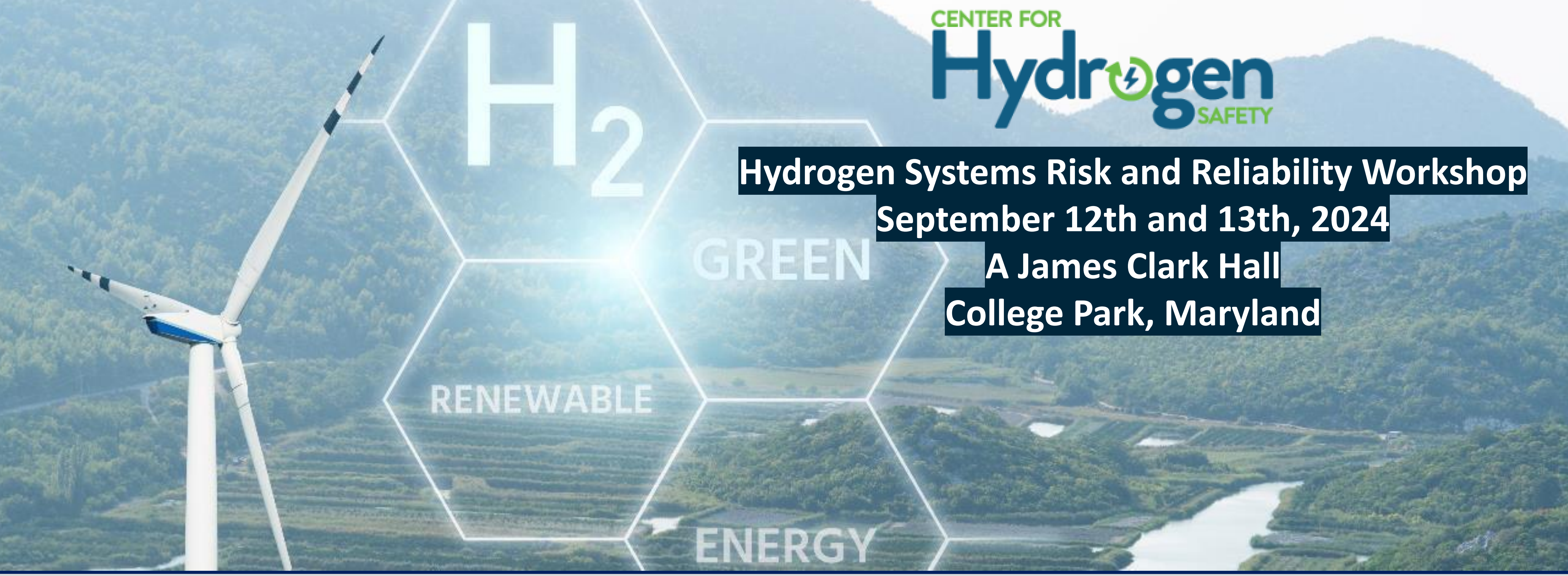


CENTER FOR Hydrogen SAFETY

Hydrogen Systems Risk and Reliability Workshop
September 12th and 13th, 2024
A James Clark Hall
College Park, Maryland

The Need for Risk and Reliability Data for the Hydrogen Industry

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

AcuTech PROCESS RISK MANAGEMENT

Presentation Overview

- The importance of risk and reliability data sharing for the hydrogen industry
- Examples of applications of data to the hydrogen industry
- Current obstacles and gaps
- Recommendations

Success of Hydrogen Initiatives

- The hydrogen industry as it evolves as a popular fuel will need to maintain the highest level of safety performance.
  - Strive for excellence in process safety - Low incident experience, highly reliable operations.
  - Minimize the impacts that a major incident with hydrogen fuels may have on the public
  - Maintain public acceptance

AcuTech
PROCESS RISK MANAGEMENT

Public Acceptance of Hydrogen

- Factors that may highly influence negative safety perception:
  - **Catastrophic event** - A single highly significant event (i.e., Bhopal, India)
  - **Public vulnerability** - A multiple fatality event involving the public in a vulnerable public/private location
  - **Concentrated events** - A series of significant events involving hydrogen in a short timeframe
  - **Comparative** - A poor safety record v other energy sources

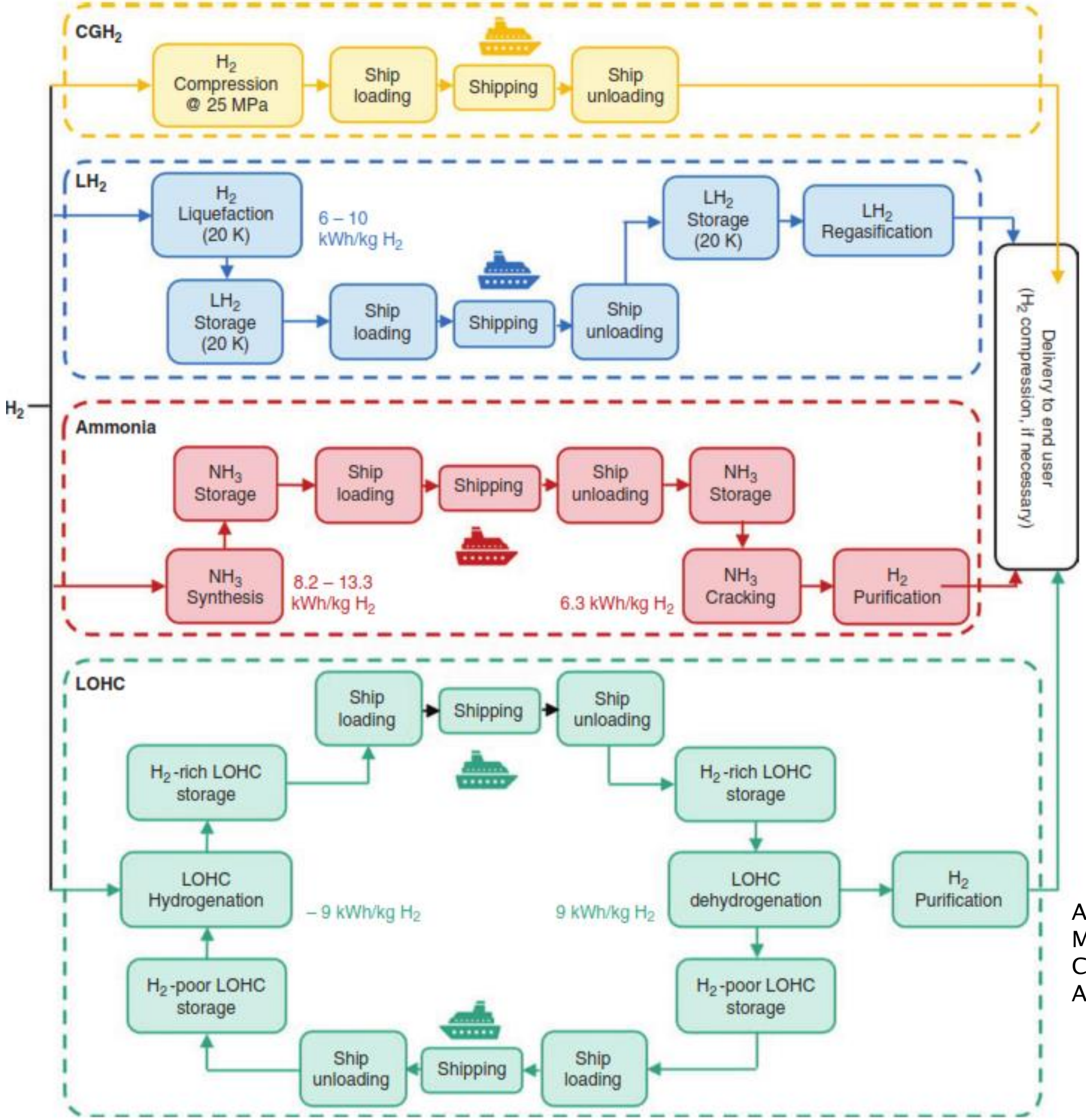
AcuTech
PROCESS RISK MANAGEMENT

Challenges to Successful Hydrogen Development

- The rapid growth of the industry
- Novel and proprietary technologies/designs
- Historic scale-up
- High opportunity for incidents due to the properties of hydrogen
- Many new developers/users unfamiliar with hydrogen risk management and inexperience
- Lack of a widely accepted process safety management system and associated risk data

AcuTech PROCESS RISK MANAGEMENT

Hydrogen Industry Risk Management Challenges



- Compounding those issues, hydrogen is planned to be used in an extremely wide range of applications and conditions

A Review of Hydrogen Storage and Transport Technologies”,
Miao Yang, Ralf Hunger, Stefano Berrettoni, Bernd Sprecher, and Baodong Wang,
Clean Energy, 2023, Vol. 7, No. 1, 190–216, https://doi.org/10.1093/ce/zkad021
Advance access publication 17 April 2023

A Need for Enhanced Management of Industrial Hazards

1974: Flixborough (UK); Nypro UK – *

Failure of an improperly engineered bypass line around reactors following maintenance; cyclohexane vapor cloud explosion; 28 deaths, > 100 injuries

1976: Seveso (Italy); ICMESA, a subsidiary of Givaudan, a subsidiary of Hoffmann-La Roche -

Release of 6 tons from a PRV of a dioxin plan, including 1 kg of TCDD (tetrachlorodibenzodioxin) due to elevated temperature and inadequate design; contaminated over 18 km2; forced evacuation and cleanup, > 80,000 animals slaughtered or died

1984: Bhopal (India); Union Carbide – *

Methylisocyanate release from MIC storage tank due to maintenance error; > 3,000-16000+ public deaths, 200,000-500,000 injuries

1988: Piper Alpha (UK) – *

Release of gas /liquidsfrom offshore condensate pump due to maintenance error; 167 worker deaths, destruction of platform

1989: Pasadena (Texas); Phillips 66 – *

Ethylene/Isobutane release from polyethylene reactor due to maintenance error; 23 deaths, > 130 injuries

2005: Texas City (Texas); BP – *

Flammable liquid/vapor release from vent stack of a refinery unit due to overfill; 15 deaths, 180 injuries

* Maintenance or startup errors

Problem Statement and Objectives

Problem Statement

- Risk and reliability data is limited on failure rate data sets for the most common components and leak rates
- Need to establish industry accepted practice for use of leak rate calculations
- Establish consistency of H2 risk assessments and risk reduction methods
  - Scenarios, how to evaluate, assumptions, etc.

Note:

- Considerable work has been done on this issue, and sources of data are available, but they are incomplete*.
- The datasets need to be 'living' allowing for ongoing learnings and additional confidence of the data
- Then the data must be widely accepted and used.

* D. Ehrhart and E. S. Hecht, "Hydrogen Plus Other Alternative Fuels Risk Assessment, Models (HyRAM+) Version 4.1 Technical Reference Manual," Tech. Rep. SAND2022-5649, Sandia National Laboratories, April 2022.

AcuTech PROCESS RISK MANAGEMENT

CENTER FOR
Hydrogen SAFETY
Connecting a Global Community

Risk Assessment Best Practices & Failure Rates Working Group

CHS Failure Rates Working Group

- CHS members recognized the need for the industry to identify global uniform failure hydrogen for the purpose of conducting risk assessments.
- CHS responded by getting volunteers from members into a working group on this topic.
- The goal is to identify what is available and how to bring consistency and uniformity to this topic
- This is in progress but challenging due to several factors:
  - Agreement on approach
  - Lack of willingness of all of industry to contribute incident and risk & reliability data
  - Effort and cost issues

Ideal Objectives

- **Objective** – Develop a hydrogen equipment and component failure rate data collection process and publication process to:
  - Improve the confidence level of risk and reliability studies
  - Assist members in understanding industry incident experience
- **Key attributes –**
  - Useful, comprehensive and statistically significant
  - Minimal cost and effort for users
  - Accepted by industry, government, and the public

AcuTech
PROCESS RISK MANAGEMENT

Project Issues

1. **Ownership and access of the data:**
   - Who would facilitate the process and be the repository for the information
   - Accessible for free or a fee?
   - Optionally accessible to all of industry and the public?
   - ‘Live’ and/or only updated regularly?

AcuTech
PROCESS RISK MANAGEMENT

Contribution Model

- Data is routinely submitted to for inclusion in the database and it is rationalized, accepted, and included with the dataset
- Example – OREDA https://www.oreda.com/history
  - Volunteers (likely a select few operating companies) would contribute data on an ongoing basis
  - Requires a taxonomy for standardization of data organization
  - More complete the better (ex; all incidents experienced over X years over X facilities)

AcuTech PROCESS RISK MANAGEMENT

Reference Model

- Data is not collected on same frequency or from a few companies – it is a global consolidation of data sources to an agreed dataset
    - Example – HSE Failure Rate and Event Data Guidance or HYRAM
    - Obtain generic failure rate data from multiple sources compiled and published
    - Any outside data sources that are reliable, useful, applicable, are candidates (but then may have to be filtered for quality)
    - Requires a team to work on the data acceptance, analysis and publication
    - Members and others may comment on drafts and final values/ranges/sources of data
    - Data is improved over time

AcuTech
PROCESS RISK MANAGEMENT

Welcome to the Hydrogen Tools Portal   helpdesk@h2tools.org   Log In

Hydrogen Tools   Home   Resources   Contact   About H2Tools

LESSONS **LEARNED**

Disclaimer: The Lessons Learned Database Includes The Incidents That Were Voluntarily Submitted. The Database Is Not A Comprehensive Source For All Incidents That Have Occurred.

Contributing Factors	Damage and Injuries	Equipment	Probable Cause
Any	Any	Any	Any

CHECK OUT OUR MOST RELEVANT INCIDENT LISTINGS!

Disclaimer: The Lessons Learned Database includes the incidents that were voluntarily submitted. The database is not a comprehensive source for all incidents that have occurred.

H2 Lessons Learned — Submit An Incident

H2 Analytics

Lessons Learned Corner — View Archives

Enter text to search

Hydrogen Gas Regulator Failure

Because the bottle was located outside at the time of the event, and the hydrogen did not find a source of ignition while venting through the relief valve, nothing serious happened.

LATEST REPORTS

- Hydrogen Gas Regulator Failure
- Hydrogen Explosion in Battery Compartment of Dinner Cruise Boat
- Hydrogen Fire in Hydrochloric Acid Leaching Solution

AcuTech PROCESS RISK MANAGEMENT

US DOE Hydrogen Safety Panel – Hydrogen Incident Examples

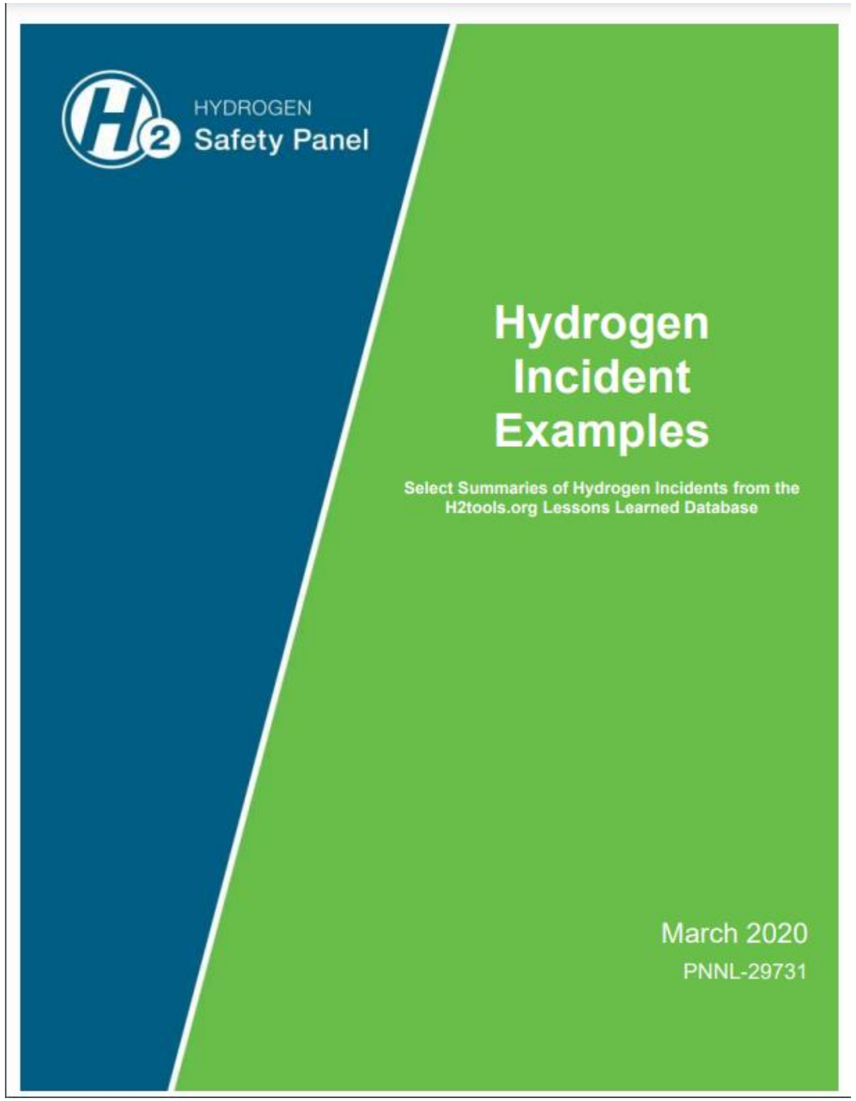


Table of Contents

Contents

i

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

AcuTech PROCESS RISK MANAGEMENT

Hydrogen Incidents – www.h2tools.com

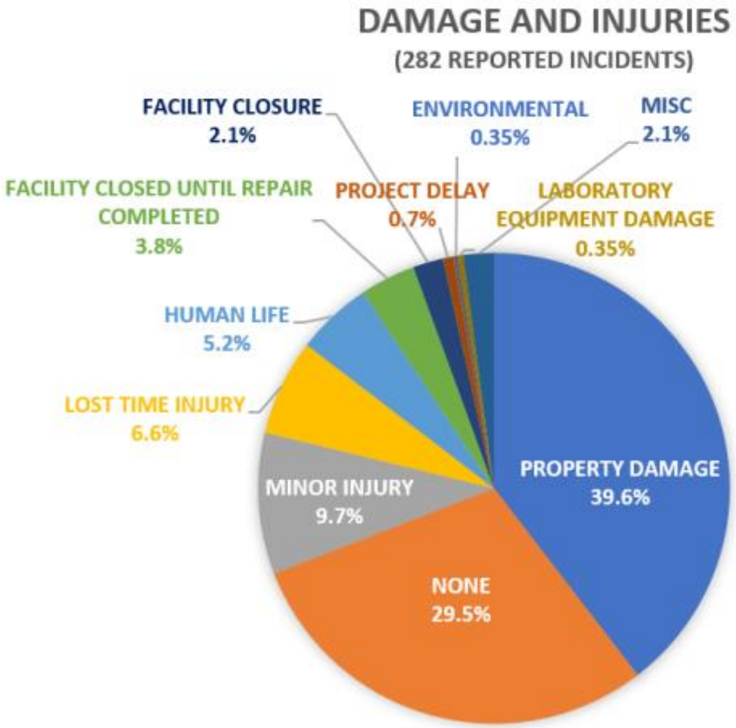


Figure 3: Reported damage and injury categories resulting from hydrogen related incidents reported to h2tools.org.

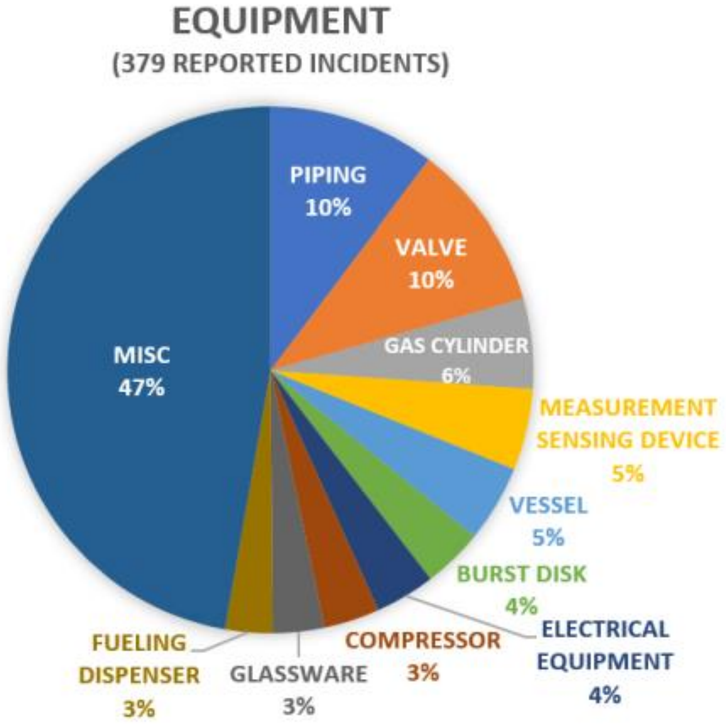


Figure 4: Reported categories for equipment involved in hydrogen incidents reported to h2tools.org. (The primary causes for the equipment-related incidents include component failure, operation error, installation/maintenance, etc.).

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

AcuTech PROCESS RISK MANAGEMENT

Hydrogen Incidents – www.h2tools.com

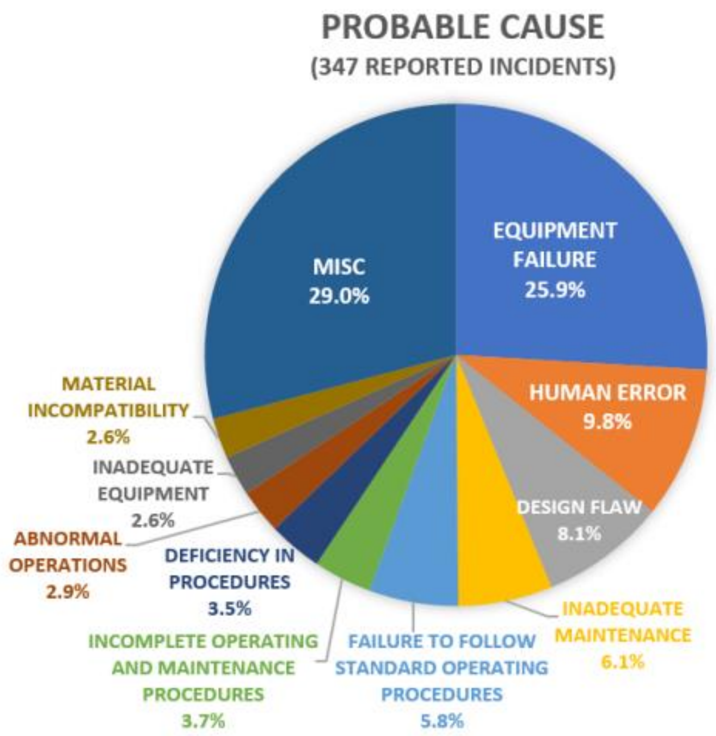


Figure 5: Probable cause categories for hydrogen incidents reported to h2tools.org.

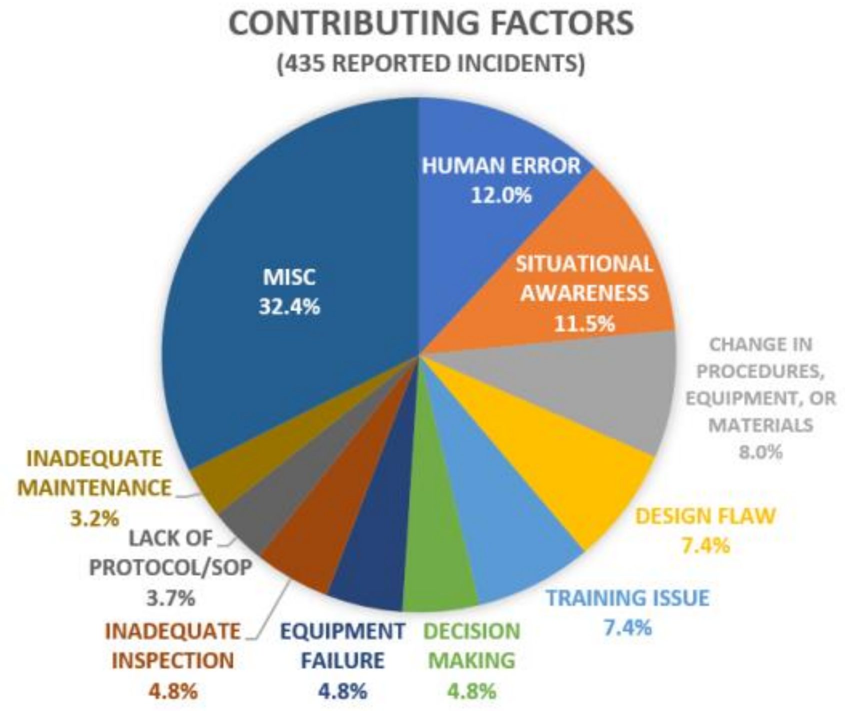


Figure 6: Contributing factors categories for hydrogen incidents reported to h2tools.org.

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

AcuTech PROCESS RISK MANAGEMENT

European Hydrogen Safety Panel Incident Analysis

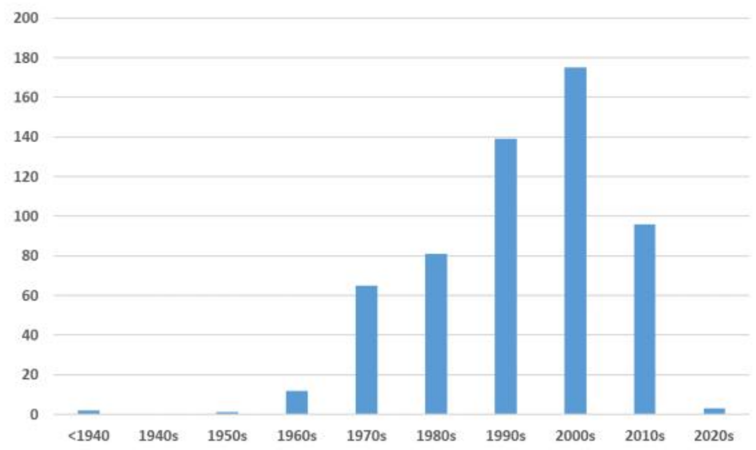
Clean Hydrogen Partnership

10th International Seminar on Fire and Explosion Hazards

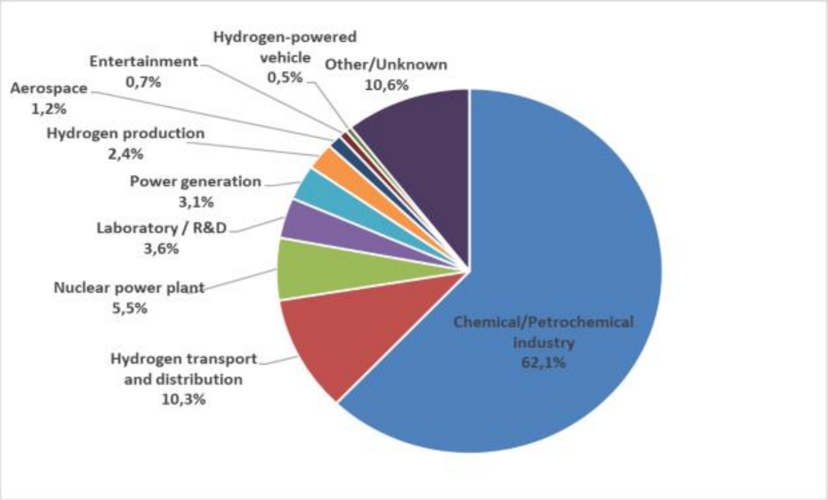
Results from the statistics analysis (1)

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

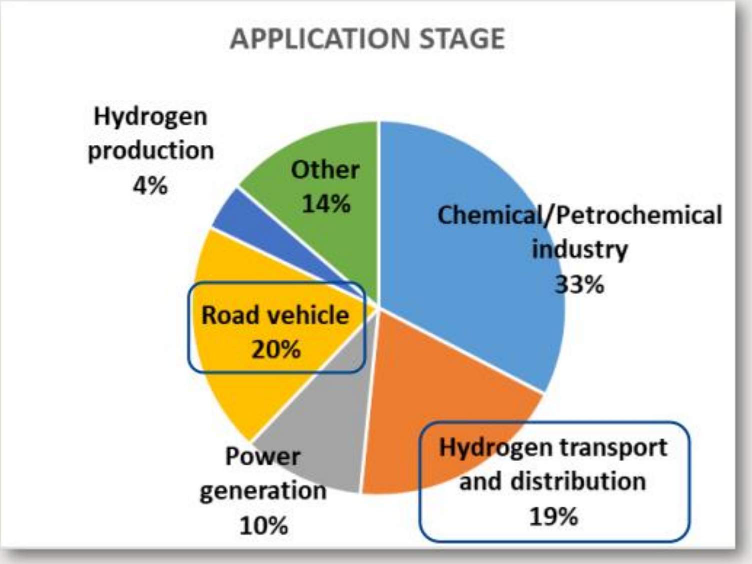


AcuTech PROCESS RISK MANAGEMENT

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

AcuTech PROCESS RISK MANAGEMENT

EU HyRam/HIAD Data Analysis

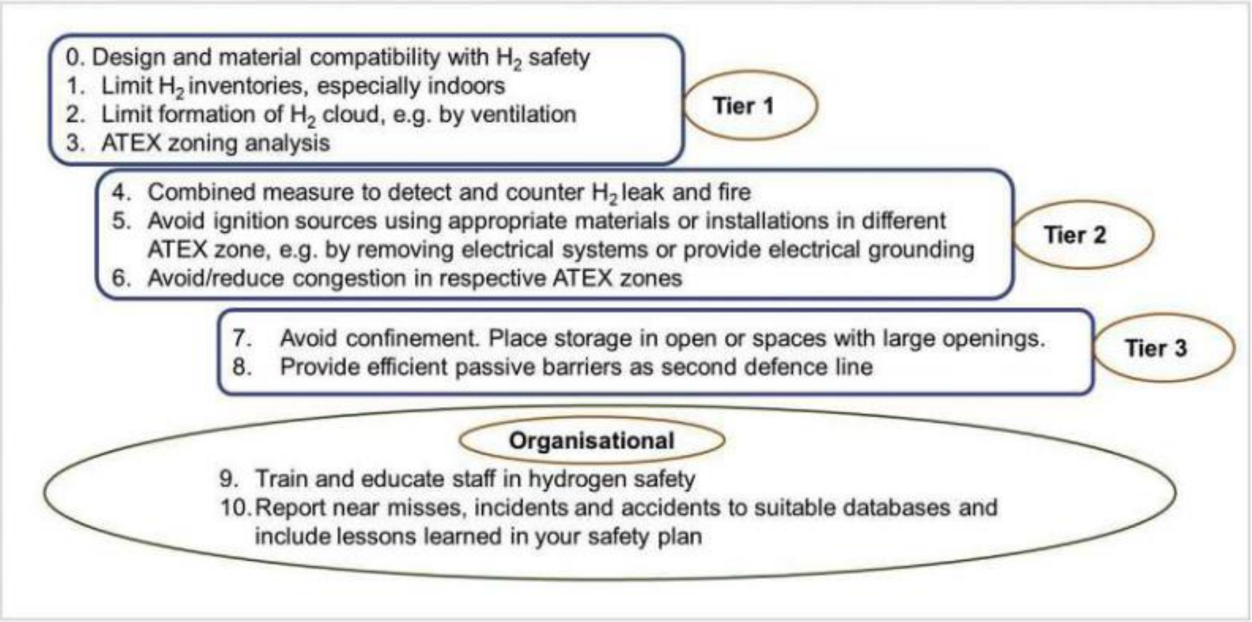


Fig. 7 — Hydrogen safety principles (SP#) (European Hydrogen Safety Panel, 2021).

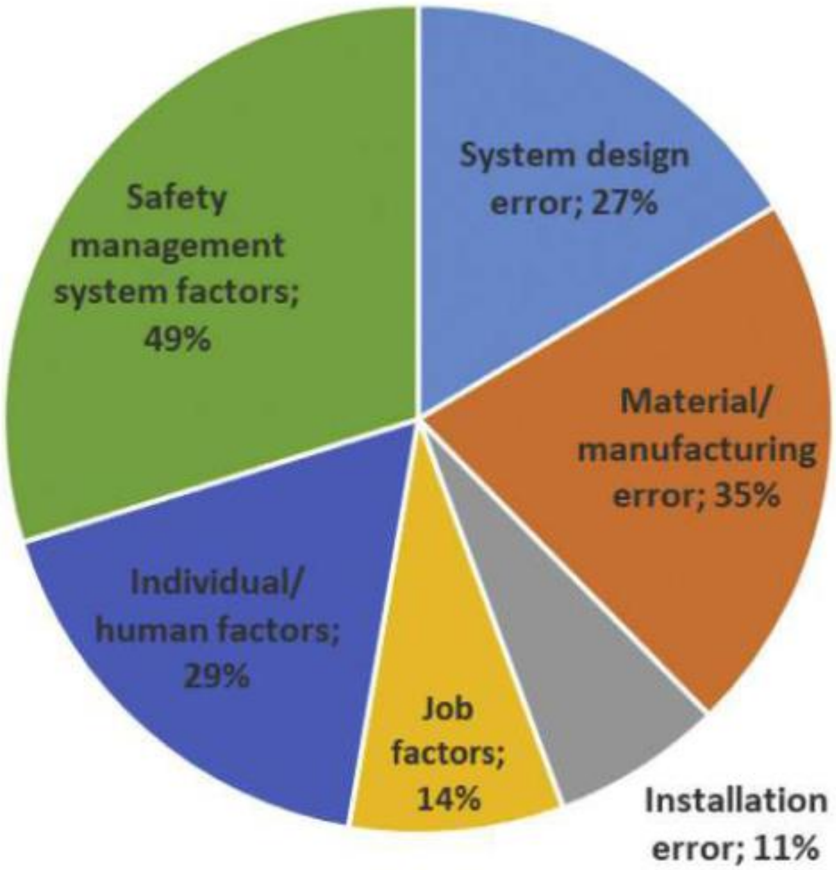


Fig. 5 — Percentages related to the causes of the events considering multiple causes per event.

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]*

AcuTech PROCESS RISK MANAGEMENT

Available Data Sources

- Four tools were critically reviewed by UMD SyRRA and NREL*
  - H2Tools
  - Hydrogen Incident and Accident Database (HIAD)
  - National Renewable Energy Laboratory's (NREL) Composite Data Products (CDPs)
  - Center for Hydrogen Safety (CHS) Failure Rate Data Collection Form

* Critical review and analysis of hydrogen safety data collection tools, Madison West, William Buttner, Ahmad Al-Douri, Kevin Hartmann, Katrina M. Groth, Systems Risk and Reliability Analysis Lab (SyRRA), Center for Risk and Reliability, 0151C Glenn L. Martin Hall, 4298 Campus Drive, University of Maryland, College Park, MD 20742, USA, and National Renewable Energy Laboratory, National Renewable Energy Laboratory, 15013 Denver West Parkway, Golden, CO 80401, USA

Critique of Available Data Sources

Table 7 — Review of current hydrogen safety data collection tools.					
Data Type		H2Tools	NREL CDPs	HIAD	CHS Failure Rate Data
Event and failure characterization	Initiating event (description)	✓	✓	✓	✗
	Location within system	✗	✓	O	✗
	Failure mode	✗	✗	✗	✗
	Failure mechanism	✗	✗	✗	✗
	Failure root cause	✓	✓	✓	✗
	Release size	✗	O	✓	✓
	Incident severity	✓	✓	✓	✓
	Consequences	O	✓	✓	O
	System response (Mitigation)	✗	✗	✗	O
	H2 accumulation	✗	✗	✗	✗
	H2 detection	✗	✗	✗	O
Life/usage	Component life	✗	✗	✗	✗
	Operations	✗	✓	✗	O
	Maintenance	✗	✓	✗	O
	Site inventory	✗	✓	✗	O
Data scope	Public access to data	✓	✗	✓	?
	Regular reporting	✗	✓	✗	✓
	Anonymous data presentation	✓	✓	✓	✓
	Data quality checks	✗	✓	✗	?
	Process documentation	✗	✗	O	✗

* D. Ehrhart and E. S. Hecht, "Hydrogen Plus Other Alternative Fuels Risk Assessment, Models (HyRAM+) Version 4.1 Technical Reference Manual," Tech. Rep. SAND2022-5649, Sandia National Laboratories, April 2022.

AcuTech PROCESS RISK MANAGEMENT

Limits of Data Sources

Database	Limitations
H2Tools -	Primarily qualitative descriptions of failure events making it primarily a safety database with the ability to determine narratives and lessons learned.
HIAD -	Potential to collect qualitative and quantitative data about failure events, however voluntary reporting has so far yielded mostly qualitative reporting and incomplete data, which can only be used to develop narratives and lessons learned.
NREL's data collection and the resulting CDPs -	Good starting point for collecting system-level data but fail to adequately define and collect failure modes and mechanisms.
CHS Failure Rate Database	Collects component level information for a limited number of components. These can be used to determine component failure rates but it lacks data on component life and failure modes and mechanisms.

* Critical review and analysis of hydrogen safety data collection tools, Madison West, William Buttner, Ahmad Al-Douri, Kevin Hartmann, Katrina M. Groth, Systems Risk and Reliability Analysis Lab (SyRRA), Center for Risk and Reliability, 0151C Glenn L. Martin Hall, 4298 Campus Drive, University of Maryland, College Park, MD 20742, USA, and National Renewable Energy Laboratory, National Renewable Energy Laboratory, 15013 Denver West Parkway, Golden, CO 80401, USA

AcuTech PROCESS RISK MANAGEMENT

HyCreD

- A very promising effort by UMD SyRRA and NREL* lays out a foundation for a hydrogen risk database
- Accomplishments:
  - Developed requirements for hydrogen component reliability databases.
  - Developed HyCReD database structure for system, incident, and maintenance data.
  - Created definitions for data elements and failure modes.
  - Built generic component hierarchy for H2 fueling stations from public designs.
  - Demonstrated HyCReD database usability by extracting data from event narratives.

* Design and requirements of a hydrogen component reliability database (HyCReD) a,*Katrina M. Groth, Kevin Hartmann, a, Ahmad Al-Douri a, Madison West b, Genevieve Saur, b , William Buttner a Systems Risk and Reliability Analysis Lab (SyRRA), Center for Risk and Reliability, Mechanical Engineering, University of Maryland, College Park, MD 20742, USA, b National Renewable Energy Laboratory, 15013 Denver West Parkway, Golden, CO 80401, USA.

AcuTech PROCESS RISK MANAGEMENT

HyCreD

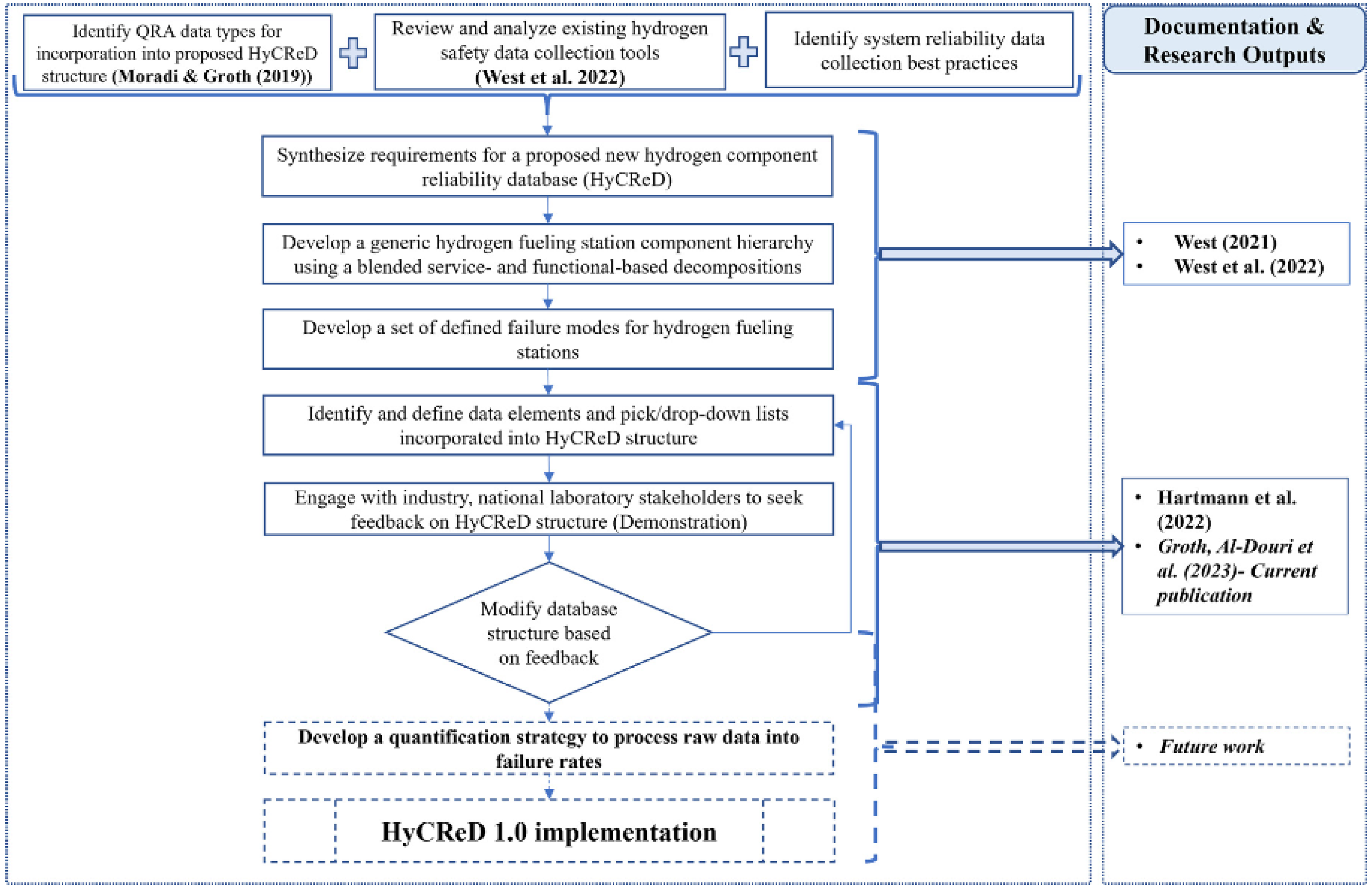


Fig. 2 – The approach for developing and refining the HyCReD 1.0 structure.

* Design and requirements of a hydrogen component reliability database (HyCReD) a,*Katrina M. Groth, Kevin Hartmann, a, Ahmad Al-Douri a, Madison West b, Genevieve Saur, b , William Buttner a Systems Risk and Reliability Analysis Lab (SyRRA), Center for Risk and Reliability, Mechanical Engineering, University of Maryland, College Park, MD 20742, USA, b National Renewable Energy Laboratory, 15013 Denver West Parkway, Golden, CO 80401, USA.

Presentation Summary

- Industry's frustration is that the lack of data is limiting to their understanding of hydrogen incidents and to the construct of models for analyzing risk
- Some efforts have developed but mostly they lack complete structure required for QRA and other detailed analyses
- There is limited repository of detailed information on incidents
- There is an urgent need to improve decision-making to avoid serious incidents as the industry rapidly scales
- It is recommended to have strong collaboration with academia, government and industry to ensure hydrogen safety through a modern process safety framework supported by data from learnings and risk and reliability data.

AcuTech PROCESS RISK MANAGEMENT

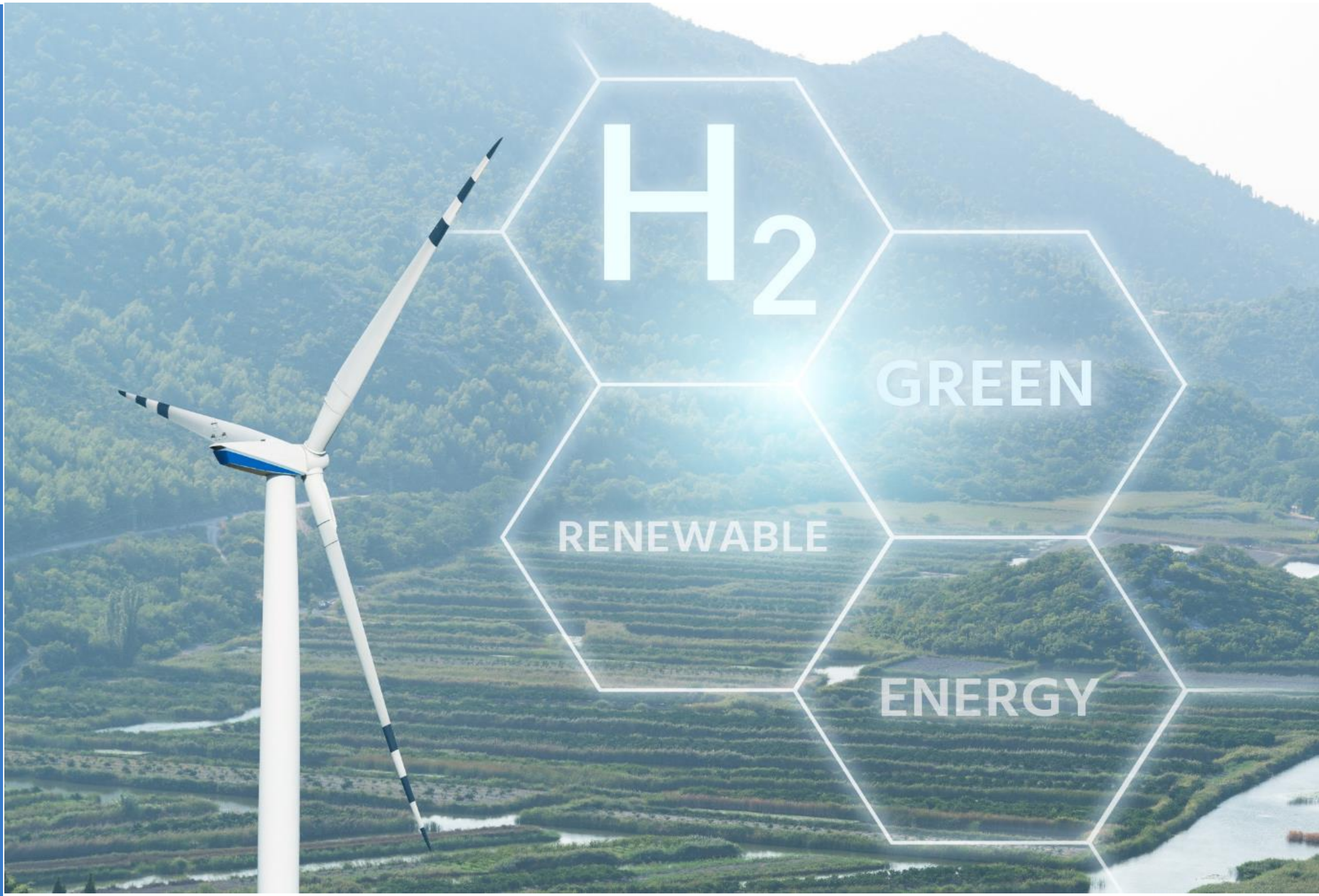
Thank You and Questions

Contact Us

AcuTech Group, Inc.
Washington, DC
Corporate Headquarters
AcuTech Consulting Group
1750 Tysons Blvd, Suite 200
McLean, VA 22102 USA

Global Offices

McLean VA – Doha
Mumbai - Singapore –
Al Khobar



AcuTech
PROCESS RISK MANAGEMENT