AcuTech

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PROCESS SAFETY
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Process Safety Culture for Hydrogen Operations

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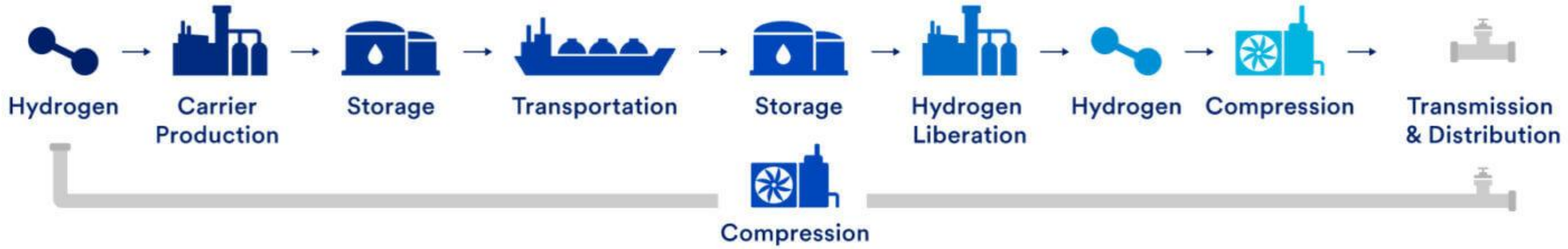
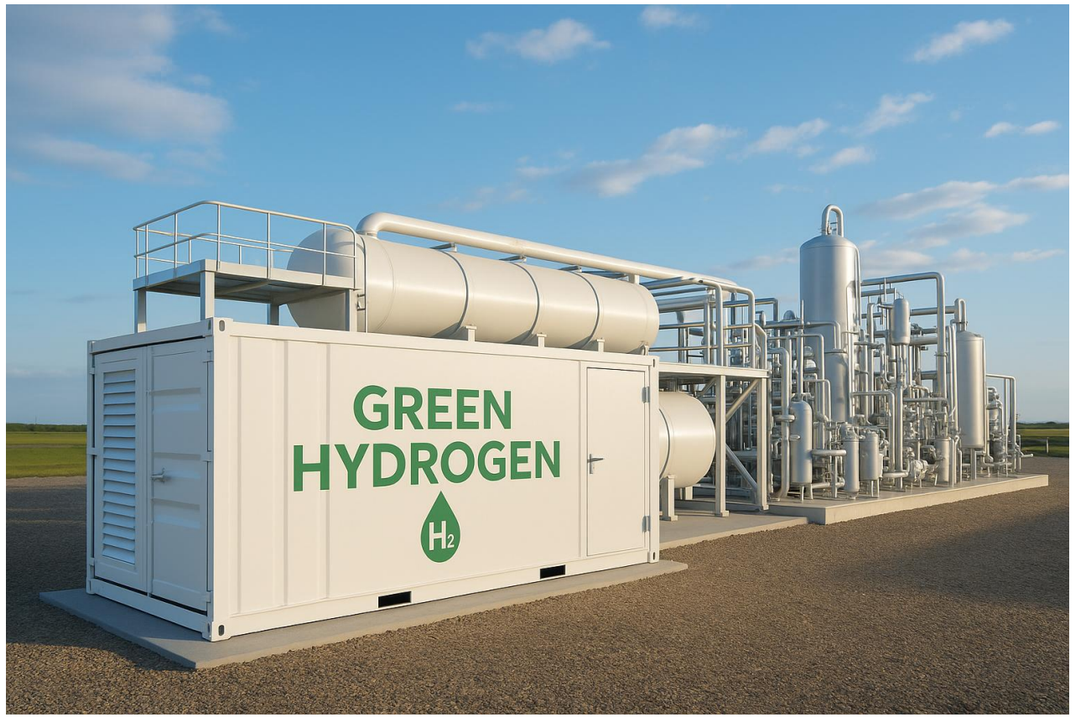
Hydrogen for Decarbonization – Safety Challenges

- 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.



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.



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 EPSC members, 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.

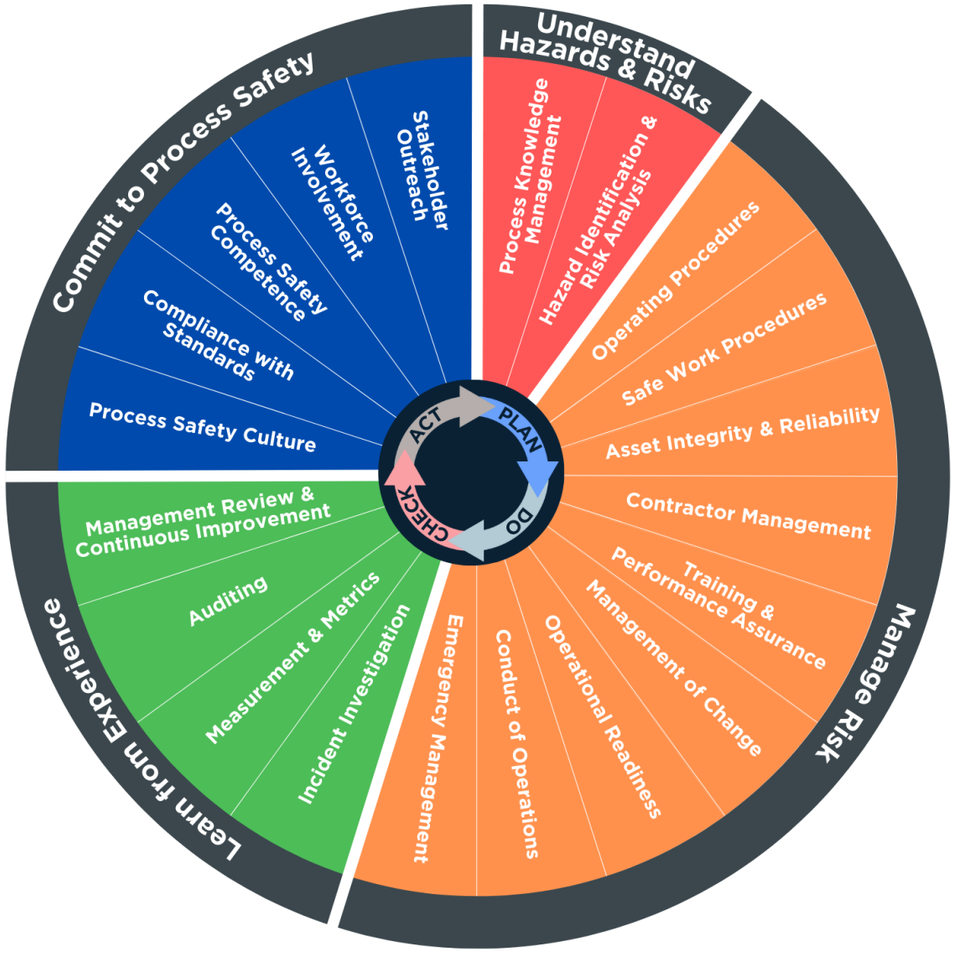
Concerns With Hydrogen Operations from Audits

- Companies with no operating experience planning to own and operate and manage hazards with insufficient process safety competency
- New designs and 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.

Recognition of Process Safety Culture

Mar 20, 2007

U.S. Chemical Safety Board Concludes "Organizational and Safety Deficiencies at All Levels of the BP Corporation" Caused March 2005 Texas City Disaster That Killed 15, Injured 180

Full Board to Weigh Recommendations to OSHA, Oil Industry, BP, and Union to Improve U.S. Refinery Safety at Public Meeting Tonight

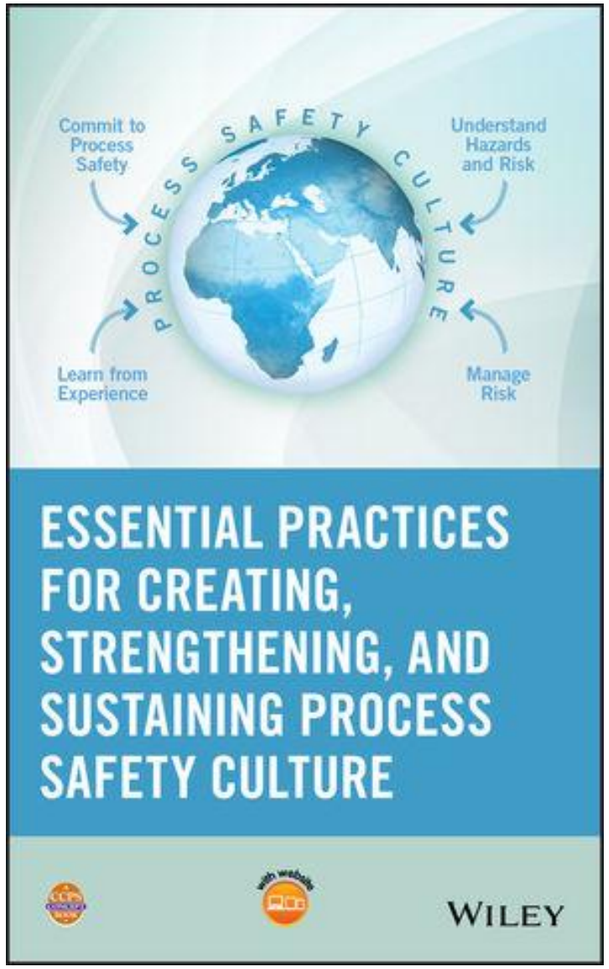
UPDATED 9:30 p.m. CDT March 20, 2007, Texas City, Texas - At a public meeting here tonight attended by more than 200 people, the U.S. Chemical Safety Board (CSB) voted 5-0 to approve its final report on the March 2005 explosion at the BP Texas City Refinery, the worst U.S. industrial accident since 1990. The full text of the report and safety recommendations will be posted on CSB.gov within the next week.

CSB Chairman Carolyn W. Merritt said: "With the vote tonight, we embark on seeking the most significant safety improvements ever pursued by this agency. The 15 men and women who died here two years ago must not be allowed to perish in vain. Their lives, their dreams, and their hopes - and the manner in which they lost them - must never be forgotten."

Houston, Texas, March 20, 2007 - In a 335-page final report released today, federal investigators from the U.S. Chemical Safety Board (CSB) conclude that "organizational and safety deficiencies at all levels of the BP Corporation" caused the March 23, 2005, explosion at the BP Texas City refinery, the worst industrial accident in the United States since 1990. The report calls on the U.S. Occupational Safety and Health Administration (OSHA) to increase inspection and enforcement at U.S. oil refineries and chemical plants, and to require these corporations to evaluate the safety impact of mergers, reorganizations, downsizing, and budget cuts.

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."

Warning Signs of Catastrophes

Slow management response to process safety concerns.	Important KPIs not monitored or not believed.	Allowing process information to become inaccurate/out-of-date.
A lack of trust in field supervision.	Employee surveys give negative feedback on process safety.	Conflicting job priorities.
Conflict between production goals and safety goals.	Process safety under-resourced.	Strained communications between management and workers.
Overdue process safety action items.	Inspection, testing and preventive maintenance tasks are chronically overdue.	Normalization of deviance allowed to persist.

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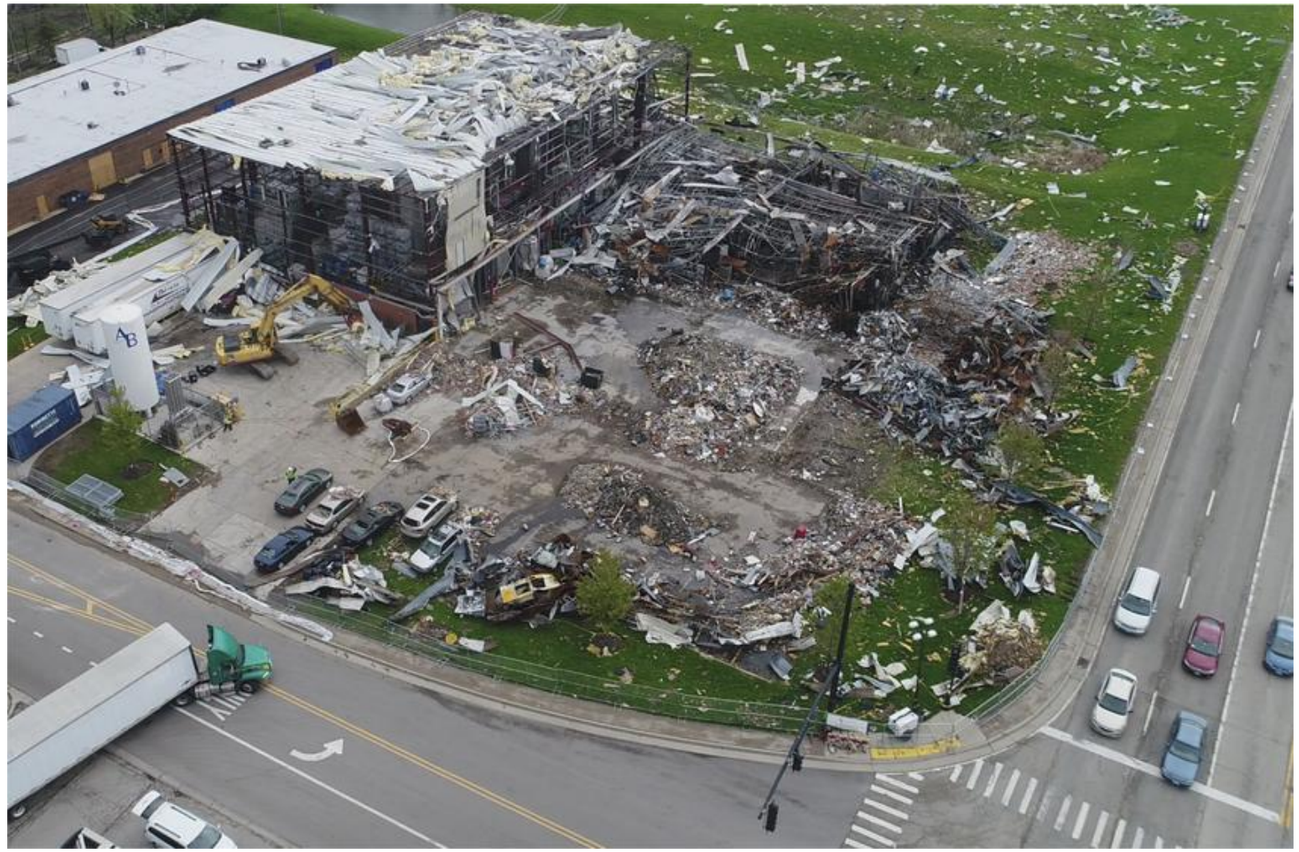
Prepare the Culture for Hydrogen Safety

- 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



Process Safety Maturity Levels

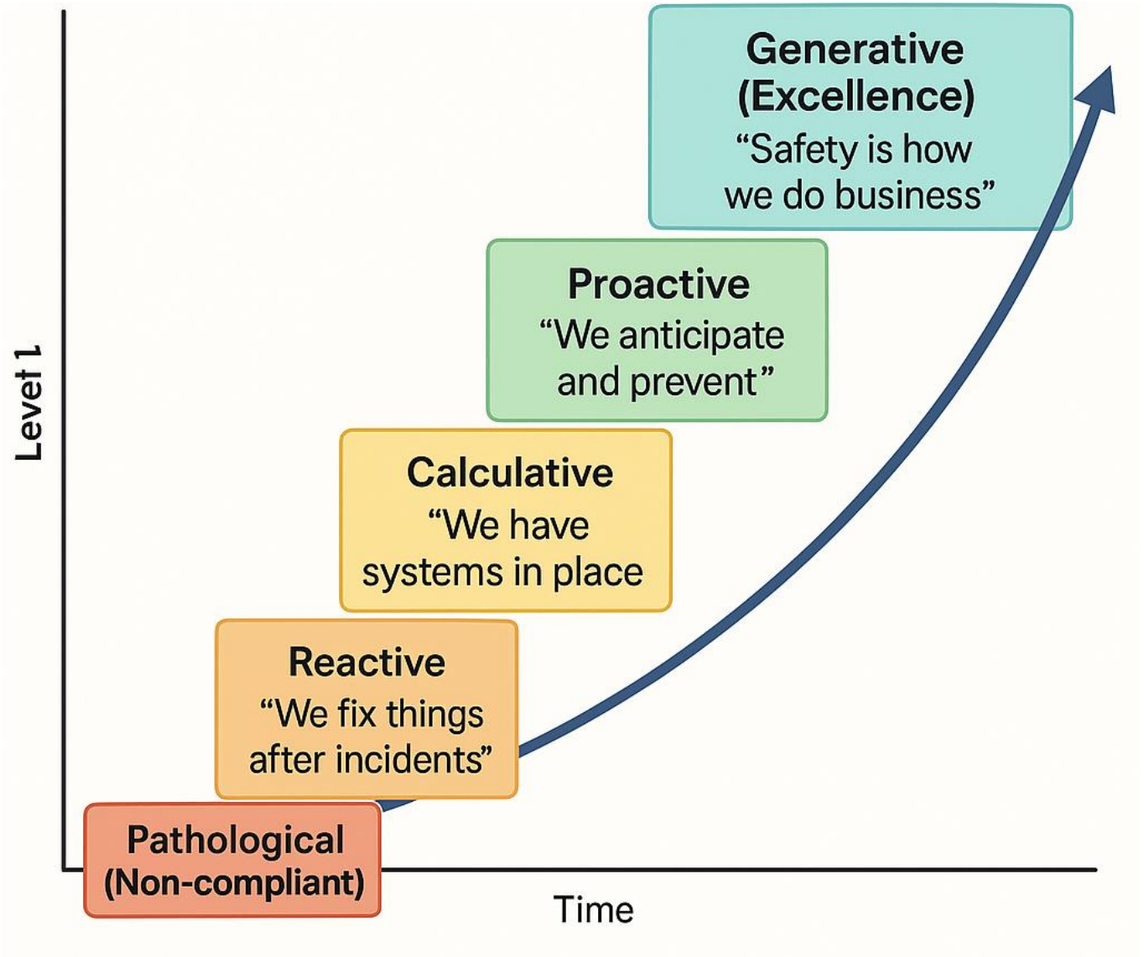
Level 1 – Pathological (Negligent)
- **Attitude**: Safety is seen as a burden or a regulatory checkbox.
- **Characteristics**:
  - Minimal compliance with PSM standards.
  - Safety incidents are ignored or hidden.
  - No learning from past events.

Level 2 – Reactive
- **Attitude**: Safety is only addressed **after** something goes wrong.
- **Characteristics**:
  - Lessons are learned the hard way.
  - Incident investigations are performed, but with blame focus.
  - Safety seen as the safety team's job.

Level 3 – Calculative (Systematic)
- **Attitude**: Systems are implemented, but behavior is compliance-based.
- **Characteristics**:
  - Formal PSM systems are in place (e.g., MOC, PHA).
  - Safety metrics tracked, but culture may be bureaucratic.
  - Leadership may support safety, but inconsistently.

Level 4 – 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.

Level 5 – 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.



CCPS RBPS v PSM Culture Principles

Example of CCPS PSM RBPS Model v Implementation in the Hydrogen Industry
(AcuTech's Observations of the Application of Hydrogen as a Fuel for Decarbonization at Less Sophisticated Sites

RBPS Elements	Issues Observed
Applicability	- Planning to have just under the threshold quantity required by a regulation - Lack of a formal documented approach for applicabilty of the PSM system
Process Safety Culture	- Policy statement does not exist for process safety management - Contractors are not directly engaged in PSM system or culture - Employees are less aware of PSM policies and programs.
Conduct of Operations	- Policy statement does not exist for conduct of operations. - Lack of operating discipline. - Iconsistentcy across sites -Employees and/or contractors don't consistently follow procedures.
Compliance with Standards	- No requirement to ensure the design is compliant with codes and standards. - RAGAGEP not defined for hydrogen systems. - Known inconsistencies to codes and standards are tolerated
Process Knowledge Management	-Policy statement does not exist for process knowledge management. Expectation for minimum engineering deliverables not consistent with industry practice.
Process Safety Competency	-Policy does not exist for process safety competancy - Inadequate expertise in hydrogen engineering and PSM for hydrogen
Training and Performance	-Refresher training is not practiced at sites surveyed. Lack of refresher training emphasis may be due to short employee tenure.

High Reliability Organizations (HRO)

- High reliability organizations: have high consequence – low frequency risks.
- HROs manage and sustain almost error-free performance while operating the processes with these risks.
- The culture of HROs helps them achieve this success.
- Examples: commercial nuclear power, naval nuclear power, airlines & aircraft manufacturers, some hospitals/medical organizations.

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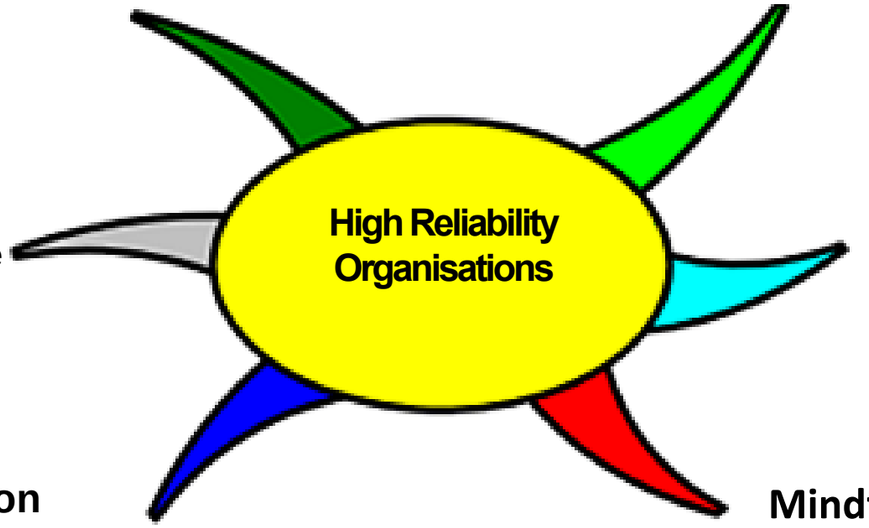
High Reliability Organizations (HRO)

Containment of Unexpected Events
Deference to expertise
Redundancy
Oscillation between hierarchical and flat/decentralized structures
Training and competence
Procedures for 'unexpected events

Just culture
Encouragement to report without fear of blame
Individual accountability
Ability to abandon work on safety grounds
Open discussion of errors



Problem anticipation
Preoccupation with failure
Reluctance to simplify
Sensitivity to operations

Definition
Tight coupling
Catastrophic consequences
Interactive complexity

Learning Orientation
Continuous technical training
Open communication
Root Cause Analysis of accidents/incidents
Procedures reviewed in line with knowledge base

Mindful Leadership
Bottom-up communication of bad news
Proactive audits
Management by exception
Safety-production balance
Engagement with front-line staff
Investment of resources

Source: UK HSE

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Characteristics of HROs

HROs exhibit mindful leadership			
Proactive commissions of audits to identify problems in the system (often in response to incidents that occur in other similar industries).	“Bottom-up” communication of bad news.	Engagement with front line staff through site visits.	Investment of resources in safety management and the ability to balance profits with safety.

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Characteristics of HROs

- The tolerance for not following approved procedures, bypassing change control processes, and other deviances is very low.
- High levels of *accountability* with expectations regarding strict adherence to procedures and where substandard performance is not tolerated
- HROs “face the facts” all the time.
- Govt regulation of HROs is close - over time, the employees tend to regard the close oversight as a normal rather than a burden.
- Operations are executed the same way every time even when the supervisors and inspectors are not around.
- HROs have learned how to delegate authority down to the lowest level in the organization–strong emergency shutdown and stop work authorities for front-line personnel.

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Core Principles of Process Safety Culture

Establish an Imperative for Safety

Provide Strong Leadership

Maintain a Sense of Vulnerability

Understand and Act Upon Hazards/Risks

Empower Individuals to Successfully Fulfill their Safety Responsibilities

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CCPS RBPS v PSM Culture Principles

Core Principle → / RBPS Element ↓	Establish an Imperative for Safety	Provide Strong Leadership	Maintain a Sense of Vulnerability	Understand and Act Upon Hazards/Risks	Empower Individuals to Successfully Fulfill their Safety Responsibilities	Defer to Expertise	Ensure Open and Frank Communications	Foster Mutual Trust	Combat the Normalization of Deviance
PSM Program Applicability	X	X	X	X		X			
Process Safety Culture	X	X	X	X	X		X	X	X
Process Safety Competency					X	X			
Compliance with Standards						X			X
Process Knowledge Management				X	X				X
Workforce Involvement					X		X	X	
Hazard Identification and Risk Analysis			X	X			X		X
Operating Procedures							X		X
Safe Work Practices	X	X	X	X	X		X		
Asset Integrity and Reliability	X	X				X	X		X
Contractor Management				X	X		X	X	X
Training and Performance Assurance					X	X	X		
Operational Readiness				X			X		X
Conduct of Operations	X	X			X		X	X	
Management of Change	X	X	X	X			X		X
Emergency Management			X	X	X				X
Incident Investigation	X	X		X	X			X	X
Measurement and Metrics		X		X			X		X
Auditing				X			X		X
Management Review and Continuous Improvement				X			X		X

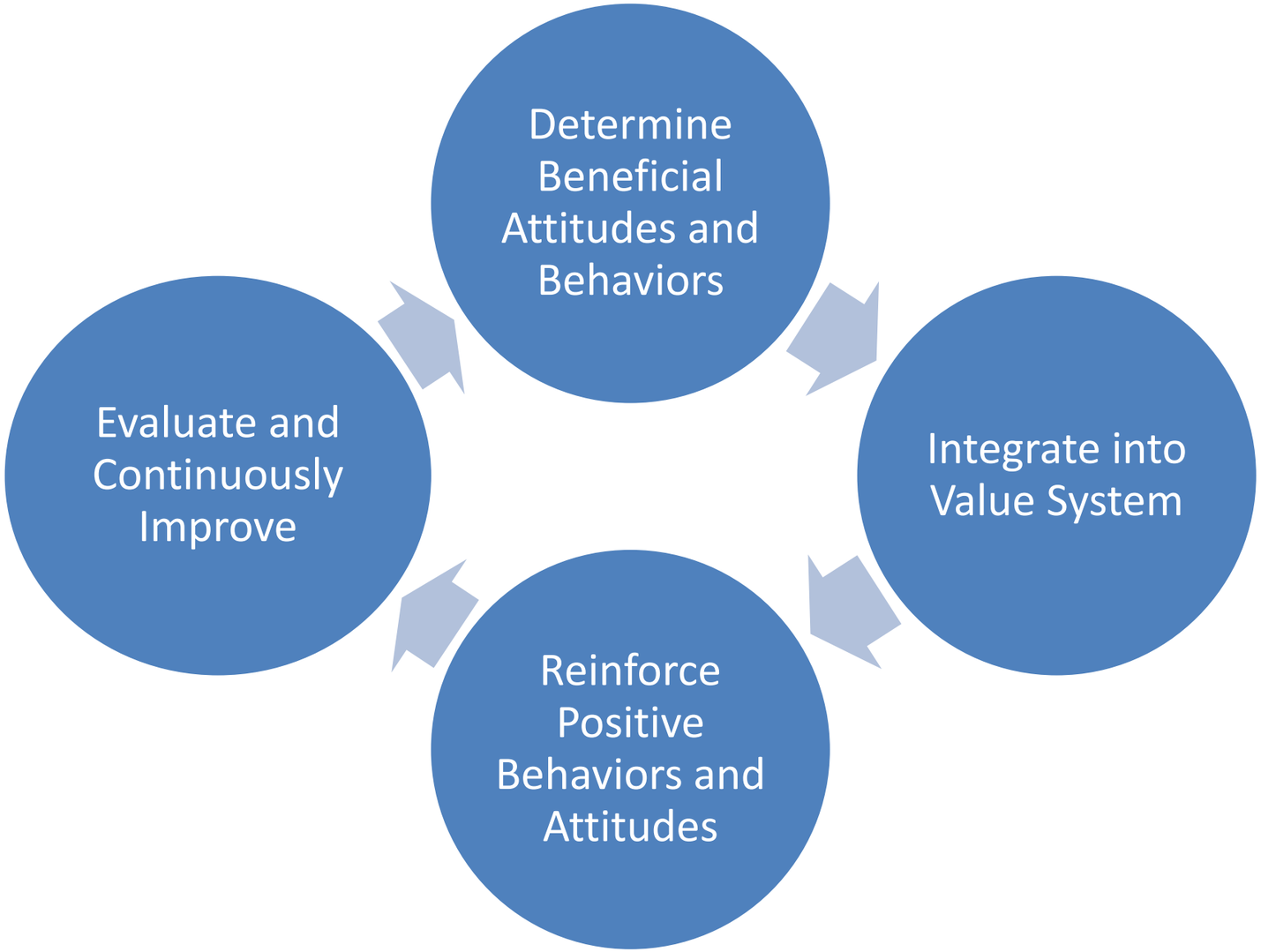
Key Building Blocks of Corporate Culture

Reflection and Improvement

"Sense of vulnerability and goal of excellence"

- Sense of vulnerability leads to healthy attitude on risk
- Continual improvement mindset
- Honest appraisal and acceptance of change
- Positive outlook rather than criticism
- Goal oriented to "excellence"

CCPS PSM Culture Lifecycle



Element Score	Description of Element Implementation and Functionality	Maturity Level
Above 90%	The element demonstrates best practice performance	Leading
80% to 90%	The element is implemented and functional	Integrated
60% to 80%	The element is implemented and partly functional	Functional
Below 60%	The element is not implemented and not functional	Informal

Benchmarking and Goal Setting for Successful Performance

- PSM culture should be analyzed (baseline) and then monitored for status/improvement.
- AcuTech uses a maturity scale as a way to define relative performance of the entire system and to set goals for improvement, including for PSM Culture.
- Periodic audits and employee surveys are useful tools to monitor progress.

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

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