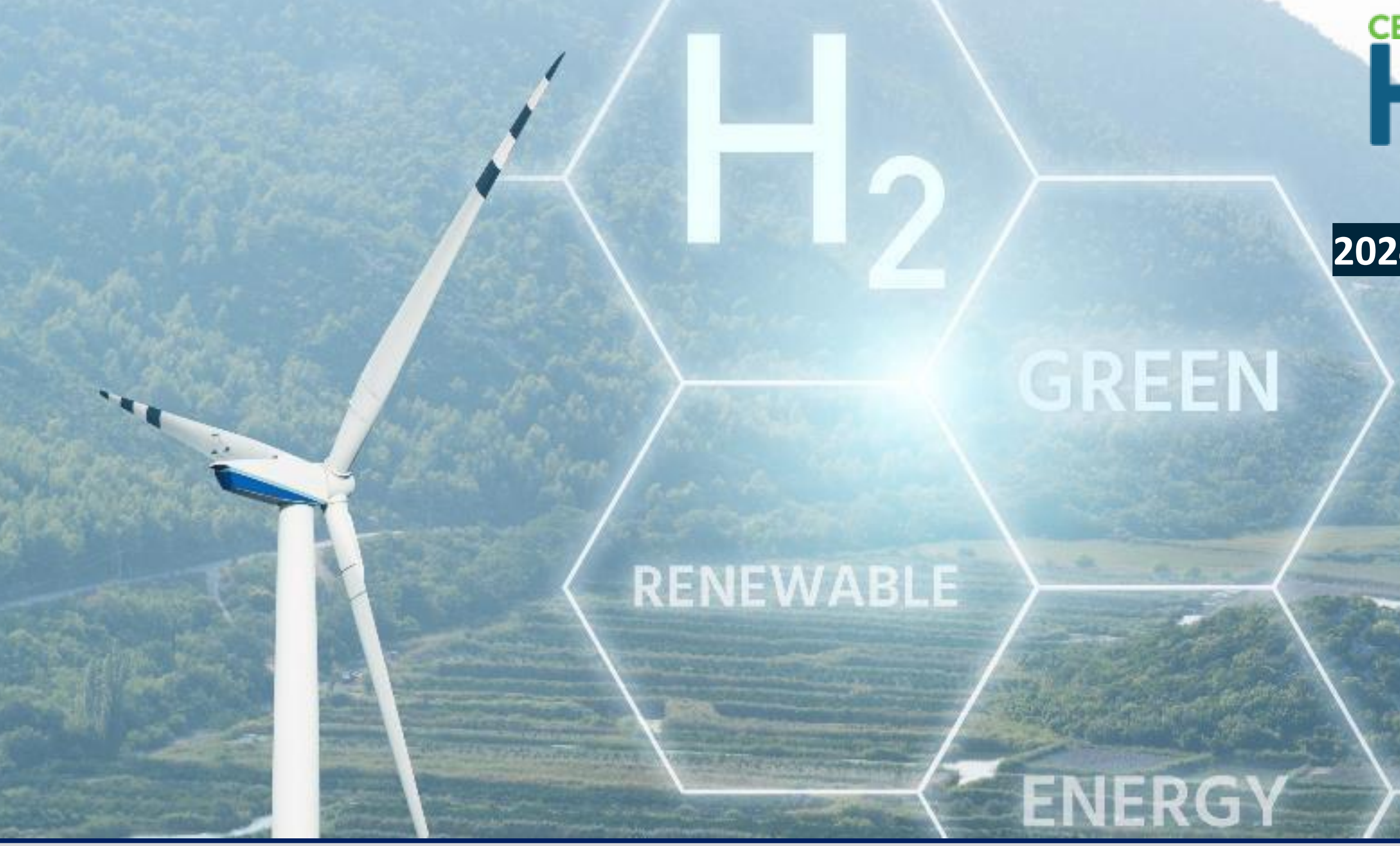

CENTER FOR Hydrogen SAFETY

2024 Center for Hydrogen Safety Americas Conference
May 21, 2024 to May 23, 2024
Hampton Inn Tropicana, Las Vegas, NV, USA

Process Safety Management for the Hydrogen Industry

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Presentation Overview

- The importance of global PSM application for the hydrogen industry
- Process safety frameworks and gaps
- Expected value and improvement potential
- Lessons learned with PSM
- Examples of applications of PSM to the hydrogen industry

Importance of a Process Safety Framework for Hydrogen

- Need for the hydrogen sector to center on a process safety management system to manage safety risks.
- Must have a full appreciation of the challenges ahead for hydrogen safety and use of best available practices to reduce risk.
- Take advantage of the lessons learned by other industries handling highly hazardous chemicals.
- Opportunity for the industry to be in a leading safety position through a universal voluntary process safety management model approach.

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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.
- Can we expect zero risk? No, accidents have already occurred.
- What effect would a major incident with hydrogen fuels have on public acceptance?

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

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Public Acceptance of Hydrogen – Most Important Risk Perception Factors

- **Risk Perception Factors*:**
  - Trust vs. lack of trust
  - Imposed vs. voluntary
  - Natural vs. human-made
  - Catastrophic vs. chronic
  - The dread factor
  - Hard to understand
  - Uncertainty
  - Familiar vs. new
  - Awareness
  - A known victim
  - Future generations
  - Does it affect me?
  - Risk vs. benefit
  - Control vs. no control

Relevance to hydrogen industry:

- Familiarity and acceptance are critical
- Trust is essential
- Record must be do no harm - minimal impacts
- Process safety management system is necessary to manage the public risks

*Understanding Factors of Risk Perception, NiemanReports, December 15, 2002

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 – *

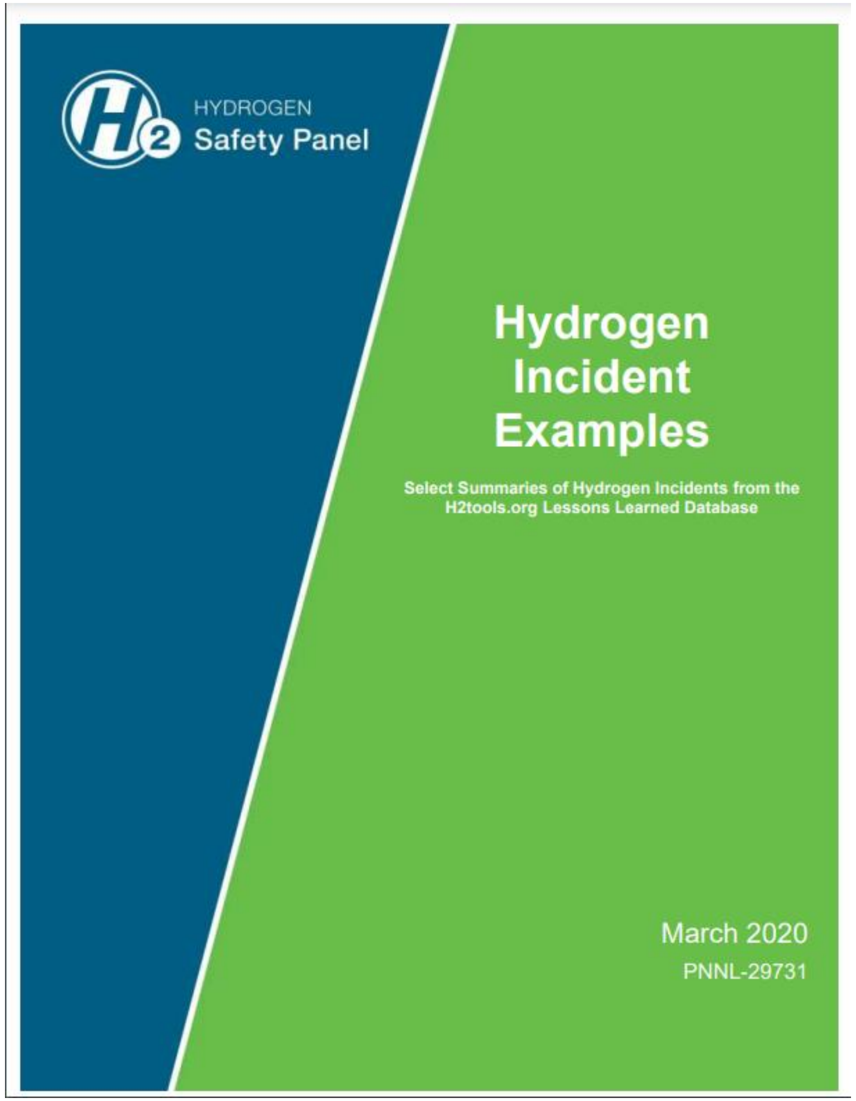
Flammable liquid/vapor release from vent stack of a refinery unit due to overfill; 15 deaths, 180 injuries

* Maintenance or startup errors

Regulatory Reponses to Bhopal India and Other Incidents

- **The Seveso-III-Directive (2012/18/EU)**
  - Aims at the prevention of major accidents involving dangerous substances.
  - 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)**
  - The prevention of major accidents involving dangerous substances, and to seek to limit as far as possible the consequences for human health and the environment of such accidents.
  - Includes submission of a Major Accident Prevention Policy (MAPP) document to the regulatory authority for review and approval
- **OSHA Process Safety Management Regulations** – (29 CFR 1910.119/1992) concerned with catastrophic chemical accident prevention in the workplace. (www.osha.gov)
- **EPA Risk Management Program Regulations** (40 CFR Part 68/1996) – concerned with chemical accident prevention to protect the public and environment. (www.epa.gov/swercepp)

US DOE Hydrogen Safety Panel – Hydrogen Incident Examples



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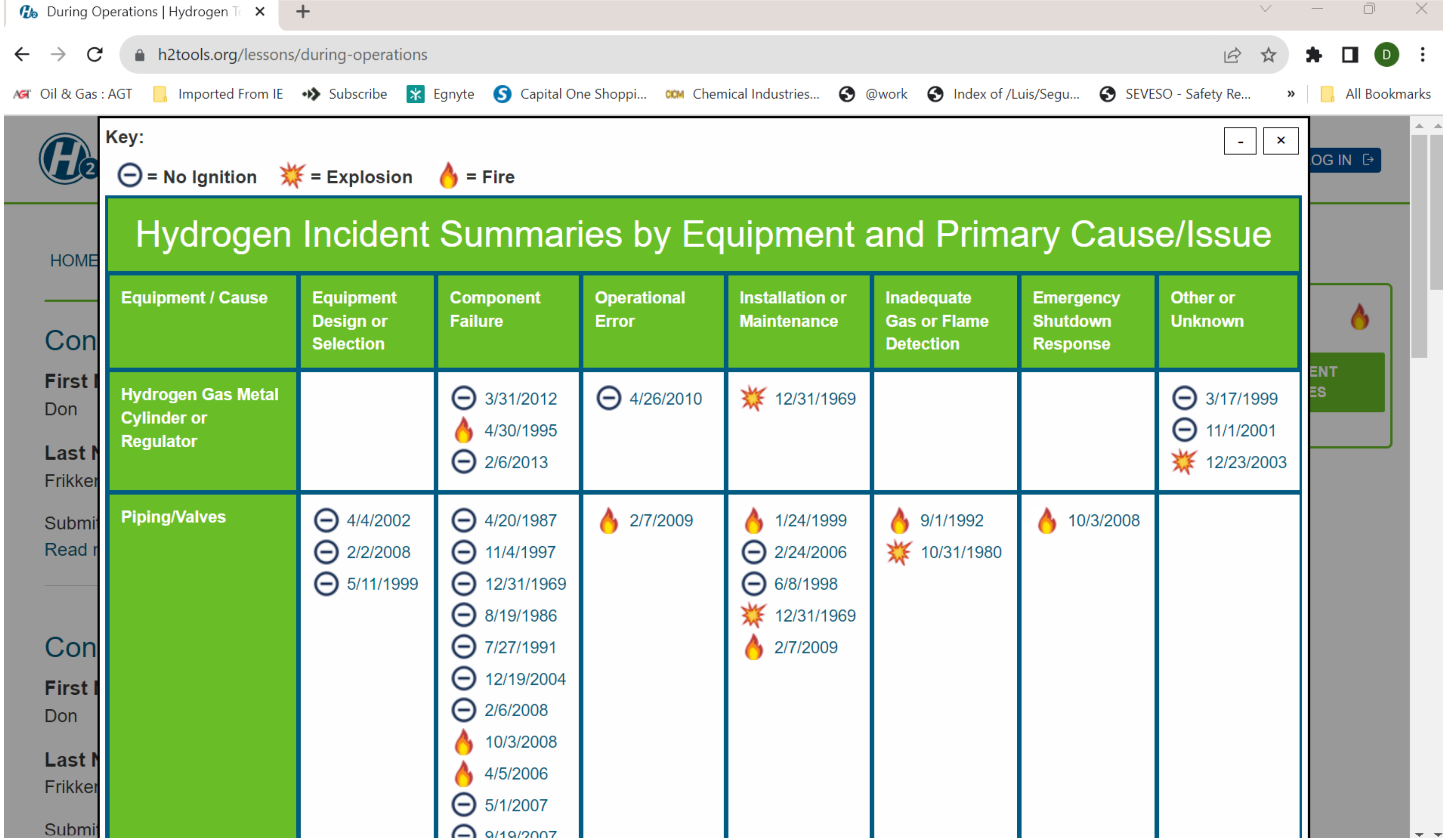
US DOE H2Tools Website Incident Summaries



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/

Hydrogen Incidents – www.h2tools.com

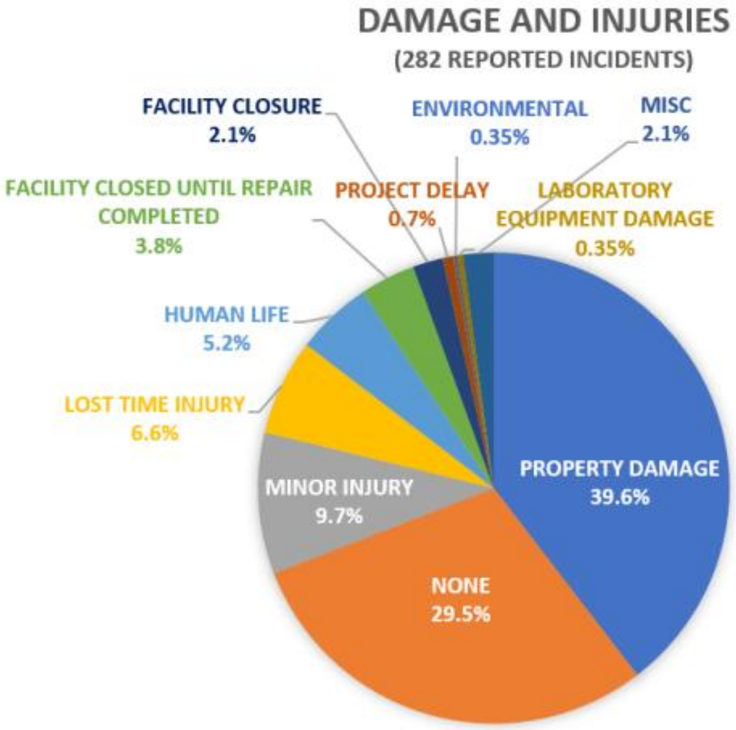


Figure 3: Reported damage and injury categories resulting from hydrogen related incidents reported to h2tools.org.

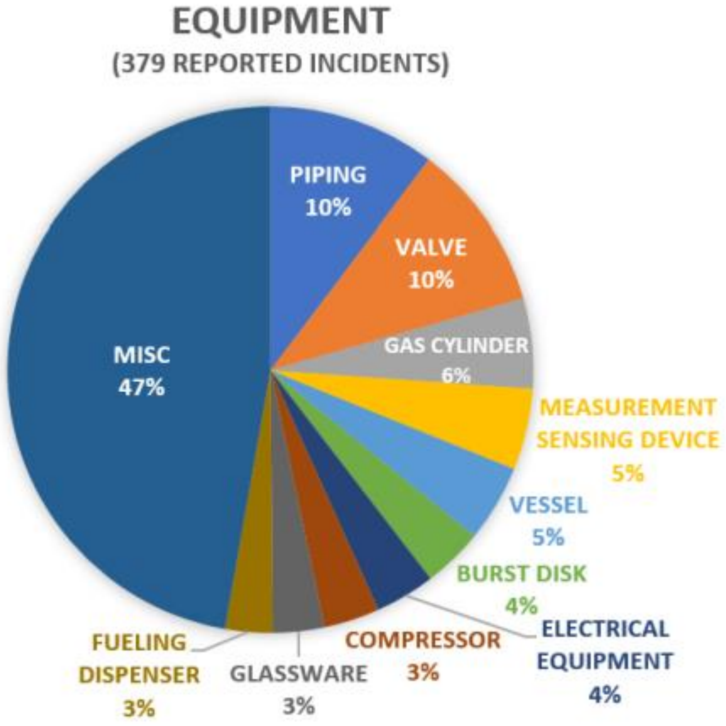


Figure 4: Reported categories for equipment involved in hydrogen incidents reported to h2tools.org. (The primary causes for the equipment-related incidents include component failure, operation error, installation/maintenance, etc.).

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

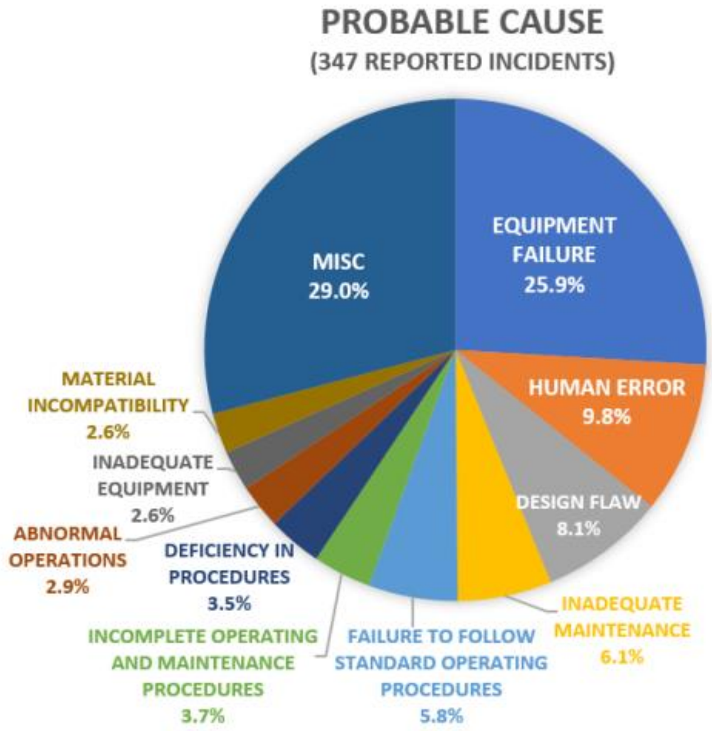


Figure 5: Probable cause categories for hydrogen incidents reported to h2tools.org.

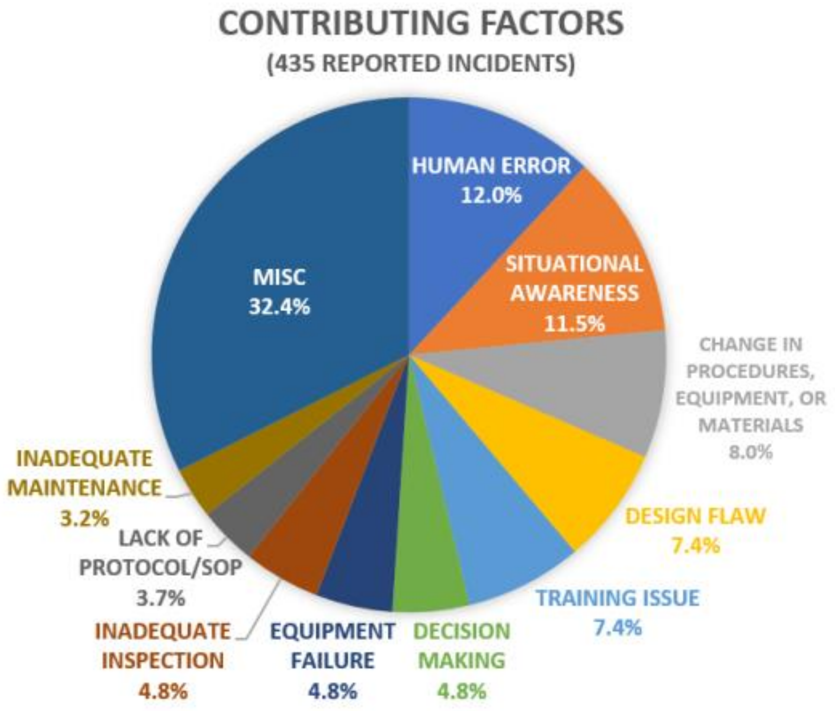


Figure 6: Contributing factors categories for hydrogen incidents reported to h2tools.org.

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

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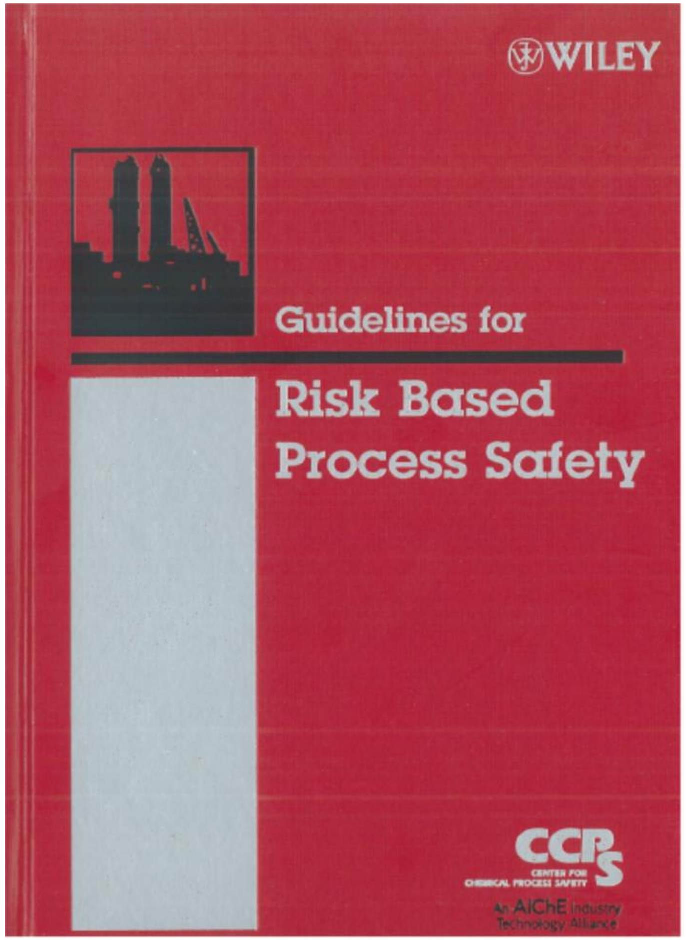
Process Safety Management

- **Process Safety Management:** Recognized best practice approach for managing the risk of catastrophic incidents involving highly hazardous chemicals in the process industries
- **Objectives:** Application of management systems to the identification, understanding, and control of process hazards to prevent process-related incidents and injuries.
- **Process Safety Management Systems:** Comprehensive sets of policies, procedures, and practices designed to ensure that barriers to episodic incidents are in place, in use, and effective.

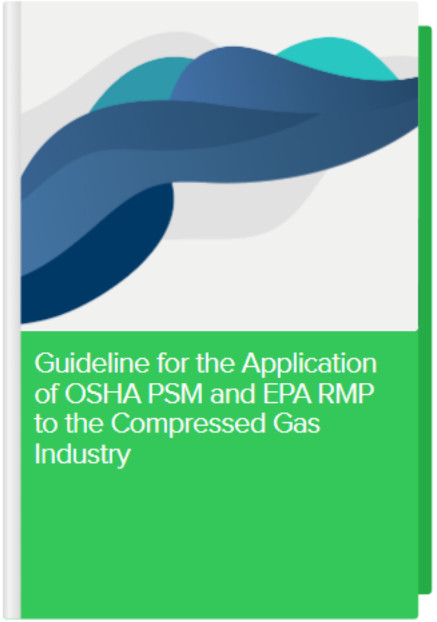
Example – CCPS Risk-Based Process Safety Management (2007)

- AIChE CCPS www.aiche.org/ccps
  RBPS Program Elements
- Built on Four Underlying Accident Prevention Pillars
  - **Commit to Process Safety**
  - **Understand Hazards and Risk**
  - **Manage Risk**
  - **Learn from Experience**
- These Pillars are Supported by 20 Elements
- Similar Guidance:
  - Energy Institute (EI): High level framework for process safety management
  - OGP: Asset integrity – The key to managing major incident risks, Report n. 415



Example Industry Guidance for PSM Regulatory Compliance - CGA PSM and EPA RMP Guidance Documents

- 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”.
- **P-28: OSHA Process Safety Management and EPA Risk Management Plan Guidance Document for Bulk Liquid Hydrogen Supply Systems**
- 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.
- **P-29, Guideline for Application of OSHA PSM and EPA RMP to the Compressed Gas Industry.**
- 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



Hydrogen Industry Safety Approach

- Network of global regulations, engineering standards, codes, and guidance for best practices for hydrogen safety.
- PSM regulations v voluntary 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

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Process Safety Management Regulations v Industry Initiatives

- **PSM regulations:** Reduce the likelihood and intensity of process safety impacts on workers, the public, and the environment.
- **Corporate Initiatives:** 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.

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 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

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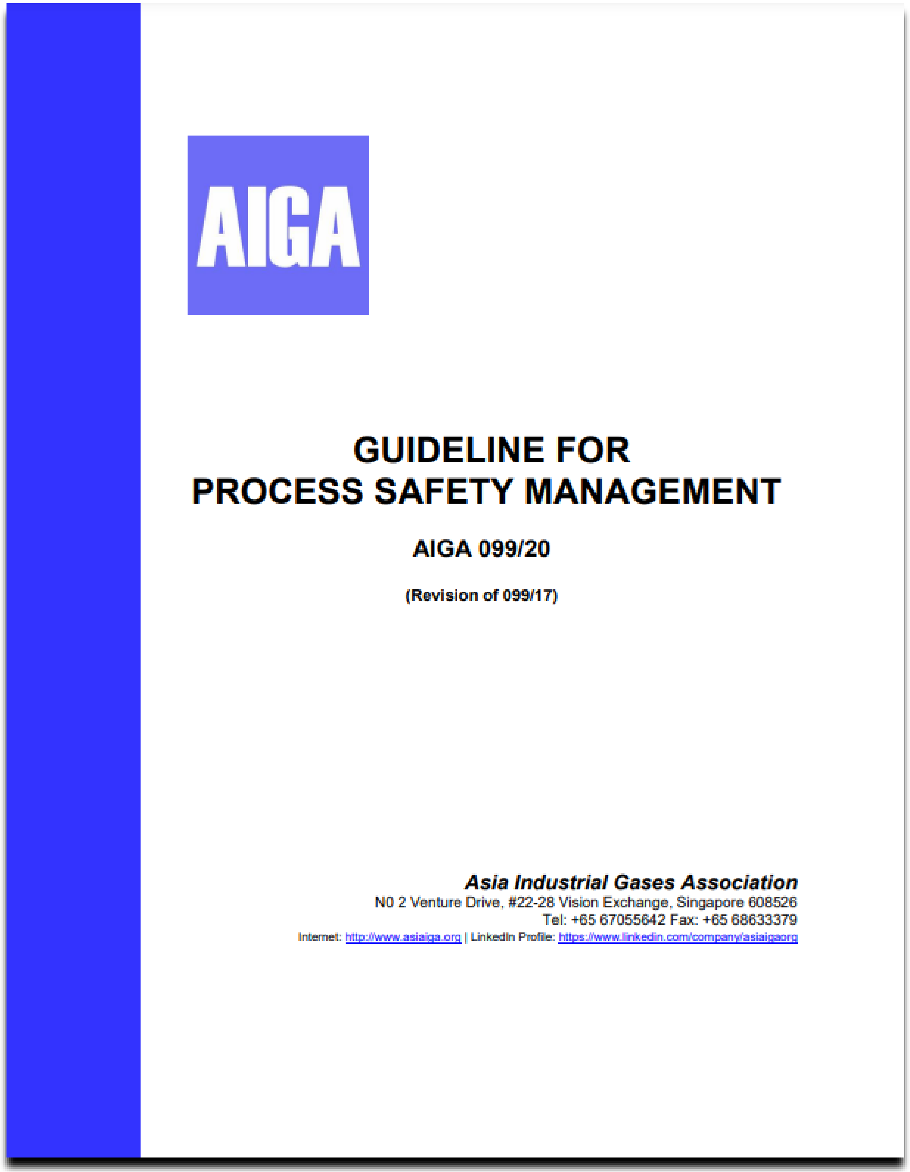
Example – Process Safety Management Guidance



AIGA

GUIDELINE FOR
PROCESS SAFETY MANAGEMENT

AIGA 099/20

(Revision of 099/17)

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ACC Process Safety Code – Responsible Care Mgmt System

- American Chemistry Council members must commit to Responsible Care (since the past 35 years)
- CEO-level commitments to the program including:
  - Signing the Responsible Care Guiding Principles
  - Tracking and transparently reporting company performance
  - Third-party audit and certification to Responsible Care Management System (RCMS®)/RC14001®

www.americanchemistry.com/chemistry-in-america/responsible-care-driving-safety-industry-performance

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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

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

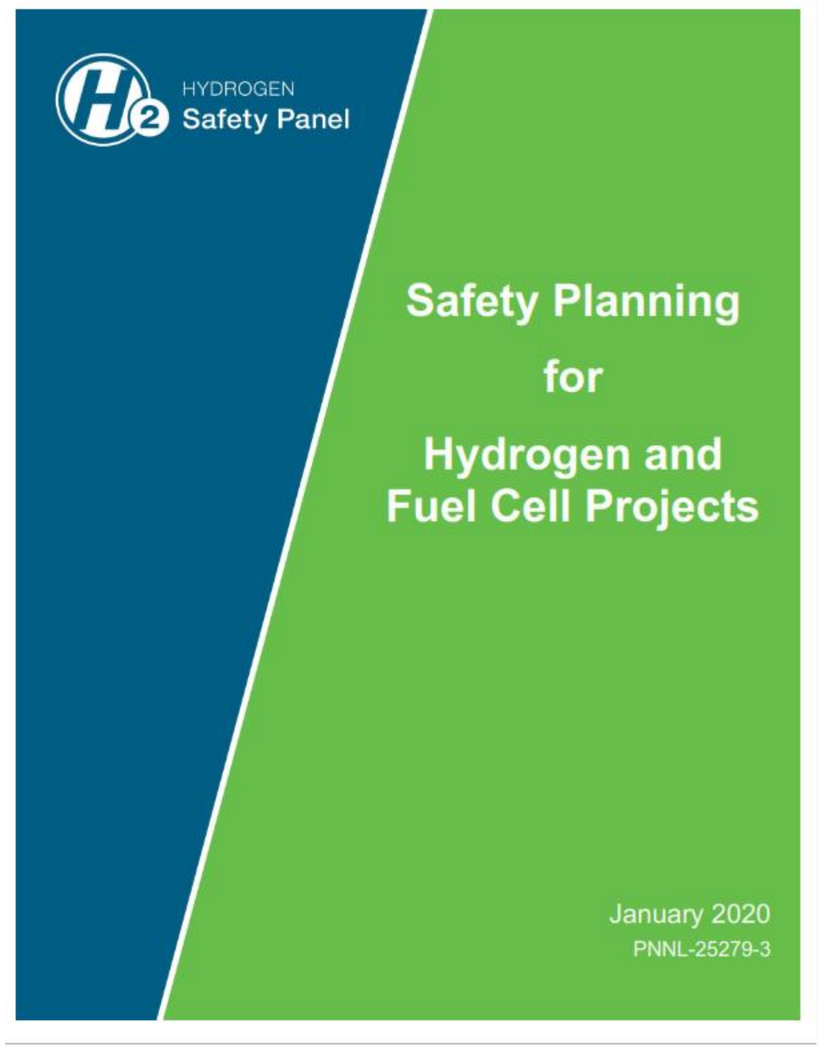

Table 2.1. Comparison of RBPS elements to OSHA PSM elements.

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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Safety Plan Template

Safety Plan Template

Element	The Safety Plan Should Describe
Description of Work	• Nature of the work being performed, including a description of the facility, pertinent processes or systems, partner organizations, and the anticipated quantity of stored/used hydrogen
Organizational Policies and Procedures	• Application of safety-related policies and procedures to the work being performed • Project leadership responsible for safety approvals
Hydrogen and Fuel Cell Experience	• How previous organizational experience with hydrogen, fue cell and related work is applied to this project
Identification of Safety Vulnerabilities (ISV)	• The ISV methodology applied to this project, such as FMEA, What If, HAZOP, Checklist, Fault Tree, Event Tree, Probabilistic Risk Assessment, or other method • Who leads and stewards the use of the ISV methodology • Significant accident scenarios • Significant vulnerabilities associated with the scenarios • Safety critical equipment • Storage and handling of hazardous materials and related topics ○ ignition sources, explosion hazards ○ materials interactions ○ possible leakage and accumulation ○ detection • Hydrogen handling systems ○ supply, storage, and distribution systems ○ volumes, pressures, estimated use rates • Additional Documentation provided (see section below)
Risk Reduction Plan	• Prevention and mitigation measures for significant vulnerabilities
Codes and Standards	• Governing codes, standards, and regulations applicable to the project • Alternate methods including their technical basis
Procedures	• Procedures applicable for the location and performance of the work • Operating steps that need to be written for the particular project: critical variables, their acceptable ranges, and responses to deviations from them

Element	The Safety Plan Should Describe
Equipment and Mechanical Integrity	• Design basis, proof testing and commissioning • Preventative maintenance plan • Calibration of sensors • Test/inspection frequency basis • Documentation
Management of Change Procedures	• The system and/or procedures used to review proposed changes to materials, technology, equipment, procedures, personnel, and facility operation for their effect on safety vulnerabilities
Safety Reviews	• Pre startup review to verify initial conformity to ISVs, mechanical integrity, etc. • Safety audits to verify continued conformity to ISVs, mechanical integrity, procedures, etc. • Other reviews normally conducted by the organization(s)
Project Safety Documentation	• How needed safety information is communicated and made available to all participants, including partners. Safety information includes the safety plan, the ISV documentation, procedures, and references such as handbooks and standards, and safety review reports.
Training	• Required general safety training - initial and refresher • Hydrogen-specific and hazardous material training - initial and refresher • How the organization stewards training participation and verifies understanding
Safety Events and Lessons Learned	• The reporting procedure within the team • The process used to investigate events • How corrective measures will be implemented • How lessons learned from incidents and near-misses are documented and disseminated
Emergency Response	• The plan/procedures for responses to emergencies • Plans for communication and interaction with local emergency response officials
Other Comments or Concerns	• Any information on topics not covered above
Supporting Documentation	• Layout of the system at the planned location • Flow diagram (see Appendix IV for an example) • Equipment component descriptions • Critical safety and shutdown table (see Appendix IV for an example)

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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.

Process Safety Management Lessons Learned (1984-2022)

Knowledge and Competence	All around competence is imperative to properly execute
Operational Discipline	Continuous operational discipline and conduct of operations
Leadership Commitment	Supportive and engaged leadership to PSM
PSM Culture	Developing and sustaining a culture specific to PSM conducive
Technical Excellence	Following all recommended and best available engineering practices
Transparency and Trust	Sustaining a trusting relationship with the public
Measurement and Metrics	Quantifying process safety performance
Responsible Operations	Responsible performance and positive trends

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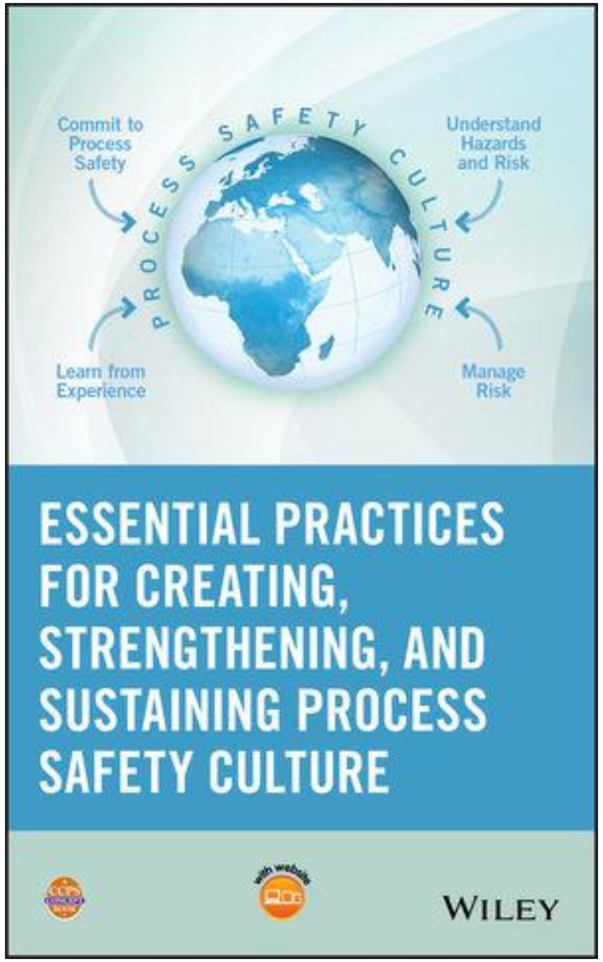
Importance of Process Safety Culture



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."

Operational Discipline - Purpose

- Operational Discipline establishes organizational methods and systems that will be used to *influence individual behavior and improve process safety*.
- Operational Discipline specify how certain PSM tasks should be performed.
- A good Operational Discipline program helps visibly demonstrate the organization's commitment to process safety.
- Operational discipline includes day-to-day activities carried out by all personnel, <u>not</u> just by Operations.
- Ensure that all tasks is performed *deliberately and correctly and minimize variations* in performance.

Presentation Summary

- Industry experience of over 40 years of PSM has shown that it has positively changed the way safety is managed
- It is necessary to deeply integrate into day-to-day operations.
- 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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