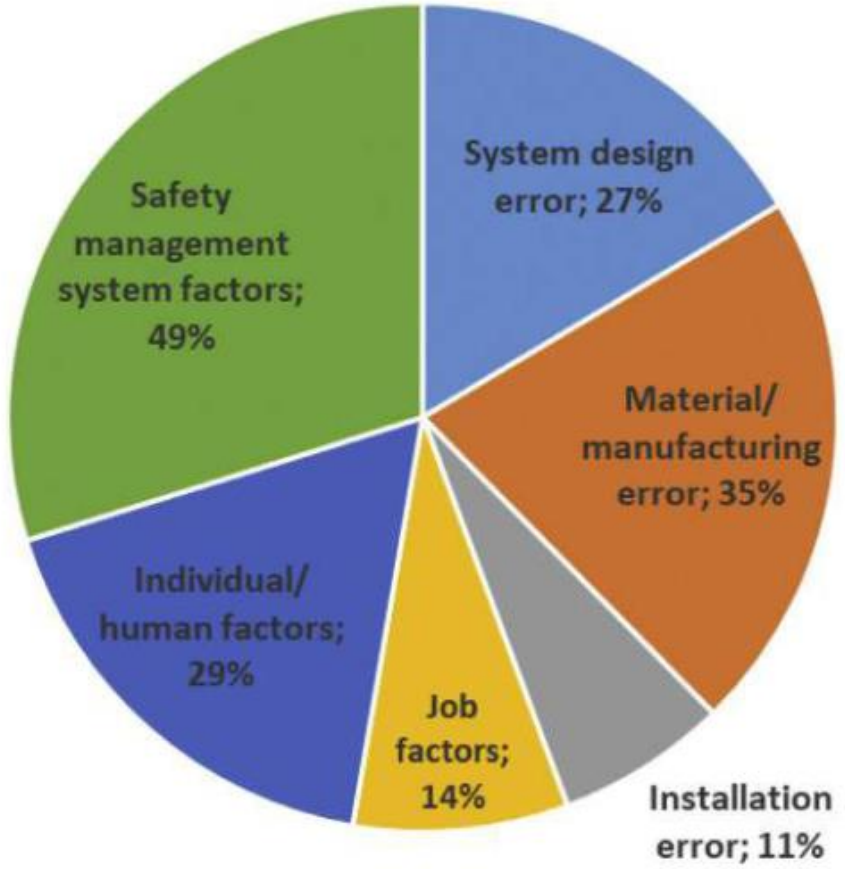


Fig. 5 – Percentages related to the causes of the events considering multiple causes per event.

Statistics, lessons learned and recommendations from analysis of HIAD 2.0 database

Jennifer X. Wen [a,], Marta Marono [b], Pietro Moretto [c], Ernst-Arndt Reinecke [d], Pratap Sathiah [e], Etienne Studer [f], Elena Vyazmina [g], Daniele Melideo [h]*

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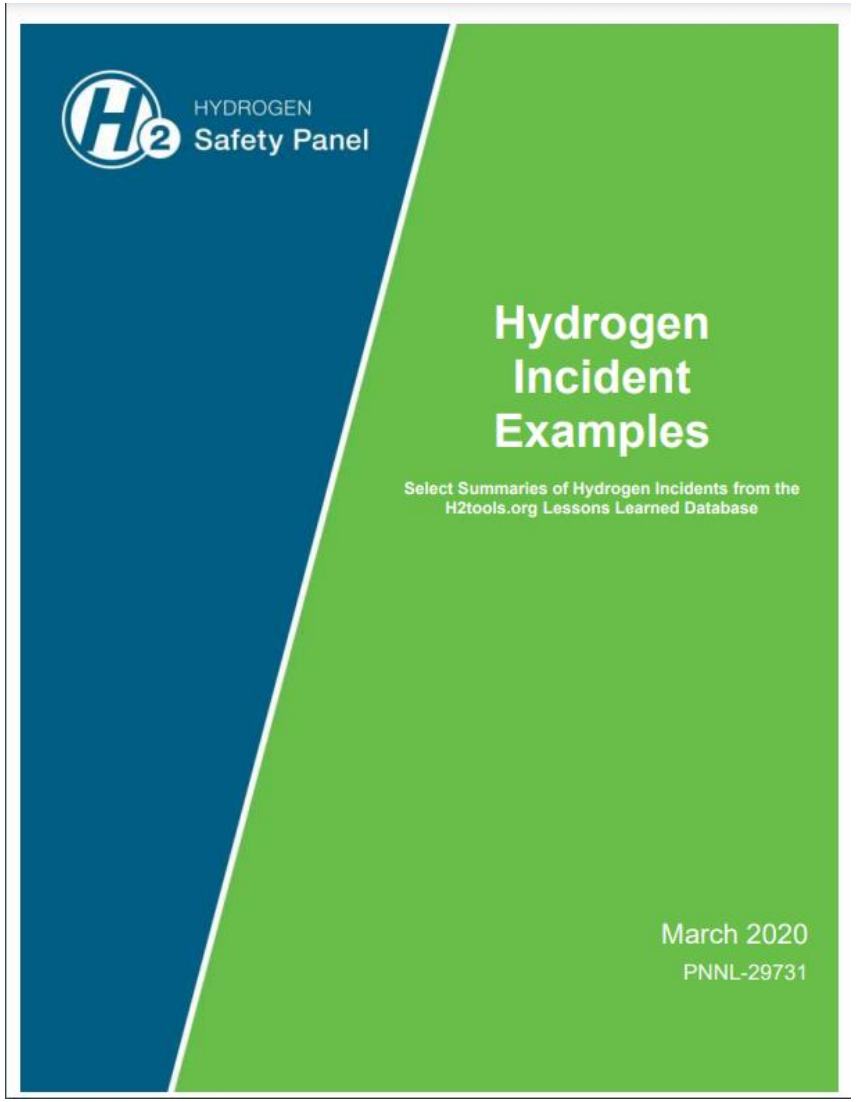
US DOE Hydrogen Safety Panel – Hydrogen Incident Examples



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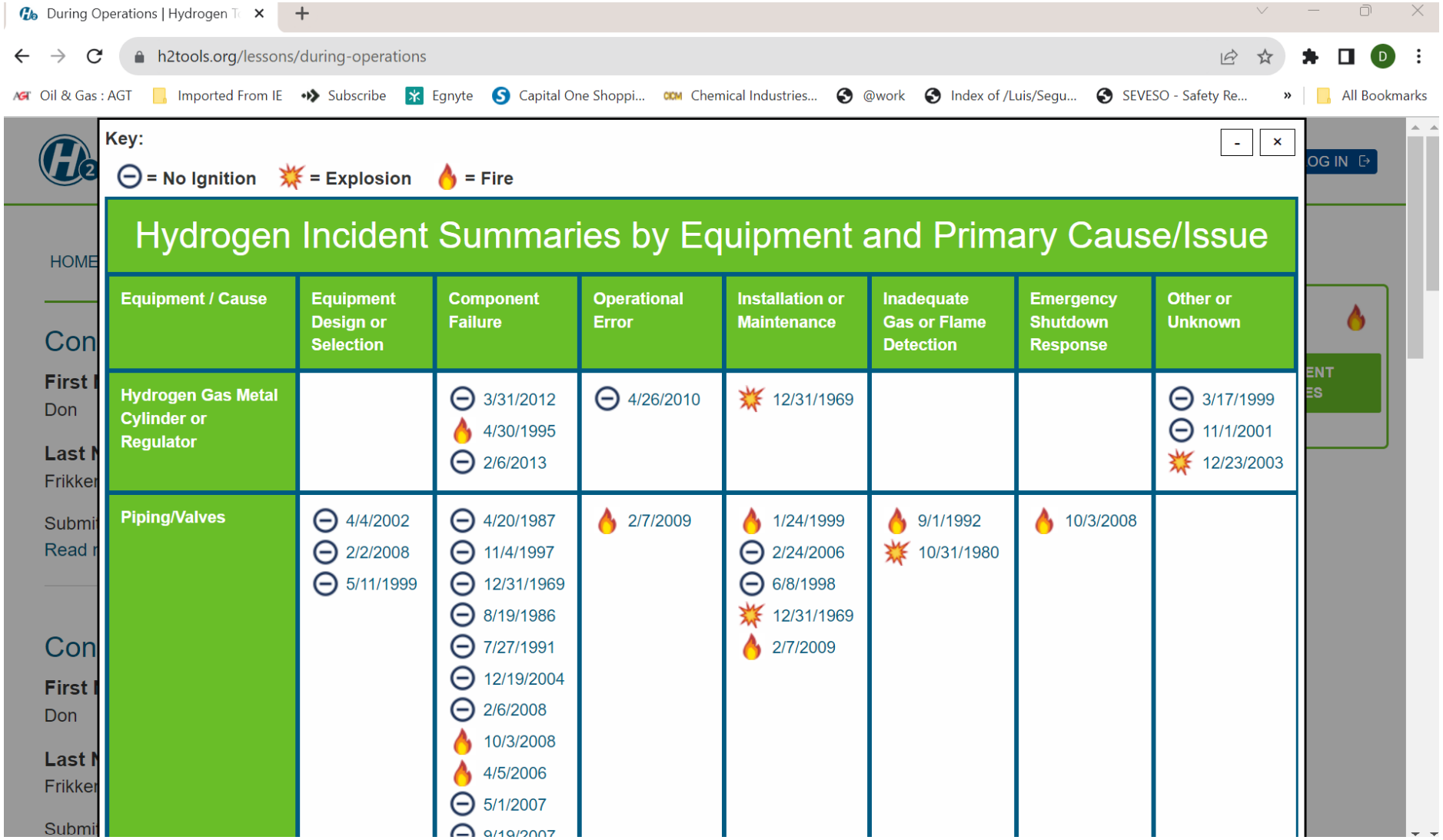
US DOE H2Tools Website Incident Summaries



Key:

= No Ignition = Explosion = Fire

Hydrogen Incident Summaries by Equipment and Primary Cause/Issue

Equipment / Cause	Equipment Design or Selection	Component Failure	Operational Error	Installation or Maintenance	Inadequate Gas or Flame Detection	Emergency Shutdown Response	Other or Unknown
Hydrogen Gas Metal Cylinder or Regulator		3/31/2012 4/30/1995 2/6/2013	4/26/2010	12/31/1969			3/17/1999 11/1/2001 12/23/2003
Piping/Valves	4/4/2002 2/2/2008 5/11/1999	4/20/1987 11/4/1997 12/31/1969 8/19/1986 7/27/1991 12/19/2004 2/6/2008 10/3/2008 4/5/2006 5/1/2007 9/19/2007	2/7/2009	1/24/1999 2/24/2006 6/8/1998 12/31/1969 2/7/2009	9/1/1992 10/31/1980	10/3/2008	

https://h2tools.org/

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US DOE H2Tools Website Incident Summaries - Trends

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

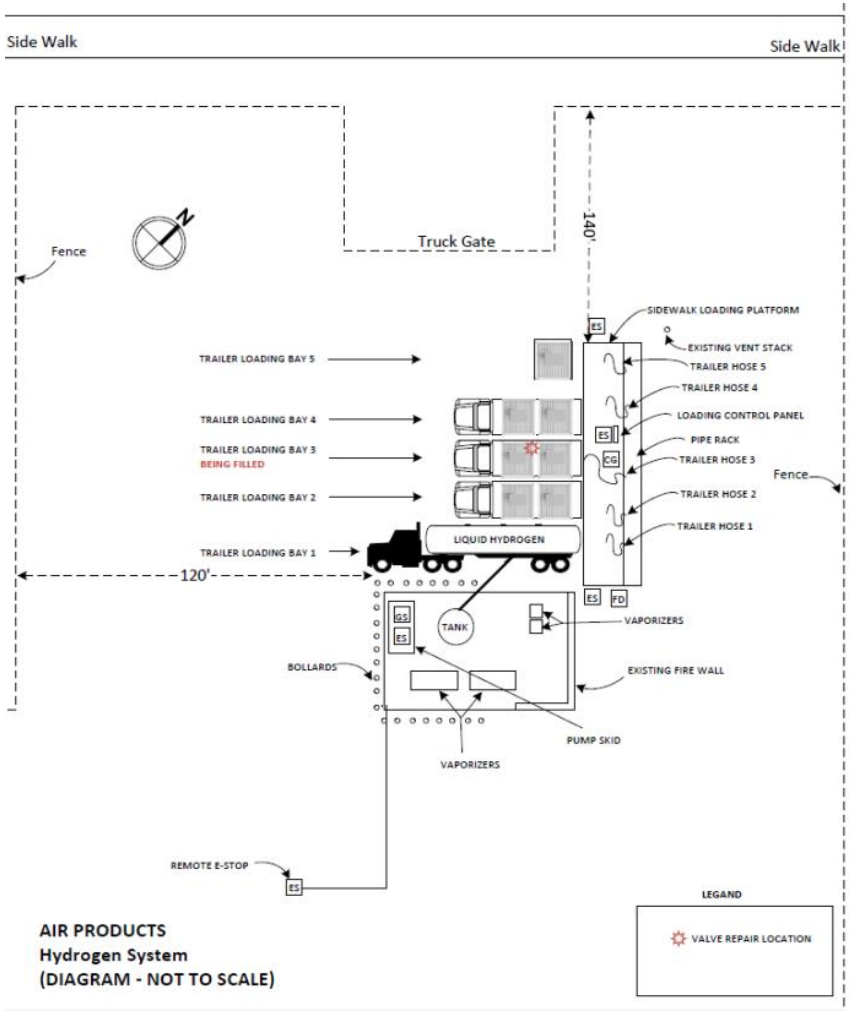
Courtesy of Gangwon Fire HeadQuarter

Damage from Electrolyzer Incident

Courtesy of Nick Barilo, Director, Center for Hydrogen Safety

Example Hydrogen Transportation Incident: Air Products Hydrogen Trailer Transfill Facility, Santa Clara, California.

- June 1, 2019, a sudden, major uncontrolled release of hydrogen gas occurred, followed almost immediately by an explosion and fire.
- Dual-module CT-500 trailer was being filled.
- Module piping had been disassembled to repair a leak in the hydrogen supply line of the forward-mounted CT-250 MEGC modules.



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Example Hydrogen Transportation Incident: Air Products Hydrogen Trailer Transfill Facility, Santa Clara, California.

- **Initial Leak** – Cracked O-ring or leaking cone and thread fitting on the hydrogen isolation valve.
- **Unauthorized Maintenance** – Unauthorized repair and improper Lockout/Tagout procedures.
- **Miscommunication** – Trainee mistakenly actuated “Purge/Enable Trailer” control button which opened the pneumatic valves and allowed hydrogen flow into the disconnected manifold pipe.
- **Hydrogen Explosion** – Confined space explosion
- **Hydrogen Jet Fires** – disconnected piping then multiple PRD actuations, broken cylinder PRDs, and fire exposure to trailer cab and the adjacent trailers

- Based on their root cause analysis, Air Products implemented the following measures.
  - Improved Training and Retraining of Drivers
  - Improved Trailer Filling Procedures
  - Equipment Evaluations and Modifications

Figure 7. Incident Trailer Cab and Front Module

[Report on the June 2019 Hydrogen Explosion and Fire in Santa Clara California](www.h2tools.com)
www.h2tools.com

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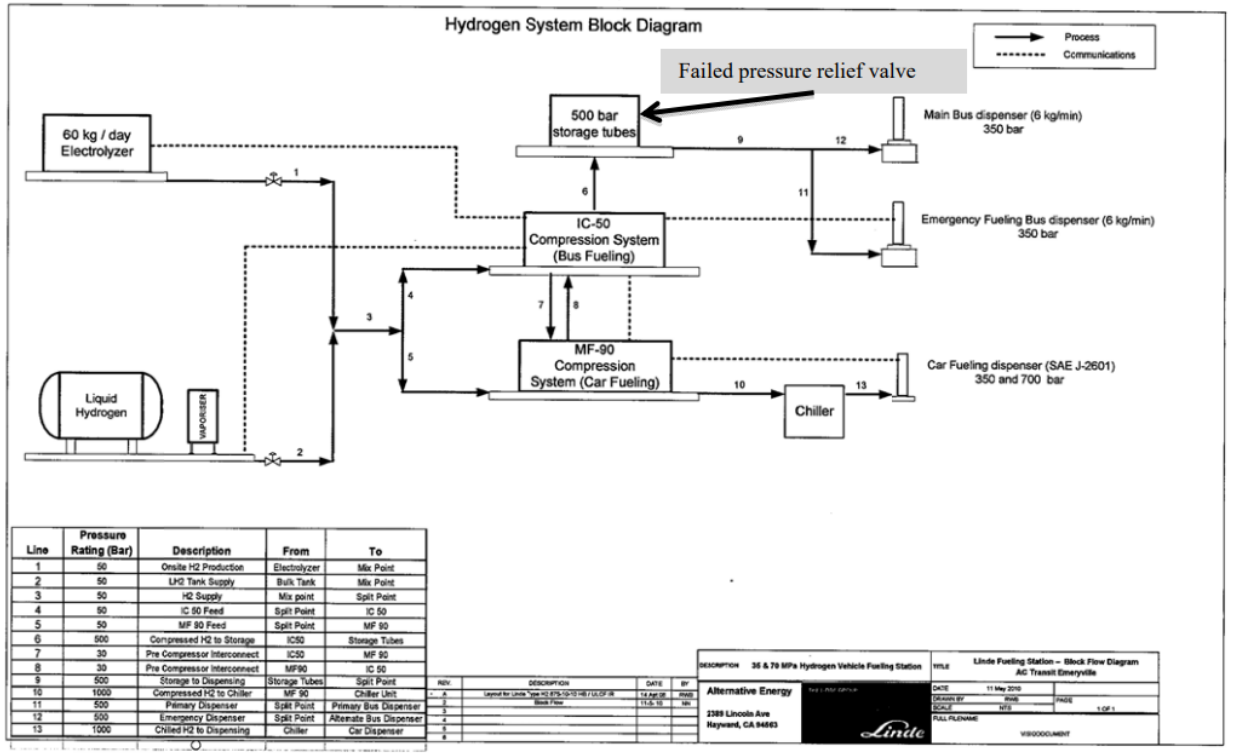
Example Hydrogen Distribution System Incident: Linde AC Transit Emeryville Facility , California – 300kg H2 release

- Root Cause –
- 1. Failed relief valve component due to wrong material selection
- Contributing factors –
- 1. The location of vent outlets in relation to nearby canopy material and the release of the entire gaseous storage through a single point.
- 2. Emergency response training and communications



Line	Pressure Rating (Bar)	Description	From	To
1	50	Onsite H2 Production	Electrolyzer	Mix Point
2	50	LH2 Tank Supply	Bulk Tank	Mix Point
3	50	H2 Supply	Mix point	Split Point
4	50	IC 50 Feed	Split Point	IC 50
5	50	MF 90 Feed	Split Point	MF 90
6	500	Compressed H2 to Storage	IC50	Storage Tubes
7	30	Pre Compressor Interconnect	IC50	MF 90
8	30	Pre Compressor Interconnect	MF90	IC 50
9	500	Storage to Dispensing	Storage Tubes	Split Point
10	1000	Compressed H2 to Chiller	MF 90	Chiller Unit
11	500	Primary Dispenser	Split Point	Primary Bus Dispenser
12	500	Emergency Dispenser	Split Point	Alternate Bus Dispenser
13	1000	Chilled H2 to Dispensing	Chiller	Car Dispenser

Figure 1 Hydrogen system block diagram; location of pressure relief valve emphasis added.

Investigation of the Hydrogen Release Incident at the AC Transit Emeryville Facility, Sandia National Laboratories, June 2012

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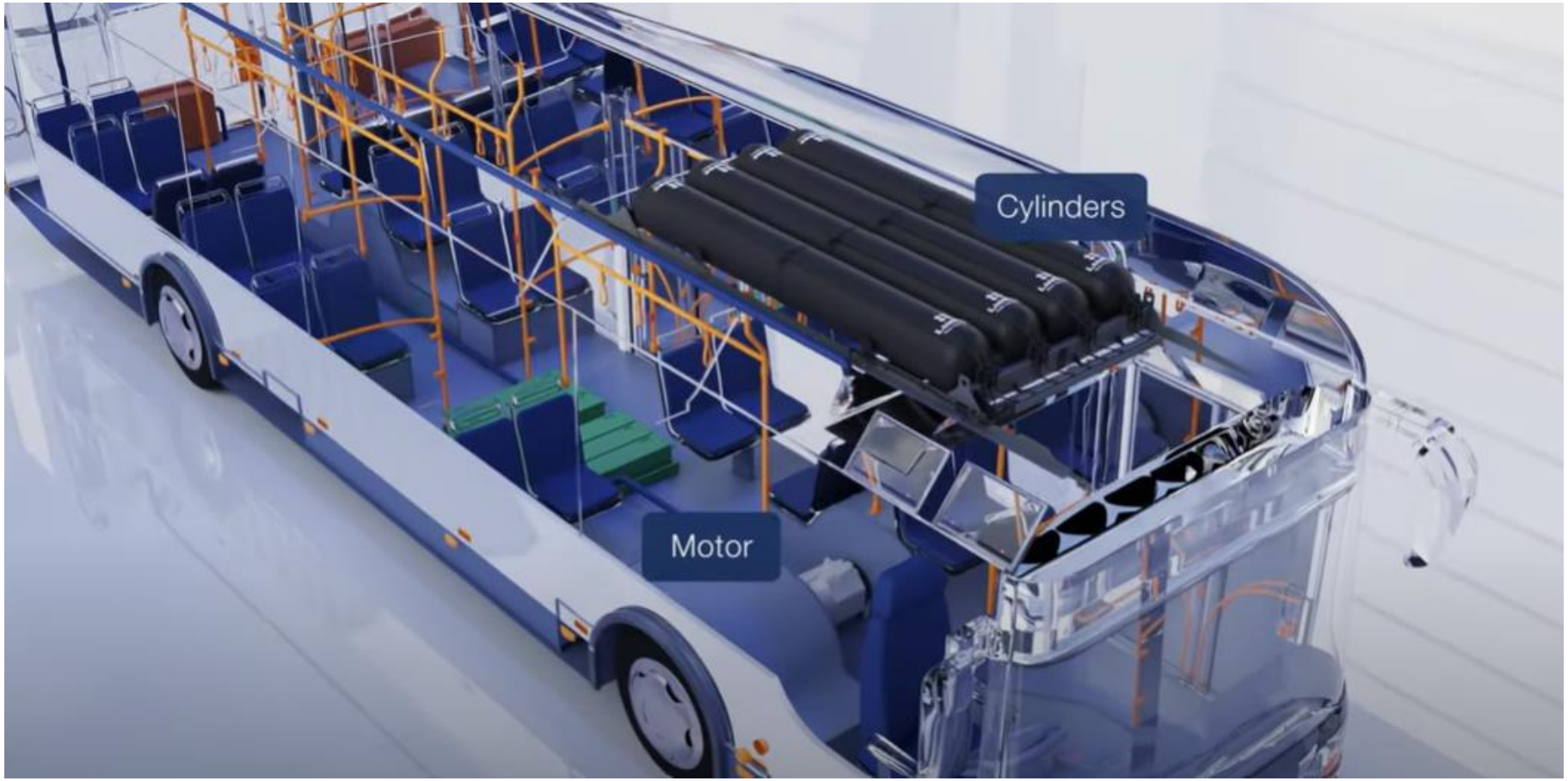
Hydrogen Mobility Sector: Hydrogen Fuel Cell Bus Design



Luxfer Gas Cylinders https://www.youtube.com/watch?v=_M7ND5hrO2o

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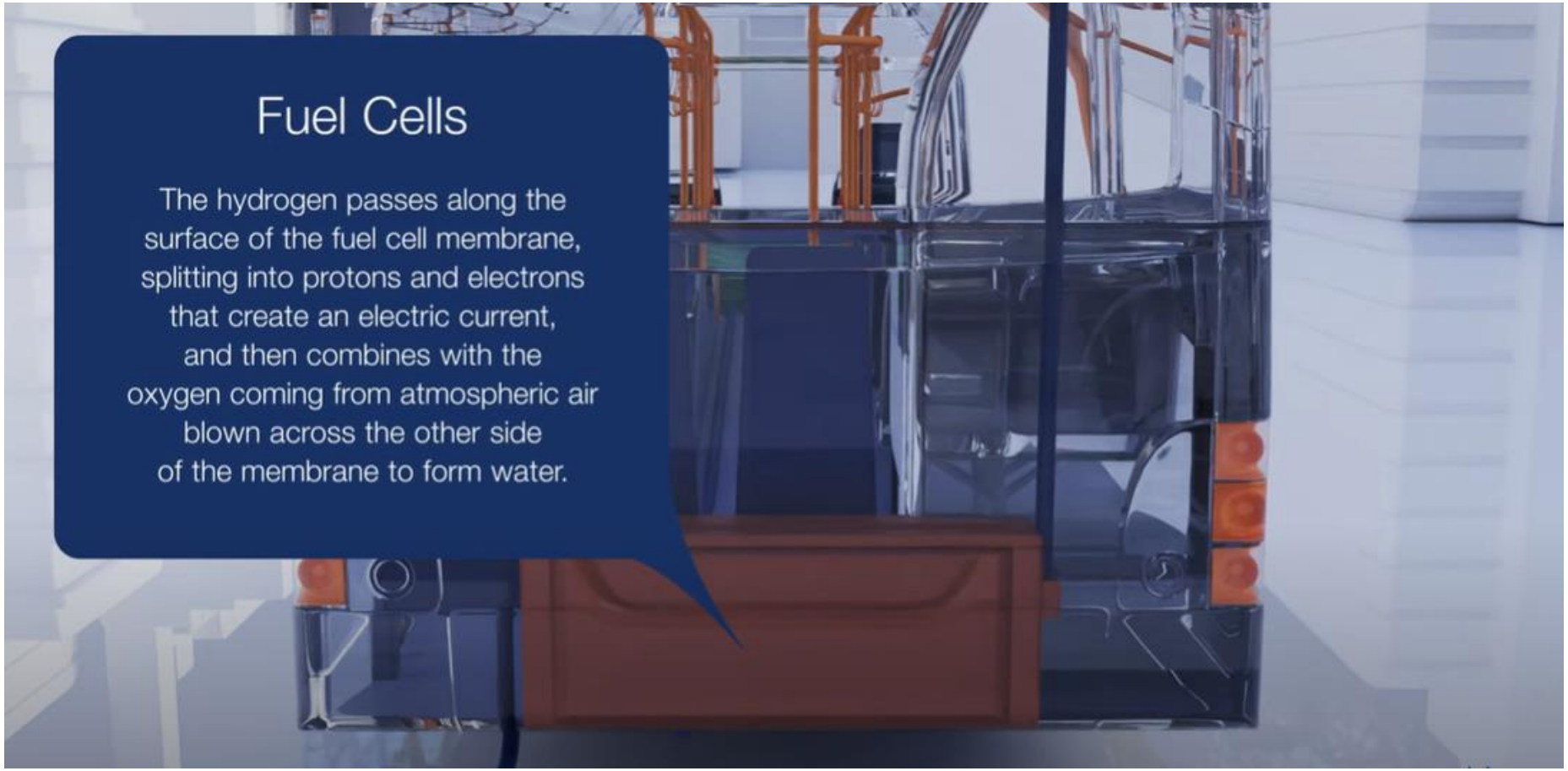
Hydrogen Mobility Sector: Hydrogen Fuel Cell Bus Design



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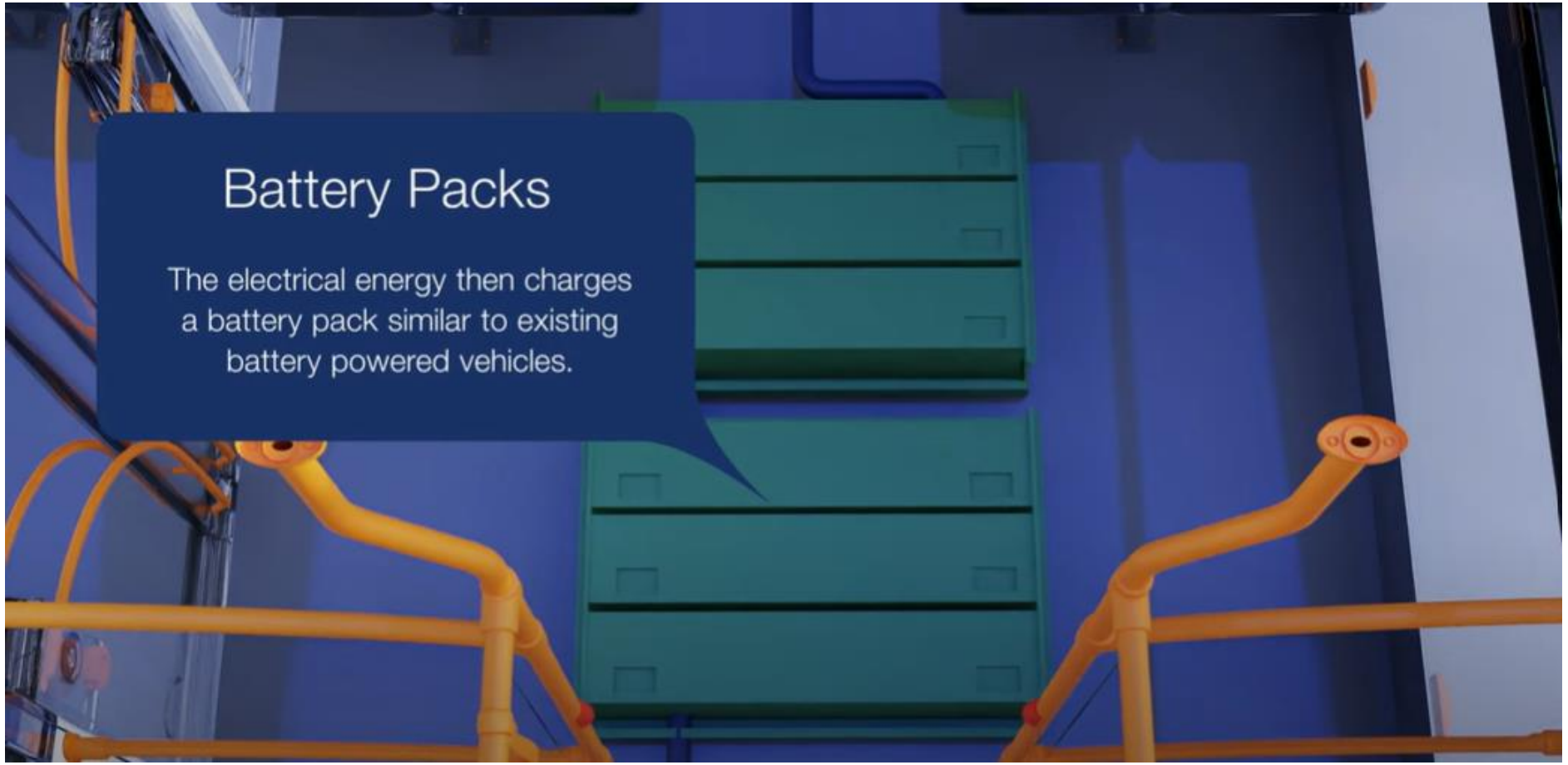
Hydrogen Mobility Sector: Hydrogen Fuel Cell Bus Design



Luxfer Gas Cylinders https://www.youtube.com/watch?v=_M7ND5hrO2o

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Example Hydrogen Mobility Sector Incident: Golden EmpireTransit, Bakersfield, California – 2023

- During refueling of a bus, a fire occurred consuming the bus ($1.1 million loss)
- Under investigation
- No injuries
- One of ten hydrogen buses as part of its transition to zero emissions fuels.
- 100% percent of new California public transport will be required to be zero-emission by 2040

KGET News https://www.youtube.com/watch?v=tx8aj-SnHu8

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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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Thank You and Questions

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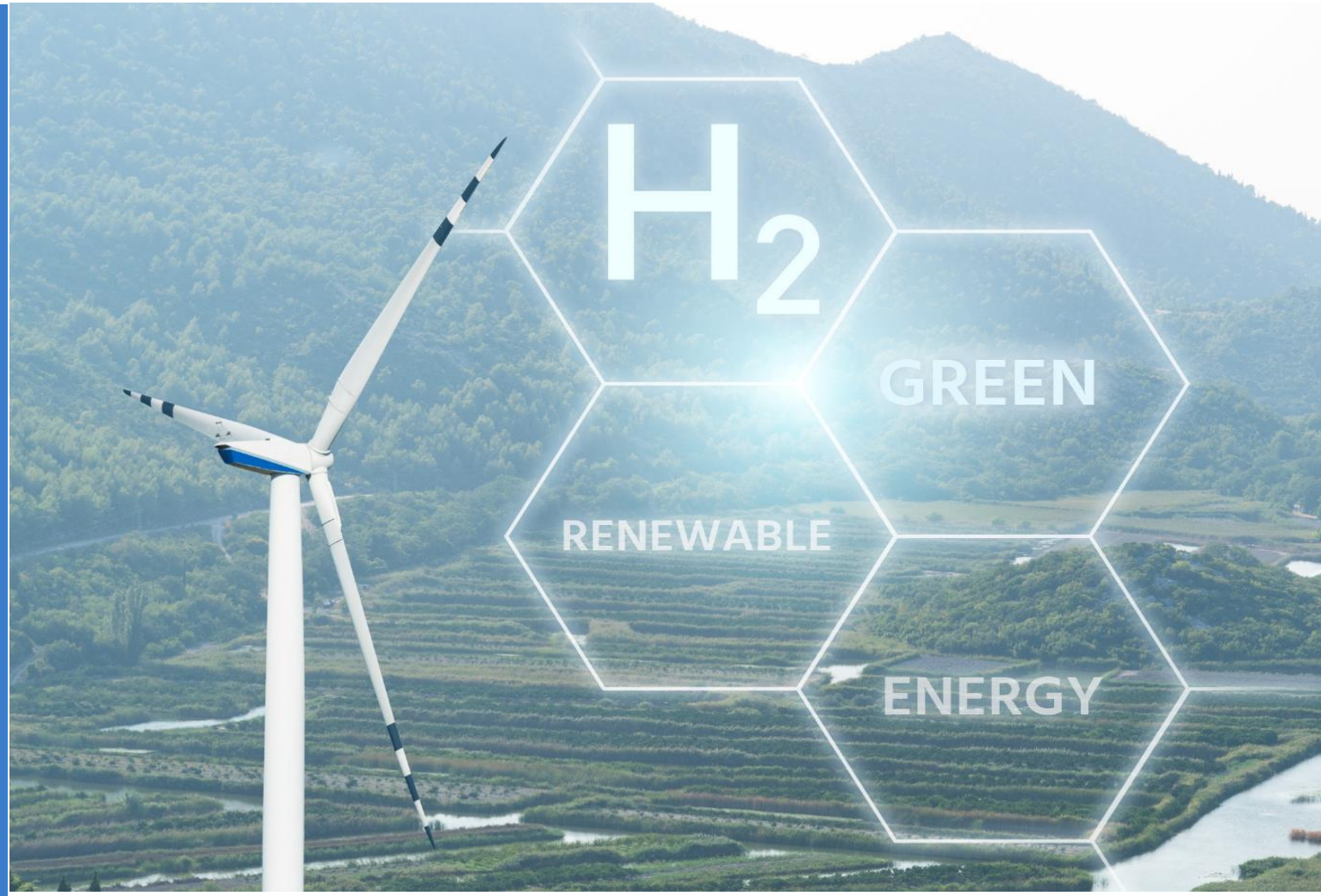

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