



Photo Courtesy of Phynix

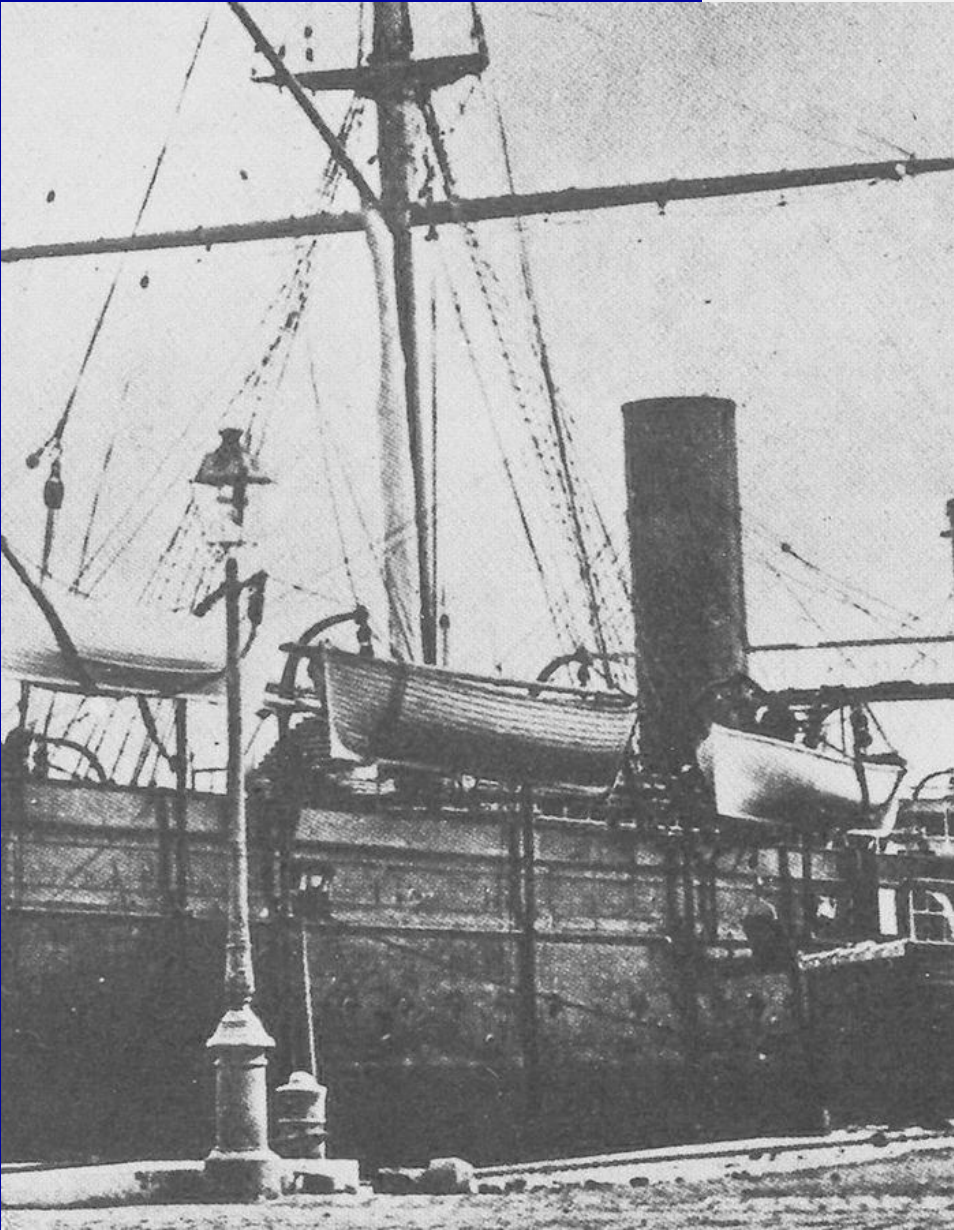
MAH H₂ Risk

13 May 2026

EUR ING Pim Reuderink DBA FIGEM



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Introduction

Bureau Veritas



Shaping the world of trust started in the Netherlands in 1828

KEY FIGURES



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billion

FY 2024



84 250
employees



400,000+
clients



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IN 140 COUNTRIES



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Understanding
human roles
influencing safety in
hydrogen facilities

HUMAN FACTORS IN MAJOR ACCIDENT RISKS OF GIGA-SCALE HYDROGEN PLANTS AND LARGE-SCALE H2 STORAGES

PEOPLE ARE NOT SOURCES OF FAILURE, THE SYSTEM FAILED!

Upscaling hydrogen is scaling up safety parallel, so raise the bar from prior learning as hydrogen is not new.....

EUR ING Pim Reuderink DBA CSci



WHAT THE ACADEMIC LITERATURE SAYS ABOUT HUMAN FACTORS

The human factor is unpredictable, but we try to predict the behaviour of persons in an environment



Role of Human Factors

Human and organizational factors are critical in causing and escalating major hydrogen accidents.



Common Human Failures

Failures include poor maintenance, inadequate training, weak supervision, and procedural lapses.



Implications for Safety Systems

Safety arguments must integrate human factors explicitly in hazard analyses and management systems.



GIGA-SCALE HYDROGEN PLANTS AND MAJOR ACCIDENT HAZARDS

Scale and Risk Profile

Giga-scale hydrogen plants handle massive energy throughputs and pressures, raising major accident hazards beyond typical installations.

Hydrogen Physical Hazards

Hydrogen's wide flammability limits, low ignition energy, and high diffusivity increase accident risk in large plants.

Human and Organizational Factors

Accidents often arise from interactions between technology, human behavior, and organizational decisions, requiring robust safety management.

Regulatory and Safety Requirements

Giga-scale plants must meet upper-tier Seveso/COMAH standards, demonstrating risk control and ALARP principles effectively.



Bow-Tie: Loss of Containment of High-Pressure Hydrogen

— MAH RISK 1

Are we hydrogen ready?



THREATS AND PREVENTIVE HUMAN BARRIERS

Human Factors in Threats

Human errors such as incorrect assembly and maintenance mistakes are primary initiators of hydrogen containment failures.

Organizational Influences

Failures in management, inspection, and oversight contribute significantly to undetected material degradation and operational deviations.

Preventive Safety Barriers

Effective preventive barriers require human reliability, including adherence to procedures, independent checks, and competence management.

Case Study Illustration

The 2019 Kjørbo hydrogen station explosion highlights how human assembly errors can defeat certified safety designs.



CONSEQUENCES AND MITIGATIVE HUMAN BARRIERS

Potential Consequences

Hydrogen loss can cause jet fires, explosions, domino effects, and off-site thermal or pressure damage.

Technical Mitigative Barriers

Gas detection, automatic isolation, emergency shutdown, and fire protection systems control and mitigate hazards.

Human and Organizational Factors

Effectiveness of mitigation depends on correct system use, maintenance, training, and leadership under stress.

Importance of Safety Management

Safety cases must ensure mitigative systems are trusted, maintained, and properly operated in all scenarios.



Bow-Tie: Hydrogen– Oxygen Mixing in Electrolyser Systems

MAH RISK 2

Are we hydrogen ready?





OPERATIONAL THREATS AND PREVENTIVE BARRIERS



Operational and Organizational Threats

Critical risks in electrolysers system from operating beyond safe limits and deferred maintenance causing hazards.

Human-Dependent Preventive Barriers

Preventive measures like operator training and defined safety envelopes rely heavily on human behavior and management systems.

Lessons from Gangneung Explosion

Unsafe operation below minimum load caused oxygen contamination leading to a fatal hydrogen explosion in 2019.

Risk Influence by Operator Behavior

Probabilistic risk assessments show operator adherence to limits significantly impacts large hydrogen facility safety.



CONSEQUENCES AND MITIGATION OF INTERNAL EXPLOSIONS

Hazards of Internal Explosions

Internal explosions from hydrogen–oxygen mixing can cause destruction, fatalities, and escalation to storage systems.

Mitigation Barriers

Mitigative measures include automatic shutdowns, pressure relief, venting systems, and emergency response protocols.

Human Factors and Safety Culture

Effective safety relies on human response, training, maintenance, and a culture of learning and conservative operation.

Bow-Tie: Interface and Organizational Failures



MAH RISK 3

Are we hydrogen ready?



INTERFACE THREATS AND PREVENTIVE GOVERNANCE BARRIERS



Human-Factor Interface Hazards

Interface failures at battery limits and simultaneous operations pose significant human-factor risks in large hydrogen plants and storage sites.

Organizational Threat Origins

Ambiguous responsibilities and conflicting procedures stem from organizational challenges across multiple operators and contractors.

Governance as Preventive Barrier

Governance mechanisms like clear responsibility matrices and unified permit-to-work systems are critical for safety prevention.

Interface Management Importance

Interface management requires senior management ownership to prevent coordination failures undermining technical systems.

CROSS-CUTTING HUMAN FACTORS INSIGHTS AND SAFETY CASE IMPLICATIONS



Human and Organizational Barriers

Human and organizational barriers are often the weakest yet most crucial elements in preventing safety escalation.

Socio-Technical Safety Management

Safety must be managed as a socio-technical property integrating human judgment with technological systems.

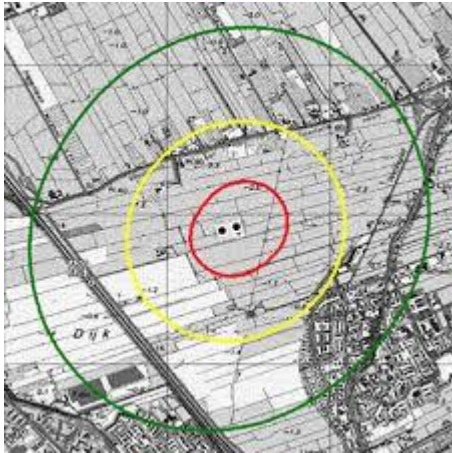
Regulatory and Competence Expectations

Safety cases require explicit human factors identification and evidence of competence, supervision, and learning.

Aligning Technical and Organizational Excellence

Effective risk control depends on aligning technical excellence with organizational maturity and learning.

PROCESS SAFETY PRACTICE



Source: RIVM.NL

Sociotechnical Barriers

Recent work on domestic hydrogen futures highlights sociotechnical barriers including policy misalignment, infrastructure lock-in, uneven governance capacity, and contested transition pathways.

Safety as a Socio-Technical Property

Conceptual work on hydrogen refuelling and related systems frames safety as the product of interactions among equipment, operators, organisational design, procedures, and safety culture.

Public Perception and Social Acceptance

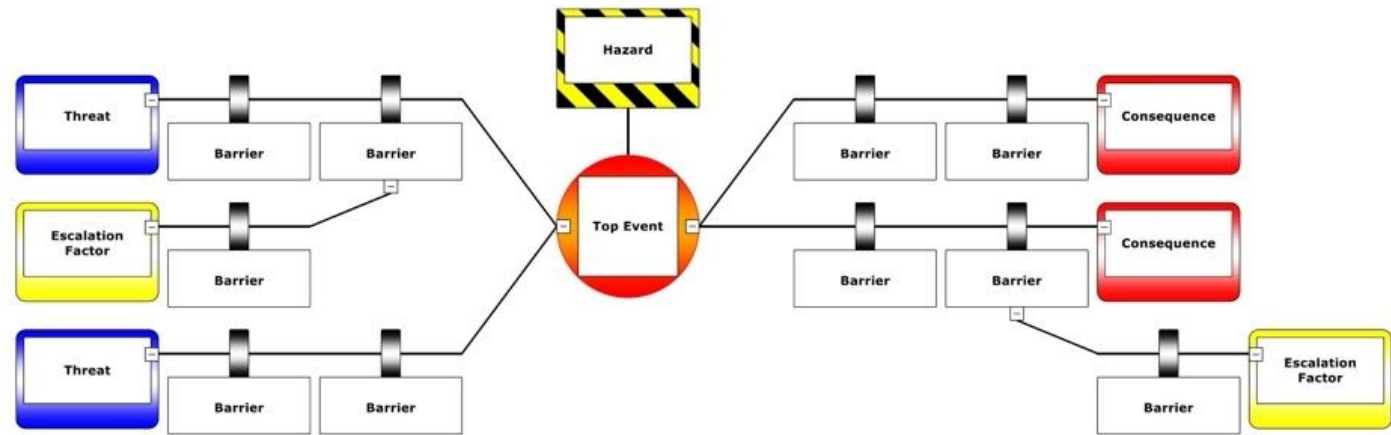
Studies on hydrogen acceptance indicate that local opposition is often shaped by unfamiliarity, media framing, trust, and perceived fairness rather than by technical risk metrics alone.

Implication for Projects

For giga-scale plants, public communication, stakeholder engagement, and transparent risk explanation should be treated as integral parts of human-factors strategy rather than as external communications only.

BOW TIE

Be prepared!



EMERGENCY READINESS



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FINAL THOUGHTS

WHAT YOU CAN APPLY TOMORROW



RAND Europe / TOTAL (2016)

This landmark report argues that major accident prevention should move beyond simplistic “human error” narratives toward systemic human and organisational factors, including reporting culture and task design.

Safety Critical Task Analysis

Industry work on Safety Critical Task Analysis shows how MAH safety cases can identify and manage tasks whose failure could defeat major-accident barriers.

Accident Investigation Foundations

Human-factors literature in accident investigation emphasises cognitive, physical, and organisational interactions, including human–machine interface and supervisory influences.

Implication for Hydrogen Safety Cases

These references support a more academic framing of hydrogen bow-tie analysis by linking barrier performance to task design, competence assurance, reporting culture, and organisational learning.

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THANK YOU – Q&A



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