CENTER FOR Hydrogen SAFETY

Center for Hydrogen Safety Europe Conference 2023
May 9, 2023 to May 11, 2023
Rotterdam Ahoy, Netherlands

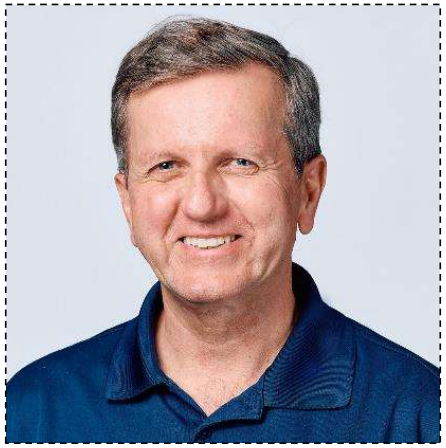
Process Safety Management for the Hydrogen Industry

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

AcuTech
PROCESS RISK MANAGEMENT

Presenter

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



- Founder of AcuTech Group, a process risk management consulting firm established in1994 www.acutech-consulting.com
- Over 40 years of experience in process safety management
- MBA(NYU Stern) and B.Sc., Fire Protection Engineering (Univ. of Maryland).
- CCPS Fellow
- Vice-Chair, Managing Board, AIChE, Center for Hydrogen Safety

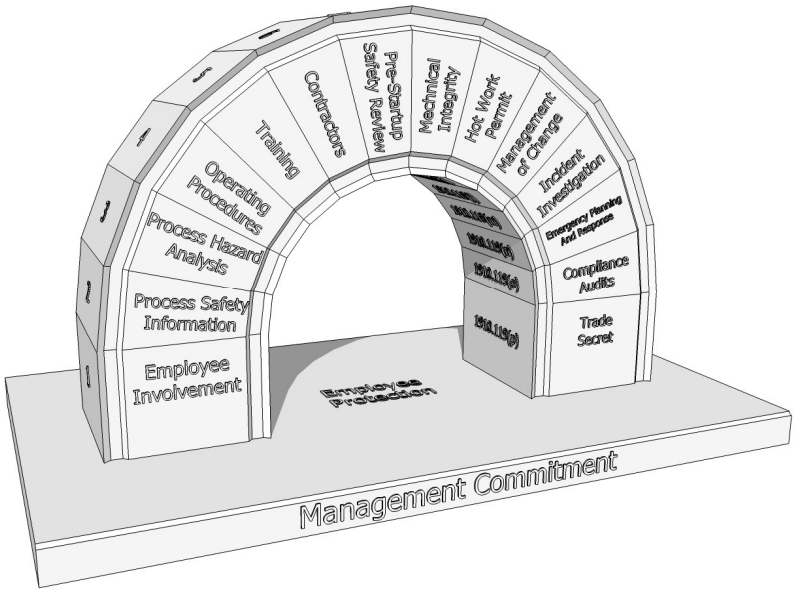
AcuTech
PROCESS RISK MANAGEMENT

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

AcuTech
PROCESS RISK MANAGEMENT

Process Safety Management Systems – License to Operate



- There is a strong business case for implementing major hazards 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 40+ years
- It takes years of development to make a PSM system effective and diligence to sustain that level

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

Critical Importance of Process Safety Management

- No company can prosper with the negative impacts of industrial accidents
  - Human costs in losses of human life, injuries
  - Moral and ethical impacts
  - Economic impacts to local and national economy and value chain impacts
  - Jeopardize hydrogen's opportunities due to perceived risks
  - Lasting impacts of reputational damage and ethical perception

Importance of a Process Safety Framework for Hydrogen

- The hydrogen industry as it evolves will need to maintain the highest of safety standards to justify the validity of the industry for its many promising applications
- The need for comprehensive planning for the hydrogen supply chain safety
- Full appreciation of the challenges ahead and use of best available methods – get ahead of the issues learned by other industries

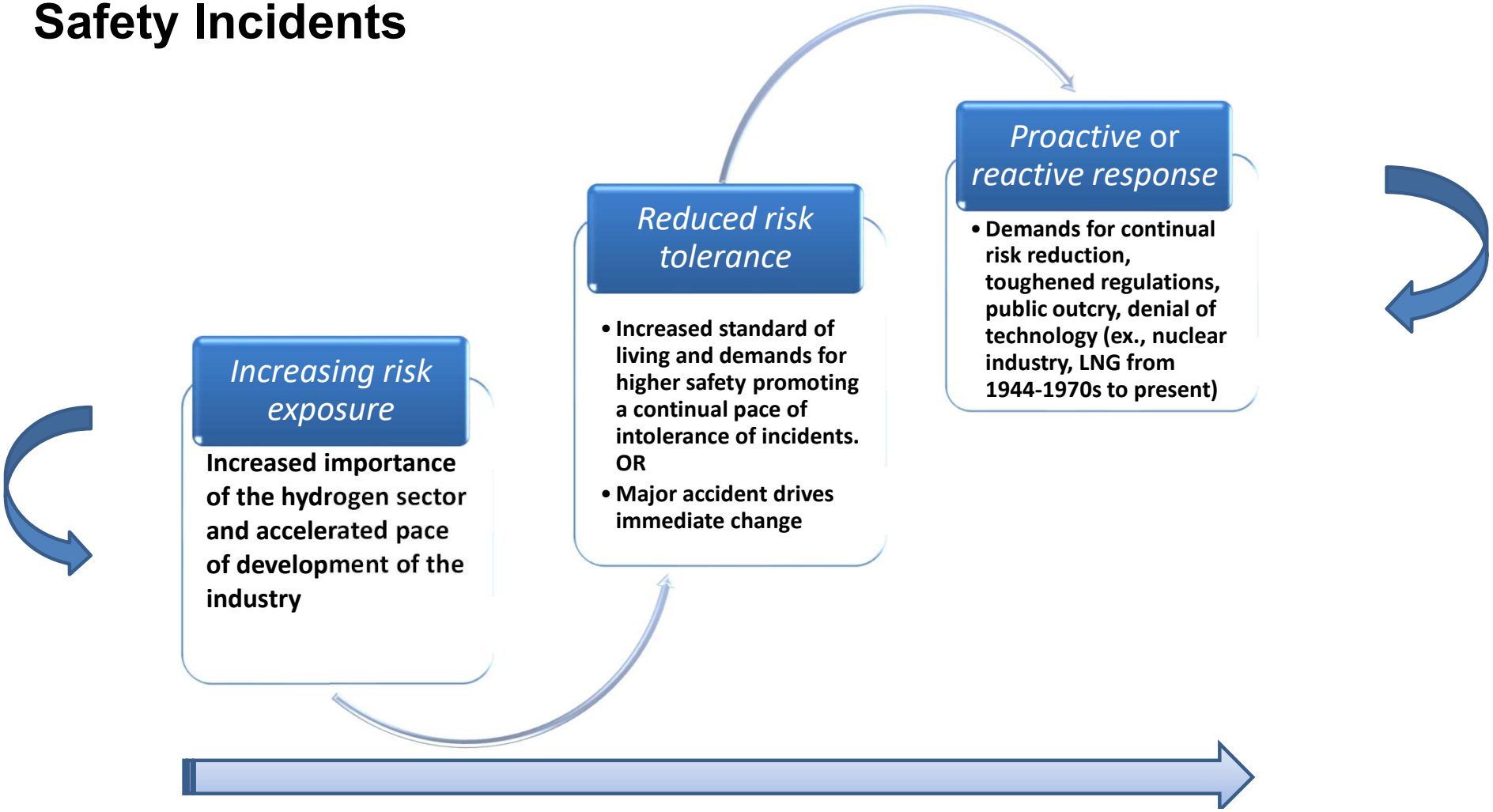
AcuTech
PROCESS RISK MANAGEMENT

Hydrogen Hazards Overview

- Hydrogen usage has well-known hazards (to experts) but new applications and uses will create many yet to be discovered hazards and risks
- There may be challenges given hydrogen physical and chemical properties:
  - wide flammability range (44.0-75 vol%)
  - low ignition energy (0.018 mJ) compared to other fuel sources
  - low viscosity and low density
  - specific damage mechanisms (embrittlement of metals)
- Widespread use of hydrogen and public risks
  - Introduction of hydrogen into public areas where it is not currently commonly present
  - Public access to hydrogen not commonly used by non-experts

AcuTech
PROCESS RISK MANAGEMENT

Evolution of Safety Perspectives Due to Impact of Process Safety Incidents



Process Safety Management History

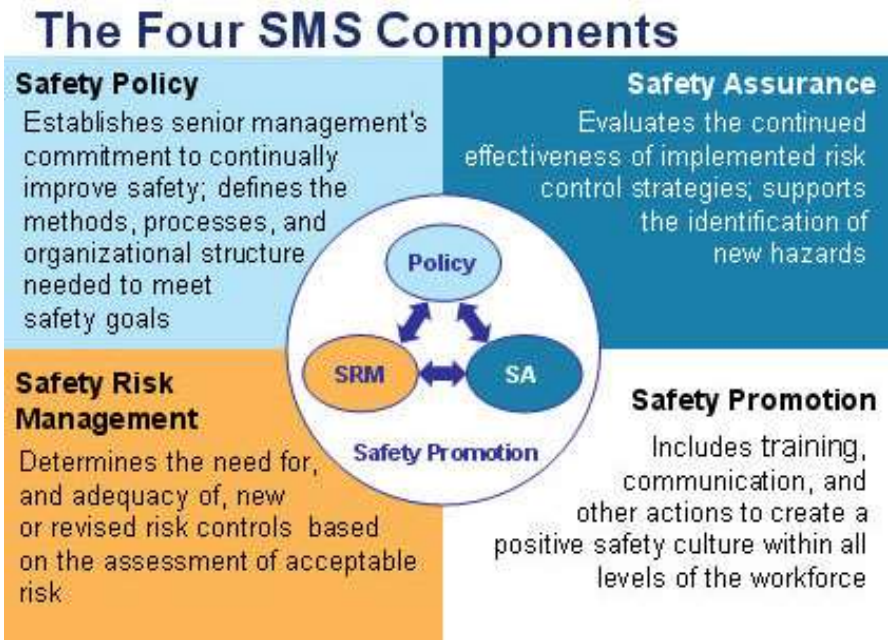
- A history of severe process industry accidents in the period from 1974 to 1989 prompted E.U. and U.S. legislation to improve process safety, emergency preparedness, and public risk management.
- Culminated in significant international process safety and risk management regulations and activities, but not uniformly applied globally.

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. 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)
- **EPA Risk Management Program Regulations** (40 CFR Part 68) - concerned with accident prevention to protect the public and environment (www.epa.gov/swercepp)

Safety Risk Management and Safety Assurance for Hydrogen

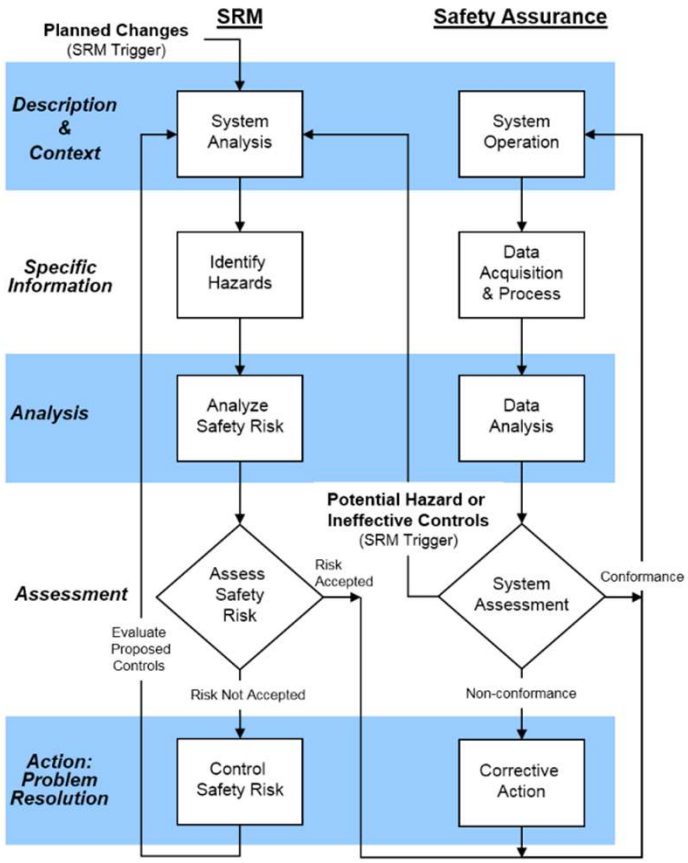
- The industry needs to center on a hydrogen safety management system framework to ensure success.
- This could include a model process safety management system which is:
  - Risk-based
  - Performance-based
  - Emphasizes risk analysis and strict control of hazards, diligence, continual improvement, and assurance, to requirements



AcuTech
PROCESS RISK MANAGEMENT

Example Safety Risk Management and Safety Assurance System*

- **Safety Risk Management** – The ongoing identification and analysis of risk and implementation of barriers to reduce risk to acceptable levels
- **Safety Assurance** – The ongoing assessment of the compliance to safety objectives and identification of non-conformities and assurance through corrective action

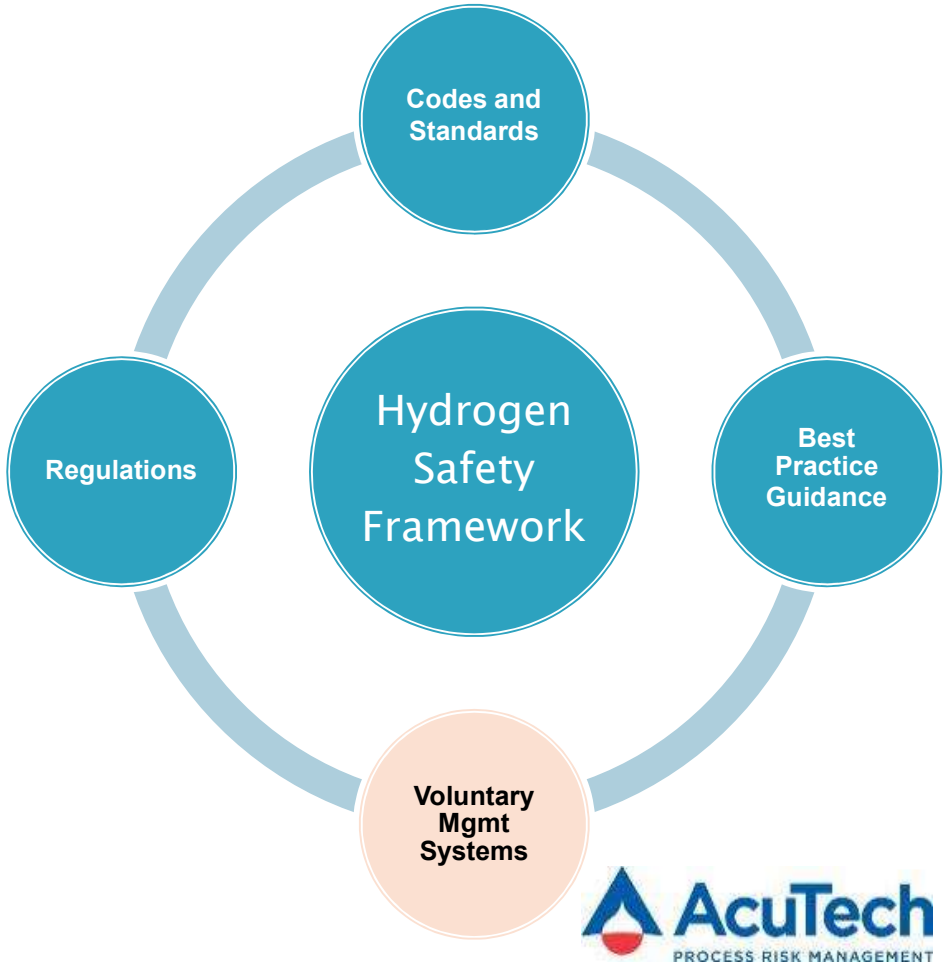


* US DOT FAA

AcuTech
PROCESS RISK MANAGEMENT

Hydrogen Industry Safety Approach

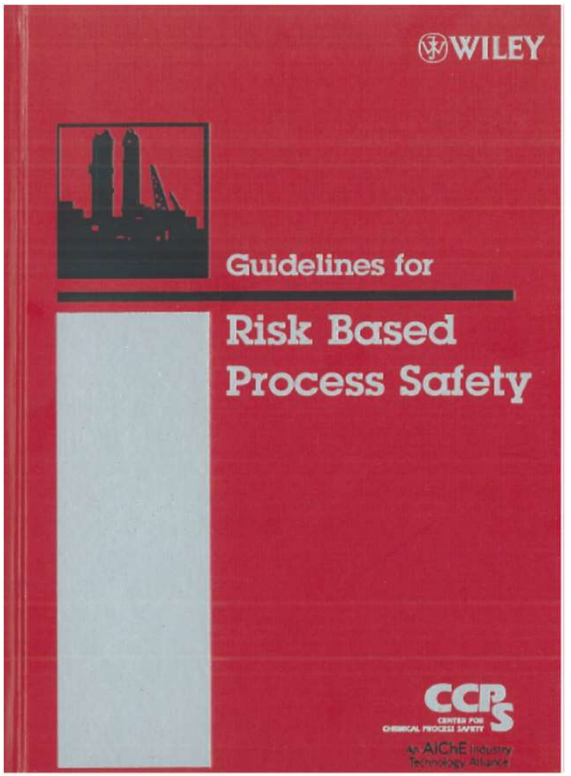
- Network of global regulations, engineering standards, codes, and guidance for best practices for hydrogen safety.
- Some operations may be subject to PSM regulations, which may vary depending on the country of operation and their regulatory frameworks.
- **Gaps?** –
  - Others may operate in countries 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



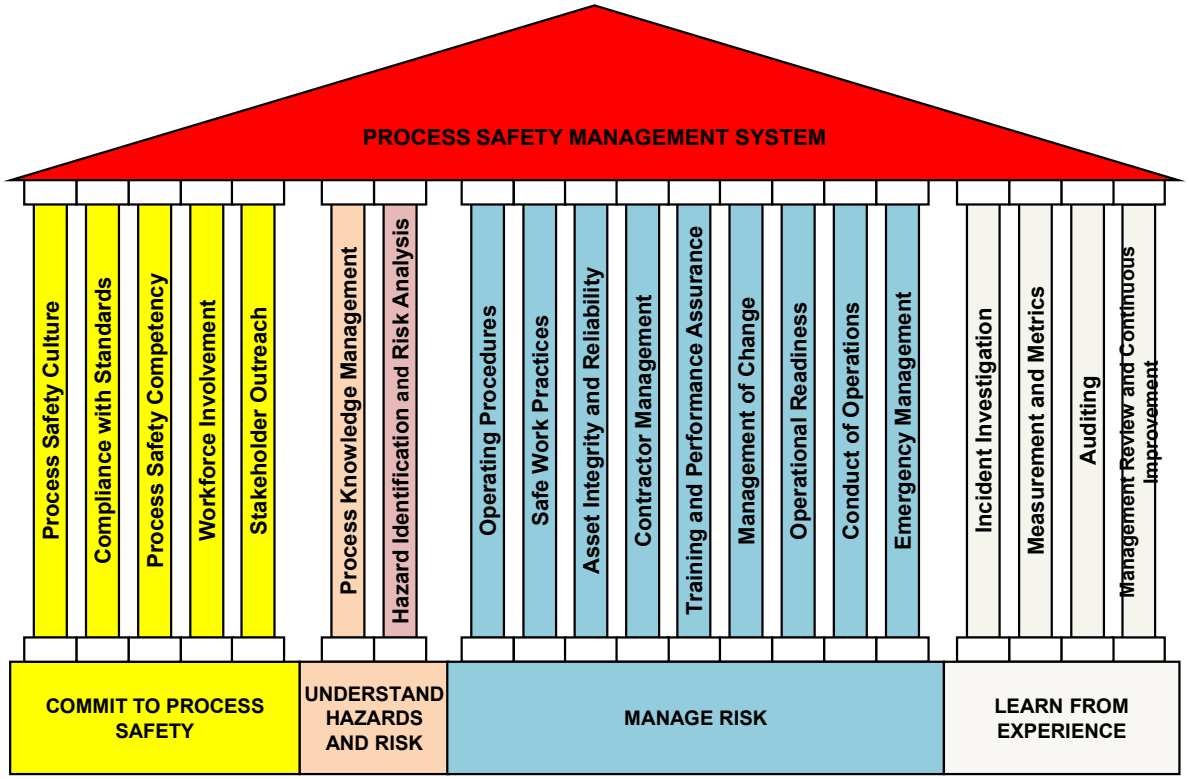
AcuTech
PROCESS RISK MANAGEMENT

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



OSHA v CCPS Risk Based Process Safety Management



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	

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

AcuTech
PROCESS RISK MANAGEMENT

Process Safety Management Lessons Learned (1984-2022)

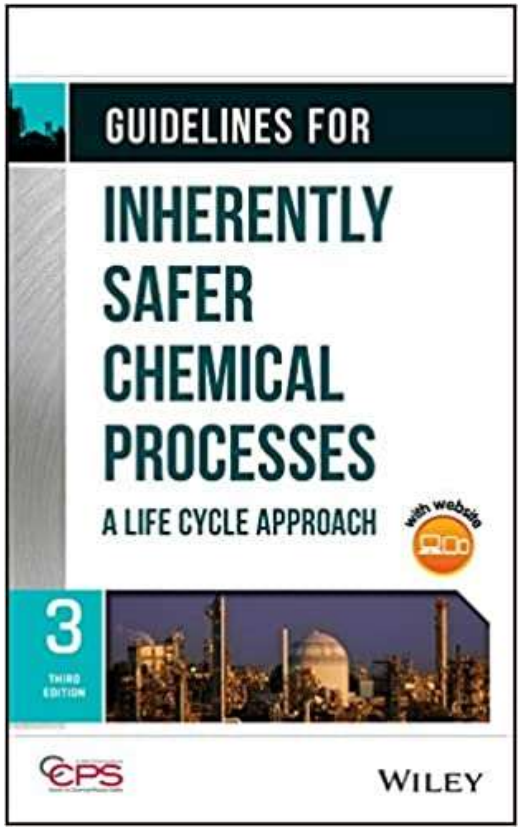
Knowledge and Competence	All around competence is imperative to properly execute
Operational Discipline	Continuous operational discipline and conduct of operations
Leadership Commitment	Supportive and engaged leadership to PSM
PSM Culture	Developing and sustaining a culture specific to PSM conducive
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

AcuTech
PROCESS RISK MANAGEMENT

Build Resilient Infrastructure, Promote inclusive and Sustainable Industrialization and Foster Innovation*

- **AIChE "Guidelines for Inherently Safer Chemical Processes", a reference on how to reduce hazards by Substitution, Moderation, Minimization, and Simplification**

*UN Sustainability Goals



"… the concepts of inherently safer design apply also to protection of the environment, industrial hygiene, and the disposal of waste. The twenty-first century challenges of sustainable development will require the adaptation and evolution of existing design principles and methods as process engineers are faced with developing new processes, not just the optimization of old ones.

Inherently safety design will be a key contributor to success in meeting these challenges as well as those related to the continuing search for alternative energy sources."*

* Process Plants Handbook for Inherently Safer Design Second Edition

Hydrogen Value Chain PSM

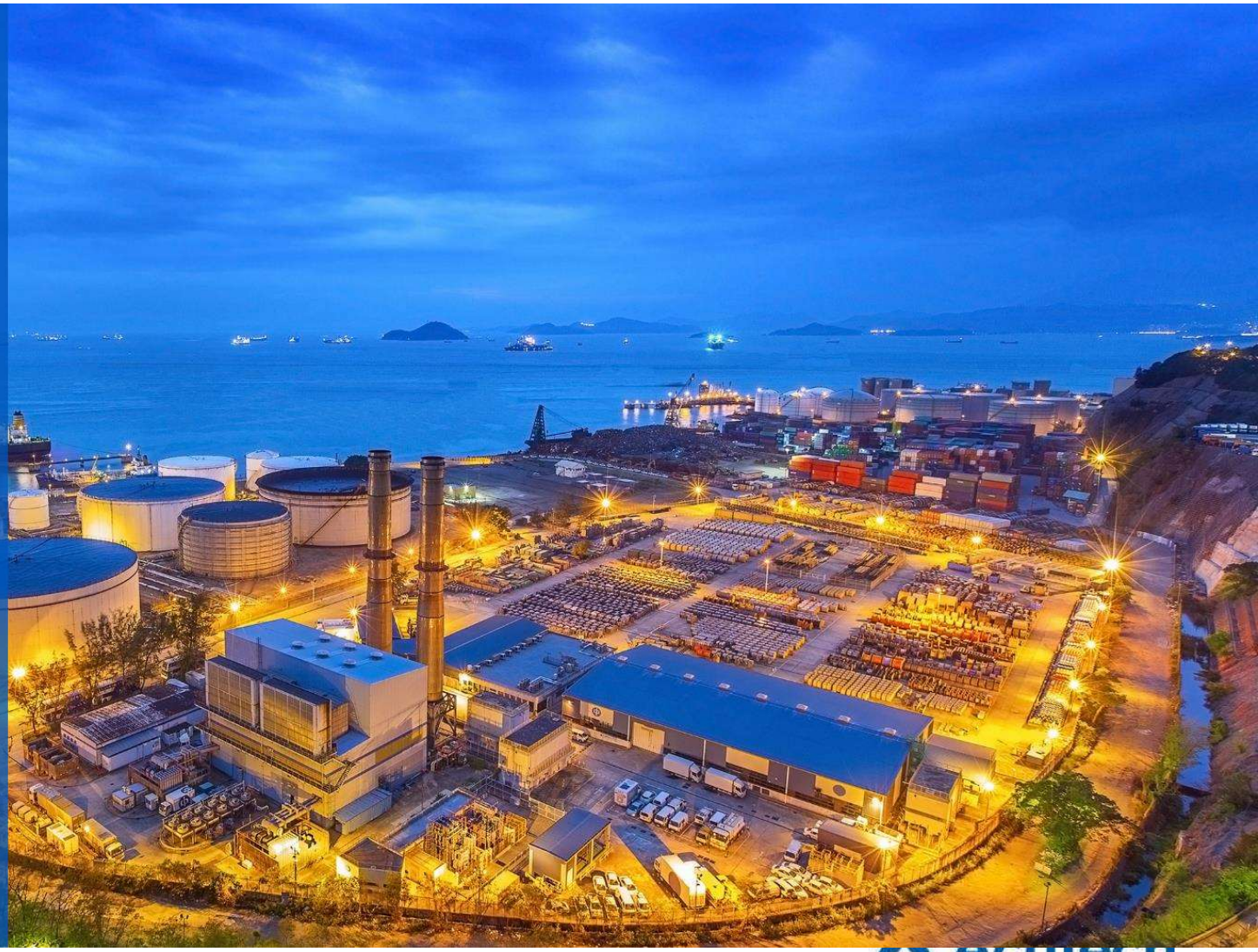
- Risk Assessment and Management
- Process Hazard Analysis (PHA)
- Transportation Risk Assessment
- Quantitative Risk Assessment (QRA)
- Consequence Modeling
- Safety Mgmt System Development and Culture
- Asset and Mechanical Integrity
- Emergency Management
- Physical and Cyber Security
- Management Systems (SMS)
- Critical Infrastructure Protection

AcuTech
PROCESS RISK MANAGEMENT

Quantitative Risk Assessments (QRA)

Methods to assess risk:

- Assessment of a full range of hazards and risks to workers and the public
- Detailed frequency analysis to consider safeguards/mitigation
- Inform leadership of risks
- Detailed results that identify risk drivers and allow for actionable risk reduction



Acutech
PROCESS RISK MANAGEMENT

Auditing PSM

- Auditing provides assurance of compliance to standards and a measure of the strength of the PSM culture
  - *Auditing Process Safety Management Systems*
  - *Essential Practices for Creating, Strengthening & Sustaining Process Safety*

- Auditing Scope
  - Complete PSM Compliance
  - Culture
  - Mechanical Integrity
  - Best Practice

AcuTech
PROCESS RISK MANAGEMENT

Example Hydrogen PSM

- Hydrogen siting study
- Venting dispersion modeling
- Hydrogen quantitative risk assessment
- Electrolyzer process hazard analysis
- HAZOP for liquid hydrogen tank installation
- Risk assessment of tube trailer installation for fuel distribution

AcuTech
PROCESS RISK MANAGEMENT

Presentation Summary

- Industry experience of over 40 years of PSM has shown that it has positively changed the way safety is managed and is necessarily deeply integrated into day-to-day operations.
- The application of a PSM framework to hydrogen operations applies throughout the lifecycle and ecosystem
  - Manufacturing of hydrogen.
  - Transportation.
  - Use of hydrogen as a fuel
- It is recommended to influence the design and use of PSM systems to ensure application is established early in the history of the widespread use of hydrogen as a fuel

AcuTech
PROCESS RISK MANAGEMENT

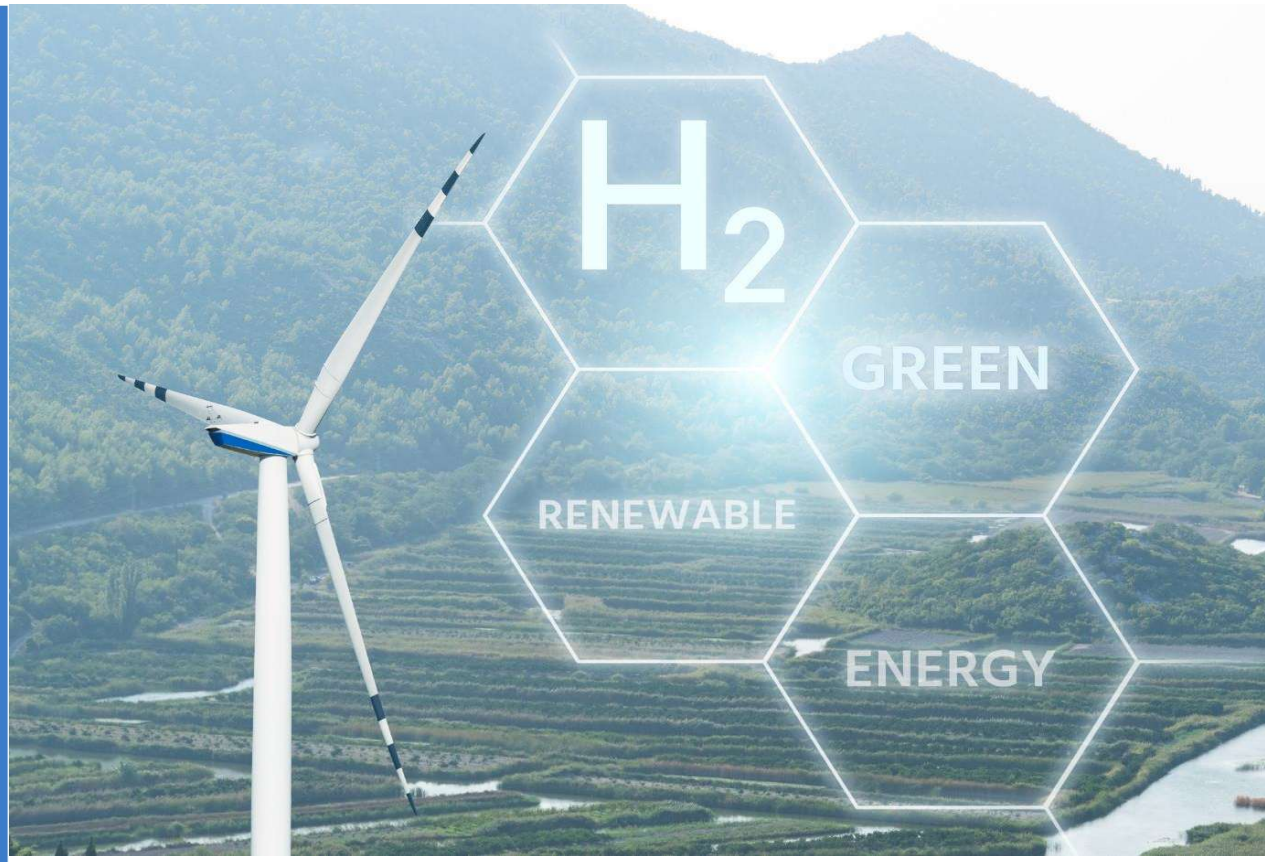
Thank You and Questions

Contact Us

AcuTech Group, Inc.
Washington, DC
Corporate Headquarters
AcuTech Consulting Group
1919 Gallows Road, Suite 900
Vienna, VA 22182 USA

Global Offices

Washington DC – Dubai
Shanghai – Mumbai
Singapore – Doha
Al Khobar



AcuTech
PROCESS RISK MANAGEMENT