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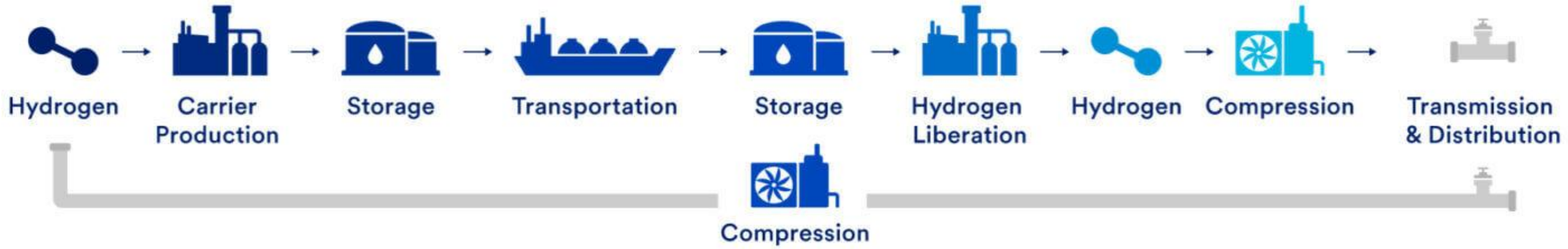
Process Safety Culture for New Energy Operations

David A. Moore, PE, CSP
President & CEO
AcuTech Group, Inc.
McLean, Virginia, USA 22102
www.acutech-consulting.com
dmoore@acutech-consulting.com

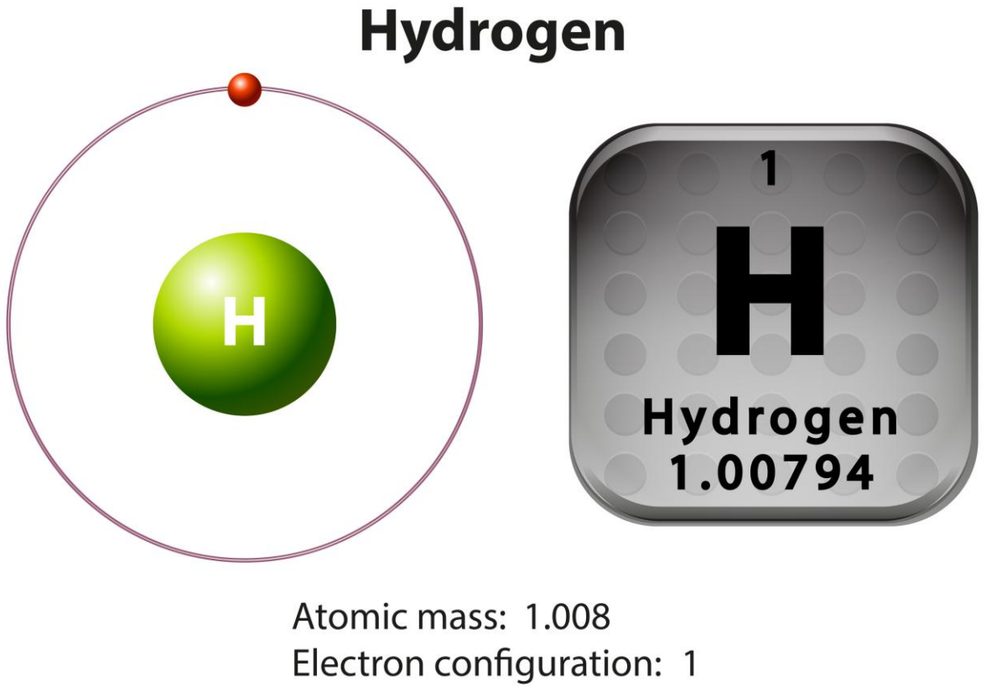
Hydrogen for Decarbonization – Safety Challenges

- Decarbonization is inevitable and is the biggest transformation of the global economy of this century.
- This often involves new technologies using well known chemicals such as hydrogen, anhydrous ammonia, methanol, Li_2O, but creating new and unusual hazards in many more applications for different purposes (direct energy).
- The widespread use of these chemicals for energy transition presents challenges.



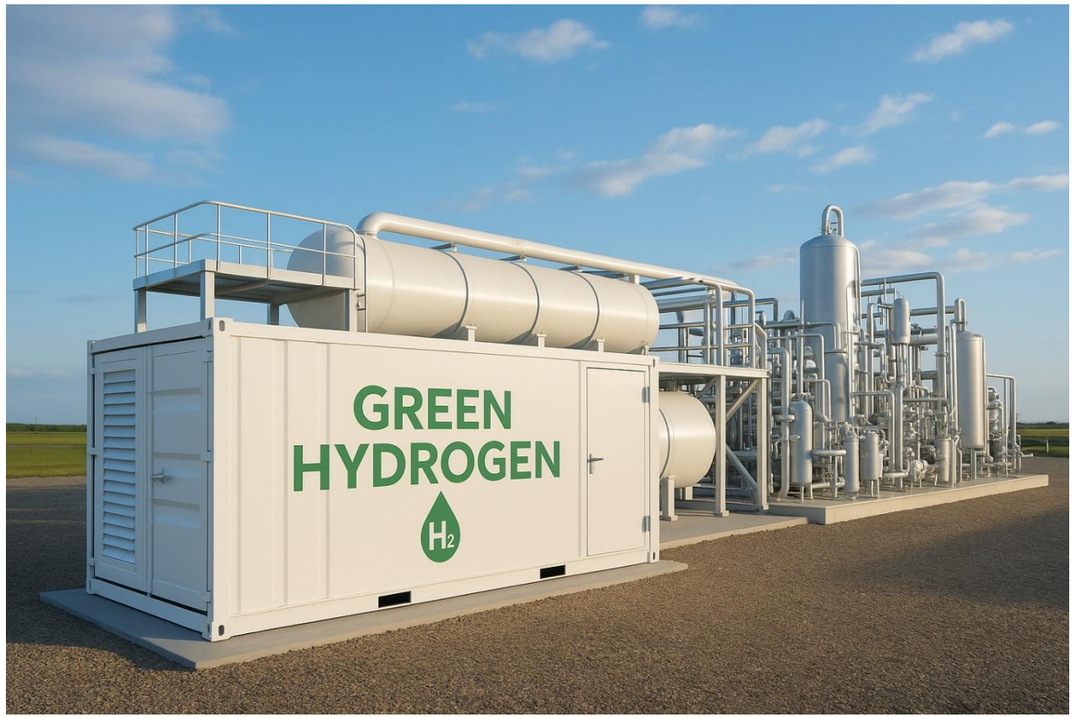
Hydrogen for Decarbonization – Opportunity and Challenges

- Hydrogen is very common and well known chemical and has an existing safety ecosystem that is mature
- It is not so well known by the potential user's and the public
- Hydrogen's physical properties make it a difficult molecule to manage safely:
  - Challenges to store and transport (high pressure GH2, cryogenic LH2)
  - Low volumetric density
  - Low boiling point
  - Reverse J-T
  - Metallurgical embrittlement
  - Wide flammability range
  - High susceptibility to leakage
  - Potential for no visible flame
  - Possible autoignition
  - Propensity to detonation



Rapid Industry Scaleup

- In a period of rapidly growing market driven by decarbonization goals
  - Expansion of the use of hydrogen for a wide variety of purposes.
  - Hydrogen industry landscape is diverse, including energy companies, specialized hydrogen producers, technology developers, and experienced and new entrants.
  - Novel technologies, scale, or adaptations with little to no prior experience for these applications
- Engineers, operators, users including the public may not be as experienced and competent for managing these risks for the new hydrogen economy.
- We likely will repeat many preventable errors in the buildout of the industry.



Public Acceptance of Hydrogen

- The hydrogen industry as it evolves will need to maintain the highest level of safety performance.
- Strive for excellence in process safety (as low as reasonably practicable).
- The industry concern is if there is poor safety experience causing harm and potentially public risk tolerance to be exceeded.
- What effect would a major incident with hydrogen fuels have on public acceptance?

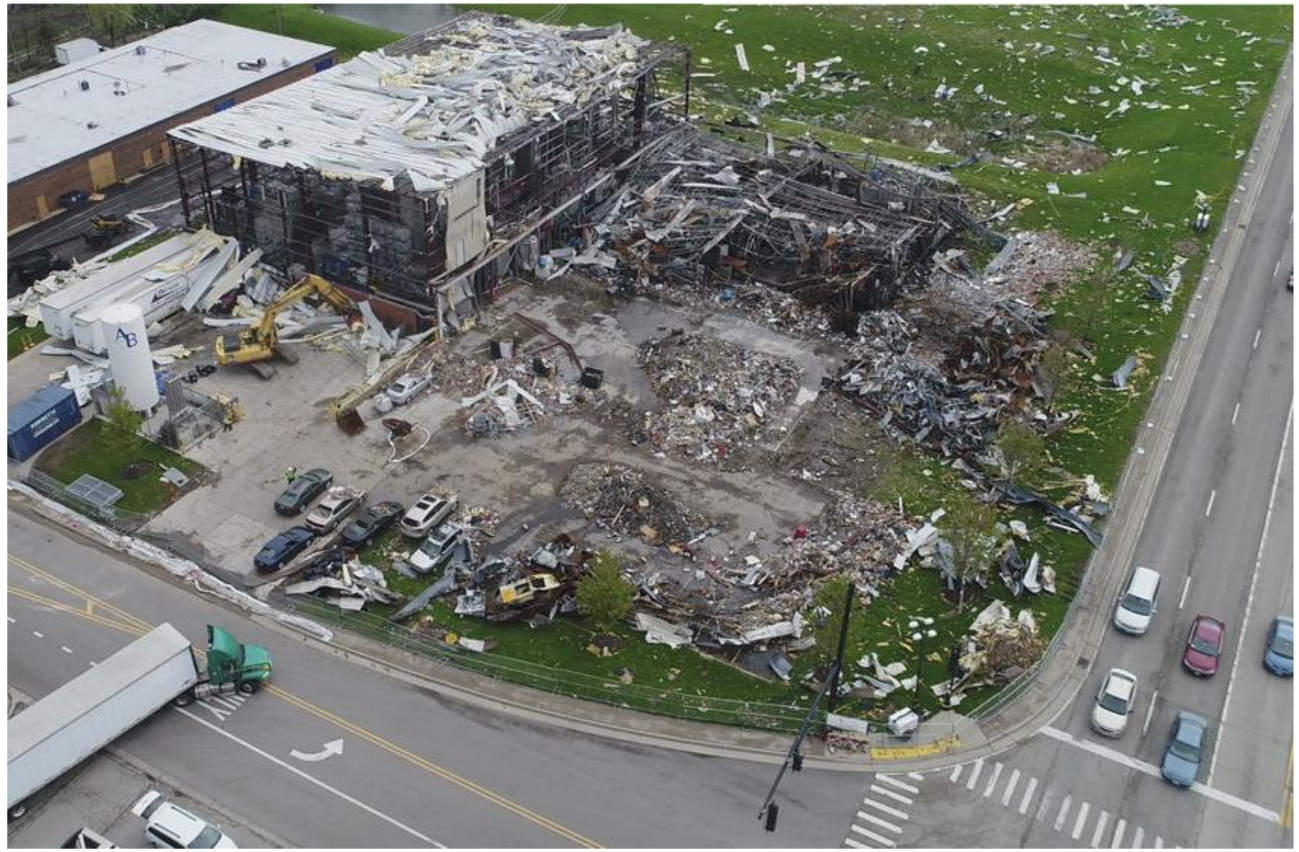


Photo: U.S. Chemical Safety Board (CSB)

Importance of a Process Safety Framework for Hydrogen

- Need for the hydrogen sector to center on a process safety management (PSM) system to manage safety risks.
- It may seem obvious to process safety professionals, especially legacy hydrogen producers, who have well-established PSM systems
- But not all users of hydrogen are familiar or even plan to use PSM as a management system
- Companies with mature PSM cultures may adapt to hydrogen but those without this culture are not applying best practice.

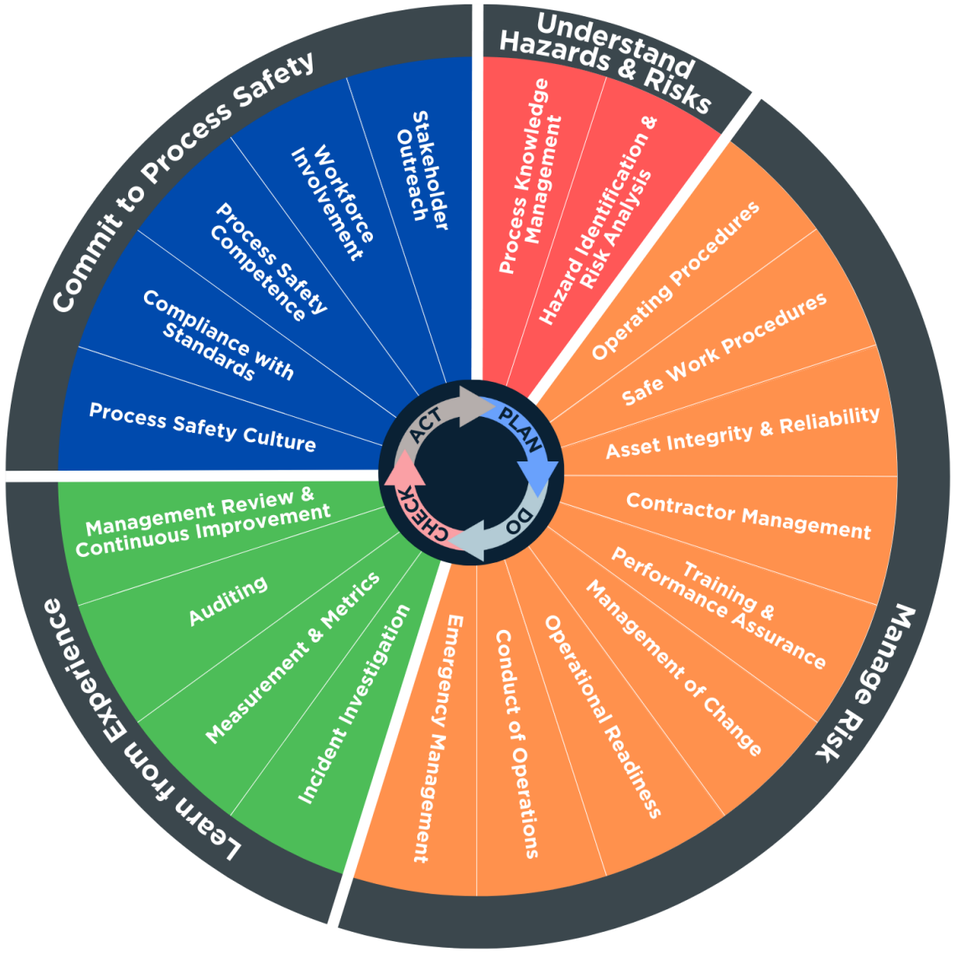
Concerns With Hydrogen Operations Based on Audits

- Companies with no operating experience planning to own and operate and manage hazards with insufficient process safety competency
- New designs and novel, emerging technology adoption with no prior operating experience
- Business objectives over process safety objectives and rush to market share
- Insufficient appreciation of hydrogen’ s properties and techniques to control risks
- Poor decisions on siting and colocation
- Dependency on equipment suppliers to operate, maintain, and control risks with a “hands-off” operating plan
- Lack of employee engagement into the operating plans and process safety management system
- Lack of appreciation of the need for emergency plans, poor planning and drills for emergencies, and unrealistic or unclear expectations for community support without proper coordination
- Tolerance for leaks without reporting, investigation, or RCA

AcuTech Model Risk Based Process Safety Management System

- Based on AIChE CCPS Risk Based Process Safety Model
- 4 Pillars
  - Commit to Process Safety
  - Understand Hazards & Risks
  - Learn from Experience
  - Manage Risk
- 20 elements
- Plan Do Check Act (Deming Cycle)

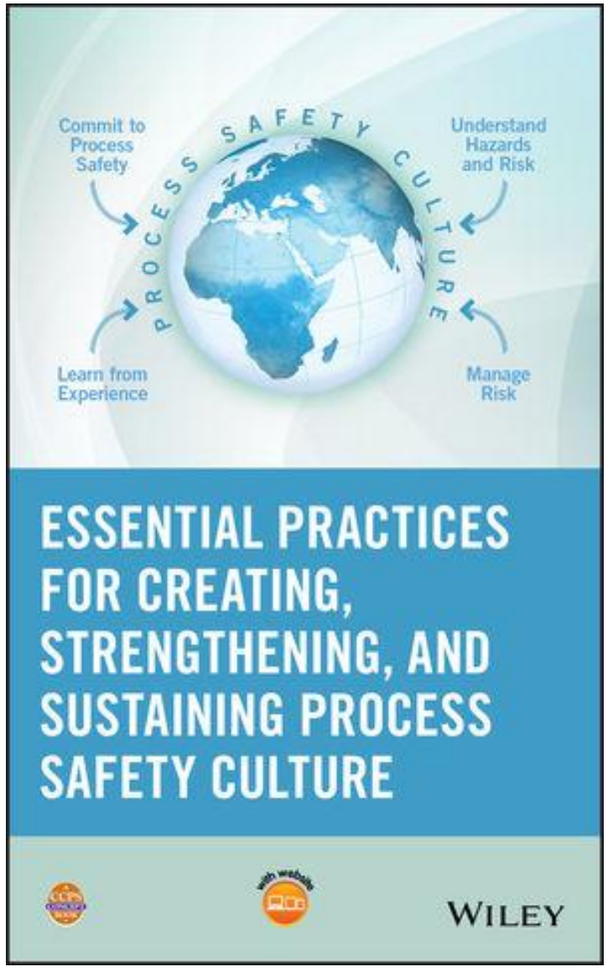
AcuTech Model Process Safety Management System



Based on four underlying pillars supported by the 20 elements of the Center for Chemical Process Safety (CCPS) Risk Based Process Safety Model.

Definition of Process Safety Culture

CCPS Guidelines Definition of PSM Culture (2017)



"The pattern of shared written and unwritten attitudes and behavioral norms that positively influence how a facility or company collectively supports the development of and successful execution of the management systems that comprise its process safety management program, resulting in the prevention of process safety incidents."

Prepare the Culture for Hydrogen Safety

- Most companies focus on how a plant should be designed and to get it built – operational plans for safety culture are not top of the list.
- Instead, develop a firm plan and management system procedure on how process safety culture will be executed, maintained, and improved.
- Safety culture takes time to levels of high performance.
- Companies that have developed their safe design and operating culture have only achieved this over many years

Photo: U.S. Chemical Safety Board (CSB)

Process Safety Culture Maturity Levels

Generative (Excellence)

Attitude: Safety is fully embedded in the organizational **DNA**.

Characteristics:

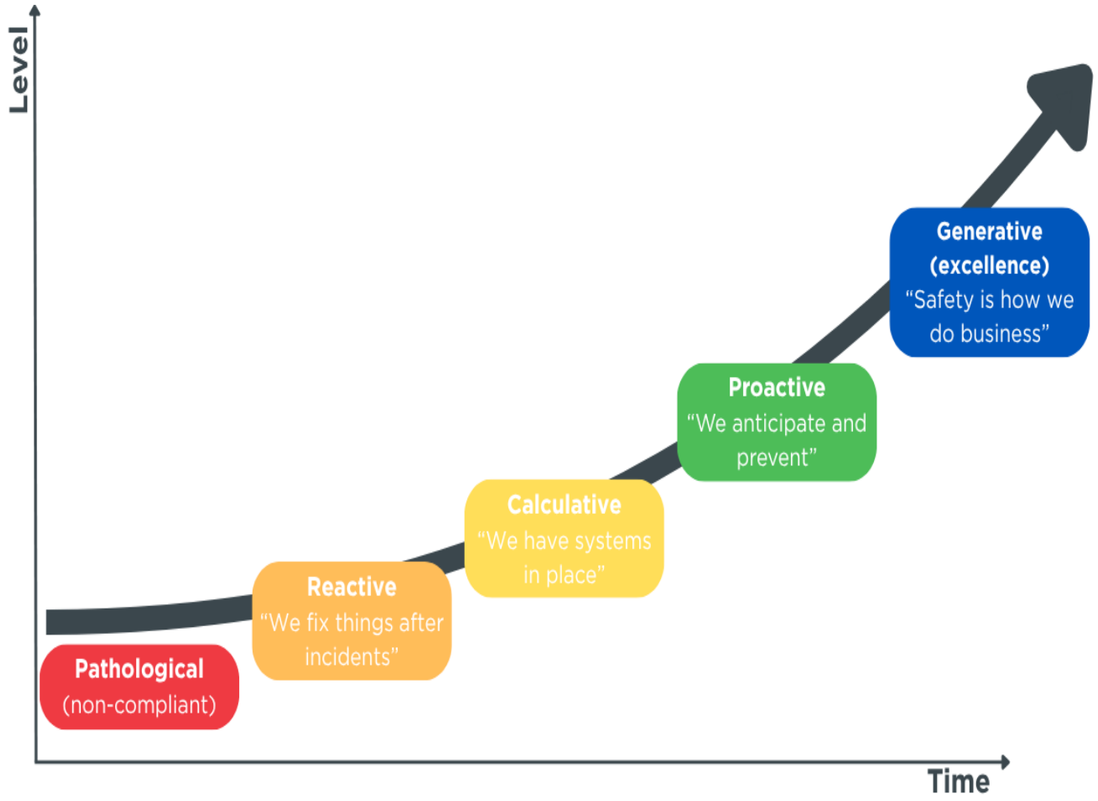
- Everyone takes ownership of process safety.
- Learning culture is robust and shared widely.
- PSM is a strategic priority aligned with business success.
- Adaptable and resilient systems that go beyond compliance.

Proactive

Attitude: Safety is valued and **anticipated**, not just managed.

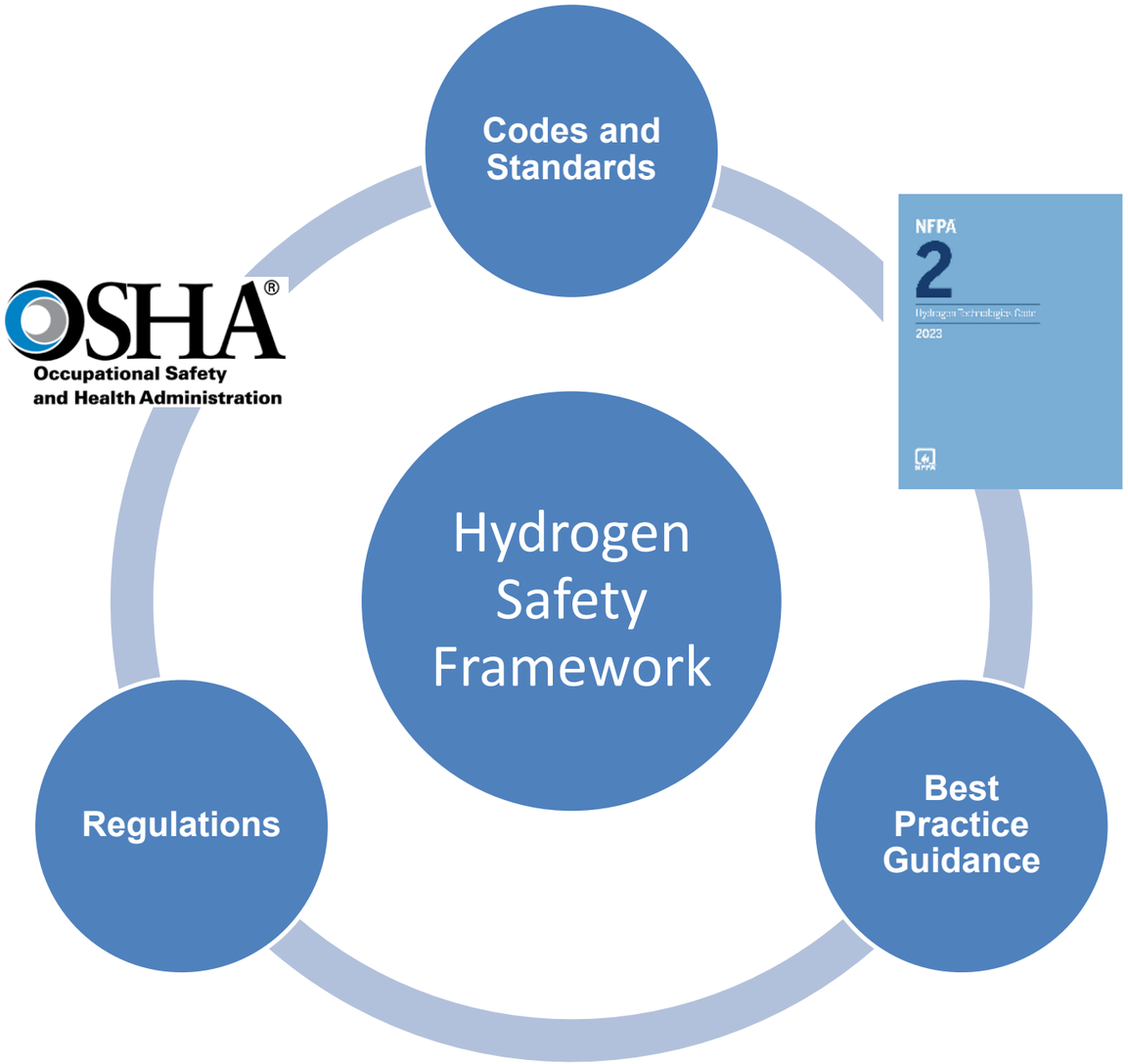
Characteristics:

- Employees actively look for potential hazards.
- Near misses and weak signals are reported and acted upon.
- Management walks the talk; safety integrated in decision-making.



Hydrogen Industry Safety Approach

- Network of global regulations, engineering standards, codes, and guidance for best practices for hydrogen safety.
- Need a management system to tie together the elements into a working system continuously improving
- **Gaps?** –
  - Others may operate in countries that do not have a PSM regulation,
  - They may be excepted by threshold quantities
  - Management may not be committed to voluntary mgmt systems



A Process Safety Management Framework for the Compressed Gas Industry – CGA P-86

- The process safety management framework provided in CGA P-86 may be applied to all processes within the industrial gases industry.
- The intent of this publication is to make process safety management understandable beyond the requirements found in (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**

Limitations of Codes and Standards

- Current codes and standards may not adequately address all hazards and current learnings especially with an emerging industry
- For example – Detonation following loss of primary containment
  - The overpressure hazards from the delayed ignition of a large H2 vapor cloud are not considered in NFPA 2 Hydrogen Technologies Code for siting of facilities
  - Several incidents have occurred in which a significant amount of hydrogen was released and ignited under a delayed ignition scenario resulting in explosions with fatalities, injury, and damage.
  - Interaction of multiple atmospheric vents simultaneously releasing may not be fully considered
  - Not all hazards are fully understood

Hydrogen Industry Safety Approach

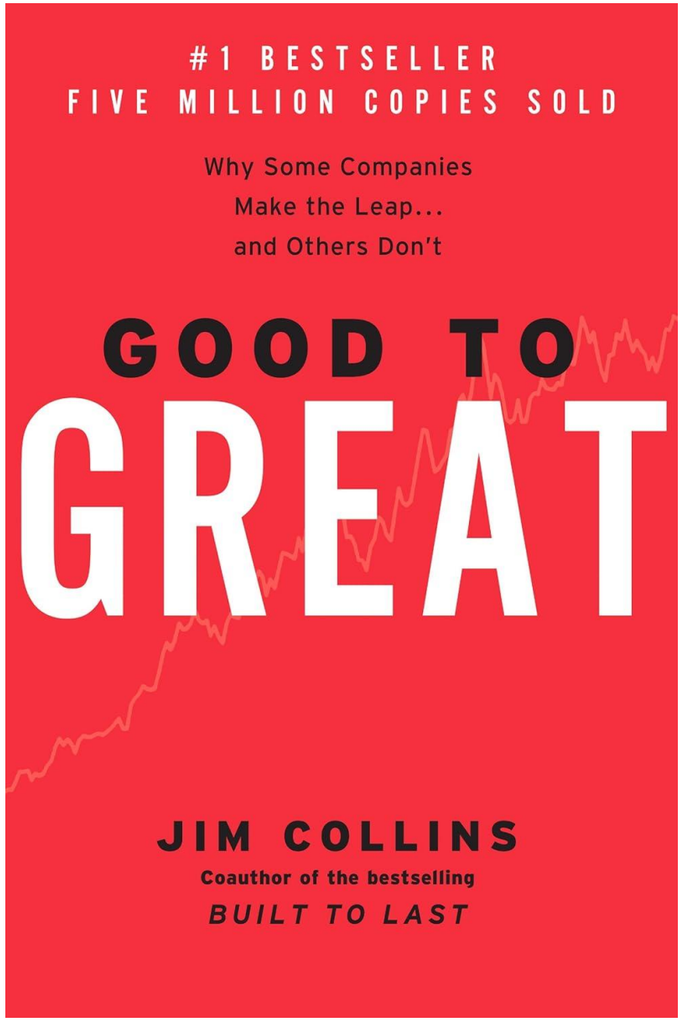
- **Recommendations:**

1. Producers, suppliers, facility operators, users, and their contractors and employees would all benefit from an industry approach to voluntary PSM even if not required by regulation.
2. The CCPS RBPS is one such model management system that is very applicable to hydrogen activities.

“From Good to Great” – James C. Collins (2001)

Summary of Key Concepts:

- **Businesses fail to become great because they become complacent.**
- Maintain a disciplined work environment where employees uphold the company’s basic beliefs and ideals.
- Leadership should put the success of the firm ahead of their own egos, displaying a rare blend of humility and willpower.
- Assemble the correct team before deciding the company’s strategic path.
- Face the harsh realities of a situation while retaining unflinching trust in the outcome.
- Focus on what the company can do best.
- Technology is considered only a tool to enhance core qualities and methods.
- Avoid reactive management - be proactive.



Source: Good to Great by Jim Collins, Harper Business, 2001.

Hydrogen Incidents of Note

- Augsburg Germany
- Commissioned 17 June 2024
- Explosion and fire 26 June 2024

- Reported to be an explosion within a compressor enclosure
- Illustrates the issue of confined space explosion potential with H2

Importance of a Process Safety Framework for Hydrogen

- The hydrogen value chain will bring more public exposures
- Transportation and mobility sectors have experienced many incidents and represent a leading indicator.
- For example, A pickup truck towing a trailer carrying full hydrogen tanks on US-23 in Delaware County Ohio explodes after crash.
  - Three people were transported to a hospital with minor injuries.
  - Contributing factors were found related to the trailer design that codes do not address at this time.

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

Kjorbo, Norway, Hydrogen Fueling Station - 2019

- Refueling stations and electrolyzers also have had incidents illustrating this point:
  - An improperly assembled cylinder boss/valve assembly caused loss of containment of hydrogen from a 950bar storage cylinder in a paneled enclosure which contained multiple storage cylinders.
  - A flammable gas cloud formed and ignited and an explosion resulted after about 3 seconds..
  - Panels around the storage cylinders may have limited dispersion
  - The surrounding wall was not designed for a delayed ignition

Damage included destruction of the storage cylinder enclosures and several equipment modules in close proximity, significant failure of the surrounding wall/fence,-the activation of air bags in several passing cars with 2 people taken to the hospital (damage to office building windows 200ft away suggested a detonation, likely due to a 2nd confined explosion event likely from an enclosed module).

Hydrogen Incidents – www.h2tools.com

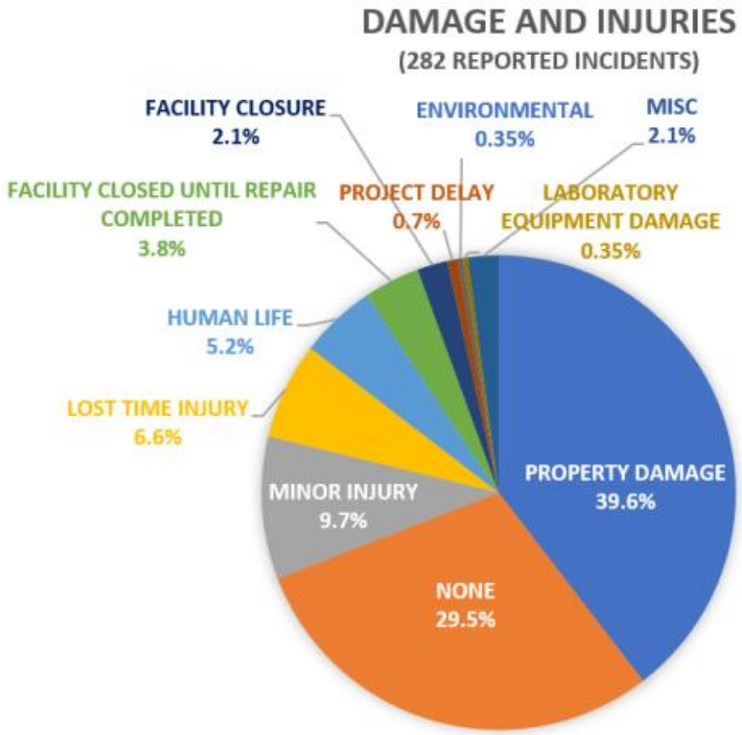


Figure 3: Reported damage and injury categories resulting from hydrogen related incidents reported to h2tools.org.

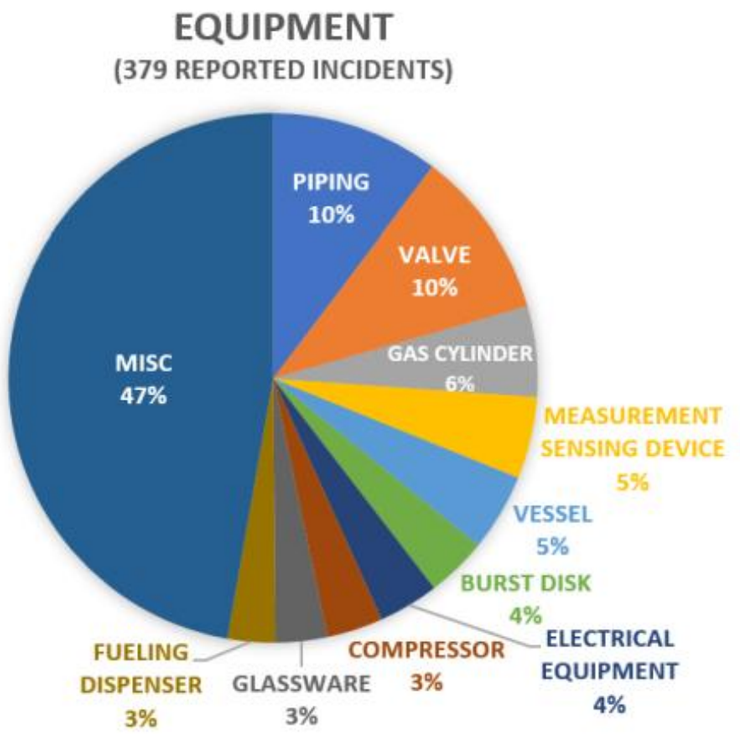


Figure 4: Reported categories for equipment involved in hydrogen incidents reported to h2tools.org. (The primary causes for the equipment-related incidents include component failure, operation error, installation/maintenance, etc.).

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

Conclusions

- Process safety management effectiveness depends on a strong culture that dictates the acceptable behaviors and attitude leading to achieving safety goals – this must be nurtured continuously.
- There is a particularly difficult process safety culture challenge given the rapid development of the hydrogen economy and widespread use of hazardous materials for energy transition
- Lessons learned:
  - it take time to develop a strong and mature process safety culture
  - prepare the right culture before operating the risk!
  - develop a standard and procedure for maintaining and evaluating process safety culture
  - continually reinforce and prioritize
  - provide the right value-driven environment and insist on conformance to the culture

About the Presenter

David Moore is the President and CEO of the AcuTech Consulting Group, a process risk management consulting firm based in McLean, Virginia, and founded in 1994 (www.acutech-consulting.com). Mr. Moore is the Chairman of the Managing Board of the AIChE Center for Hydrogen Safety, serves on the Technical Steering Committee of Center for Chemical Process Safety (CCPS) since inception and serves on the US Dept of Energy Hydrogen Safety Panel. He is actively involved in energy transition process safety management and culture improvement.

Mr. Moore has over 40 years of experience in chemical safety and security management and is a recognized expert in and frequent speaker on these topics. He has provided risk consulting services and training to industrial companies globally. Mr. Moore has taught process safety and security courses to many of the world's largest corporations and to US and foreign governments.

Mr. Moore was formerly a Senior Engineer with Mobil Corporation and a Fire Protection Engineer with the National Fire Protection Association and has been a PSM consultant for 28 years. Mr. Moore is a Registered Professional Engineer. He has an MBA, (NYU 1987), and a B.Sc., Fire Protection Engineering (University of Md. 1979).

Thank You and Questions

Contact Us

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

Global Offices

Washington DC – The Hague
Mumbai – Singapore – Doha
Al Khobar