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Bridging the Gap: Managing Process Safety in Scaling Novel Technologies

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ABSTRACT

Scaling novel technologies from the laboratory to pilot-scale presents significant process safety challenges. Unlike mature industries, these technologies often lack historical safety data, well-defined design standards, and established risk management frameworks.

Additionally, *Safety in Design* as defined in the Work Health and Safety Act 2011 is often unfamiliar to both researchers developing the technology and the countries where these technologies originate. Consequently, integrating process safety into early-stage development is often overlooked, leading to knowledge gaps in the safe design of the technology that become apparent only during scale-up.

This paper will explore the lessons learnt in the scale-up of a reactor membrane used in the production of a liquid hydrogen carrier, focusing on the following key themes:

Flexible Application of Risk Assessment Tools—Risk assessment tools must be integrated into technology development rather than treated as standalone workshops. When introduced early in design, mature risk assessment methods exposed critical gaps in the researchers' knowledge, driving targeted test work and failure mechanism analysis. For example, the layers of protection analysis (LOPA) process was not a one-time workshop but an iterative process, evolving as new data emerged to resolve uncertainties or validate assumptions.

Complexity and Uncertainty in Failure Mechanisms—Novel technologies present unique failure modes and uncertain consequences. This paper will examine failure mechanism analysis for overtemperature and pinhole leaks in a specific membrane type. Prototype equipment often lacks comprehensive failure data, making cross-disciplinary expertise essential. Process safety assessments must ensure test results are thoroughly understood and effectively integrated to address complex failure scenarios.

Challenges and Opportunities in Research and Development (R&D)—Laboratory testing provides critical insights, enabling a data-driven approach to risk mitigation by assessing fundamental failure mechanisms early. However, risk management in R&D environments is challenging due to confidentiality constraints, such as restricted access to materials, fabrication techniques, and design details. Safety in design studies must be comprehensive, engaging all stakeholders while respecting these limitations. Additionally, traditional quantitative techniques often face constraints due to technical uncertainty, cost, and budget limitations.

Process safety in novel technologies requires a proactive, adaptive approach. Integrating risk assessment early, adopting an iterative process, and fostering cross-disciplinary collaboration enable companies to better anticipate and mitigate hazards. As industries push technological boundaries, refining safety frameworks for emerging technologies will be essential to ensuring safe, scalable, and commercially viable operations. This paper will propose a refined safety framework to support the ssafe development and scale-up of emerging technologies.

KEY WORDS

Process safety; Novel technologies; pilot-scale; risk assessment; failure mechanisms; safety in designl hydrogen safety

BIOGRAPHY

Thomas is a process and risk engineer at GPA Engineering, specialising in hydrogen technologies and process safety. Since completing his master's in large-scale hydrogen developments, he has supported GPA's future fuels portfolio, including delivery of some of Australia's operating hydrogen production and refuelling facilities, quantitative risk assessment for projects in development, and conducting compliance/safety assessments for novel technologies, including electrolyser and fuel cells for hydrogen and liquid derivatives (i.e., ammonia and methylcyclohexane). He maintains academic ties to the Dow Centre, Future Fuels CRC, and ME-093 and is passionate about advancing a commercially competitive and safely operated, future fuels economy.

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