Empowered *workforce*, Thriving *workplaces*

Regulatory Perspective on Cleantech Advancement

MINISTRY OF MANPOWER

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Contents

Towards Net-Zero Carbon Emissions

From fossil fuels to cleaner energy sources

WHAT IS IT?

The Shift

Moving from fossil fuel–based energy systems to cleaner, more sustainable, low-carbon energy sources to achieve a net-zero future.

WHY IT MATTERS

The Impact

Reduces greenhouse gas emissions, combats climate change, and fulfils net-zero commitments made by nations worldwide.

THE SOLUTION

Low-Carbon Fuels

Countries are diversifying to zero-emission sources — including hydrogen and ammonia (as an energy vector for hydrogen) — to decarbonise at scale.

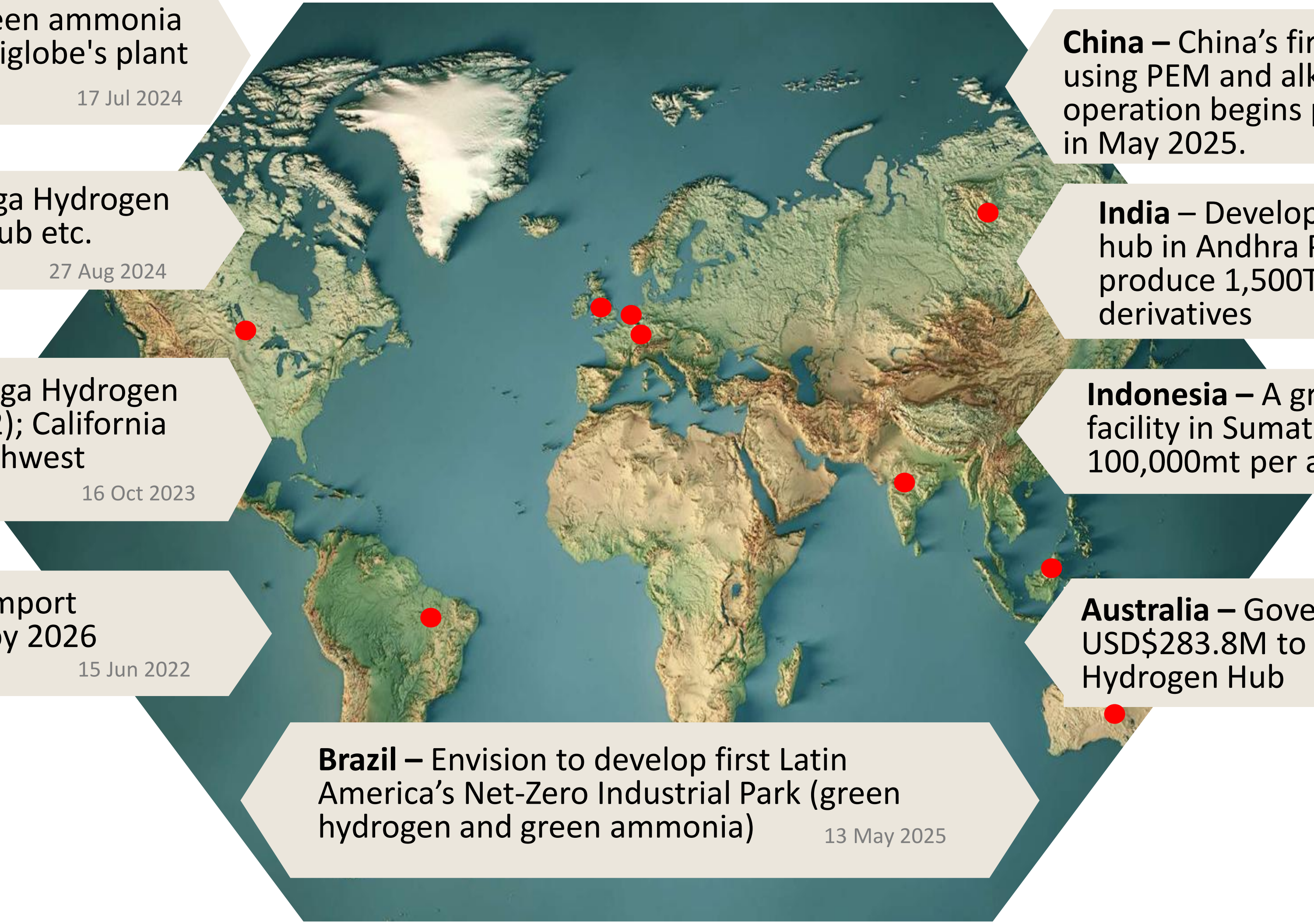
Rising global adoption of cleantech fuels to achieve Net Zero Emissions

Germany – 19,500mt green ammonia import in 2027 from Fertiglobe's plant in Egypt
17 Jul 2024

UK – Development of mega Hydrogen Hubs: Suffolk Hydrogen Hub etc.
27 Aug 2024

USA – Development of mega Hydrogen Hubs: Appalachian (ARCH2); California (ARCHES); and Pacific Northwest (PNWH2)
16 Oct 2023

Netherlands – Ammonia import terminals to be launched by 2026
15 Jun 2022



China – China's first green hydrogen project using PEM and alkaline electrolysers in joint operation begins production in Hubei province in May 2025.
6 May 2025

India – Development of green hydrogen hub in Andhra Pradesh state by 2032 to produce 1,500TPD and 7,500TPD of green derivatives
17 Jan 2025

Indonesia – A green hydrogen production facility in Sumatra capable of producing 100,000mt per annum
24 Oct 2024

Australia – Government to pledge USD$283.8M to support Hunter Valley Hydrogen Hub
4 Jul 2025

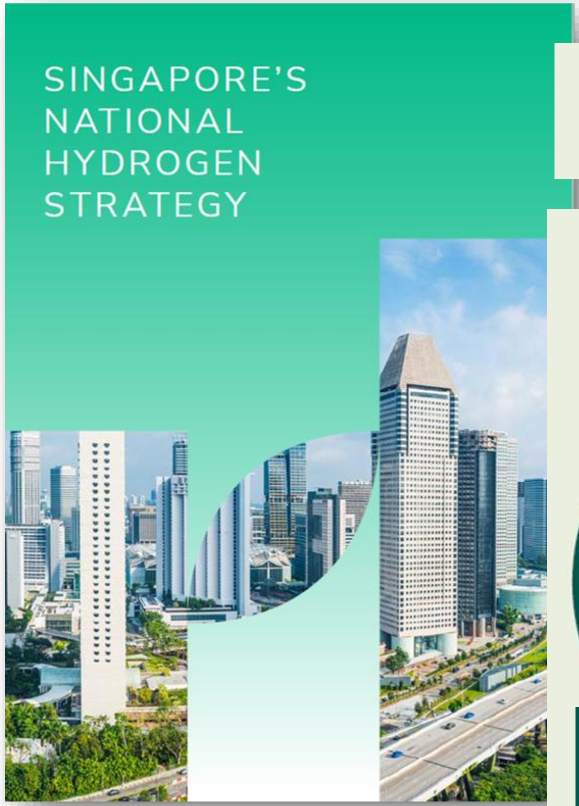
Brazil – Envision to develop first Latin America's Net-Zero Industrial Park (green hydrogen and green ammonia)
13 May 2025

Singapore has committed to Net Zero by 2050

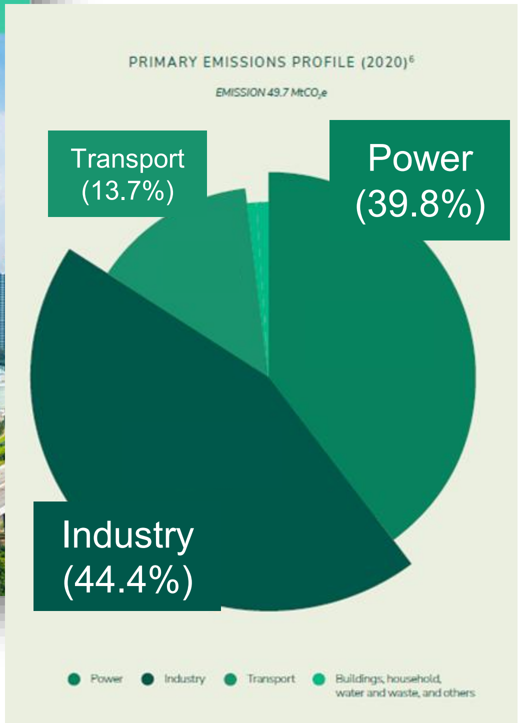
- Singapore has identified clean energy industry as a strategic growth area and is actively exploring adoption of low-carbon technologies, which offer a scalable decarbonisation pathway for Singapore

- **Hydrogen** plays an important role in decarbonising different sectors in Singapore

- Companies are encouraged to consider alternative energies, for a more sustainable manufacturing, including the use of **hydrogen** and **ammonia**



Towards Net Zero, what are the key areas to reduce emissions?



Cleantech fuel developments driving Singapore's Net Zero Transition

Import and Distribution – Feasibility study to construct **hydrogen** pipeline between Malaysia and Singapore

Transport – **Hydrogen** transportation solutions (e.g. using pipelines, trailers, other novel tech such as using metal hydrides

R&D – Low-Carbon Energy Research (LCER) projects hosted by Agency for Science, Technology and Research (A*STAR) to support research, development and demonstration projects to advance **low-carbon technologies**

R&D – National University of Singapore's (NUS) Centre for Hydrogen Innovations to support research and development to make **hydrogen** a viable green energy source

Power – At least nine **hydrogen-**compatible power plants ready by 2030

Industry – Greening data centres operations with **hydrogen** power (e.g. use of hydrogen fuel cell)

Aviation – Completed technical feasibility study of an airport **hydrogen** hub

H2 Vehicles – Development of **hydrogen** refuelling station (HRS) and ongoing **hydrogen** fuel cell vehicles (HFCV) trials in Jurong Innovation District

Maritime – Developed distribution infrastructure and guidelines for bunkering for **ammonia & methanol**

Import and Distribution – Sembcorp and Indonesian gas transporters company exploring the establishment of a **hydrogen** pipeline linking Sumatra and Singapore

Cleantech fuels are not necessarily safer due to their inherent hazardous nature

Hydrogen

- ❑ Stored/ transported as compressed gas, cryogenic liquid or in solid hydride
- ❑ Produced using electrolysis, used in fuel cell and gas turbine

H H

- **Very flammable with low ignition energy**
- Difficult to detect with naked eyes due to pale blue flame
- High risk of explosion under confinement
- High diffusivity leads to material degradation, e.g. hydrogen embrittlement and high temperature hydrogen attack

Adopted from *Hydrogen & Energy Information Resource*

Ammonia

- ❑ Stored/ transported as compressed gas or cryogenic liquid
- ❑ Carrier of H2. Used in direct combustion or cracked to H2

N H H H

- **Very toxic**
- Ammonia gas can disperse over long distances
- Corrosive in nature and can lead to material degradation, e.g. stress corrosion cracking

Adopted from *Vopak Singapore*

Process Safety Risks associated with cleantech fuels

Unknowns in nascent technologies

- Hazards associated with novel approaches might not be fully understood (e.g. storage of hydrogen in metal hydrides)

Upscaling challenges

- Different risks dealing with commodity chemicals vs specialty chemicals
- Operational complexities (e.g. larger scale mitigative measures and emergency response requirements)

Degradation concerns

- Material degradation mechanism (e.g. hydrogen embrittlement)
- Limited data (e.g. temperature cycling on material fatigue)

Adopted from The Korea Times

Hydrogen tank explosion at Gangwon Technopark
In Gangneung, South Korea (23 May 2019)

Precautionary approach should be applied when there is greater uncertainty

The Workplace Safety and Health Act (WSHA) and its subsidiary legislations set out the legal framework to cover the safety, health and welfare of persons at work in a workplace

Occupiers and Employers to take reasonably practicable measures to ensure safety of the workplace, employees and others under the Workplace Safety and Health Act (WSHA) and Subsidiary Legislation.

Covers the **handling, storing, processing, manufacturing or use of any hazardous substances**, including hydrogen and ammonia.

WSH Subsidiary Legislations

The WSH subsidiary legislation provide detailed regulations and specific requirements that support the overarching WSHA. This includes:

- WSH (Risk Management) Regulations
- WSH (General Provisions) Regulations
- WSH (Incident Reporting) Regulations
- WSH (Safety and Health Management System and Auditing) Regulations
- **WSH (Major Hazard Installations) Regulations**

Leveraging Safety Case Principles to enable safe adoption of Low Carbon Fuels

Descriptive
Describe the plant and its environment

Safety & Health Management System
Systems in place to keep measures robust

Predictive & ALARP
Estimate consequences and the risk of hazards

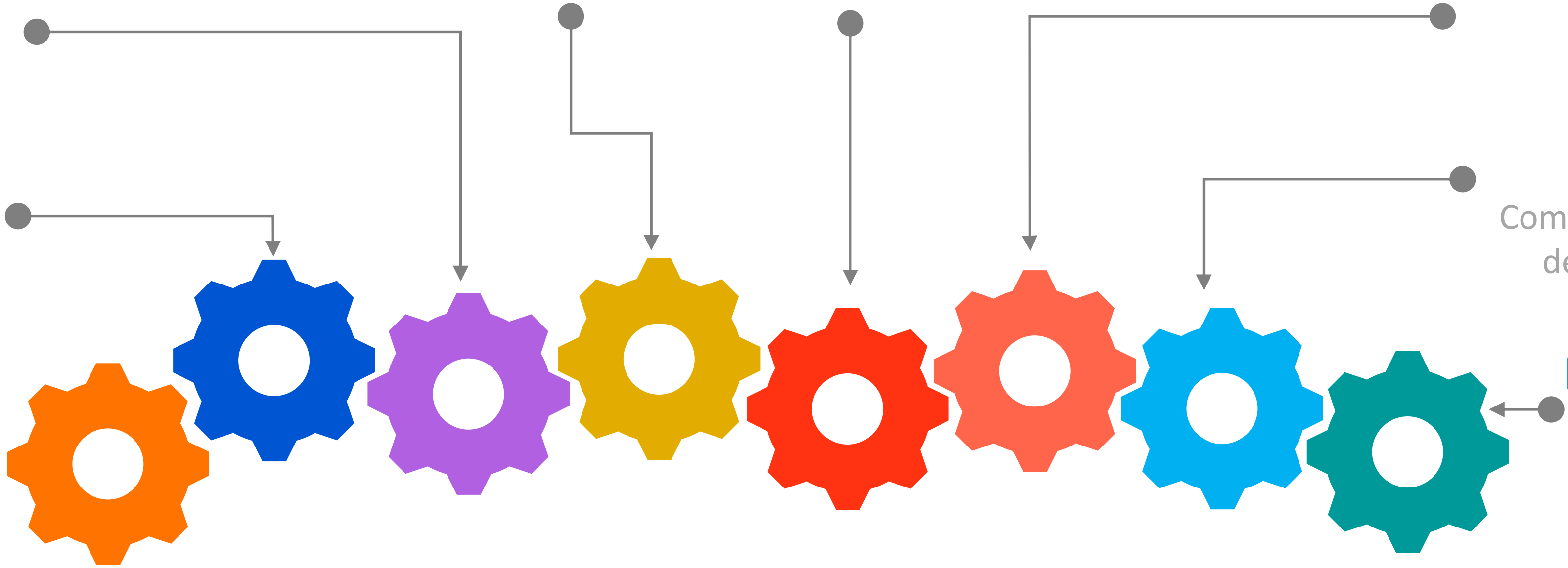
Process Safety
Redundancy, diversity, layout, containment, protection from excursions

Mechanical
Structural integrity, construction verification, maintenance protocols

Electrical Control & Instrumentation
Safety-related control systems, ignition control

Human Factors
Competency, performance and designs to prevent errors

Emergency Response
Plans and resources for emergency, and plans for de-inventorising



Details on the requirements of each component can be found under the **Safety Case Technical Guide** and **Safety Case Assessment Guide**

Hazard Identification and Reducing Risks to ALARP

Predictive & ALARP

Estimate consequences and the risk of hazards

Scope

- Identify **hazards** and their **causes**
- Predict the **consequences** and **frequencies** of major accidents using appropriate models.
- Assess **adequacy of risk reduction measures**

Other Considerations

- **Failure mechanisms** of new technologies may not be well known
- **Verify that modelling tools** is appropriate for purpose; advance modelling such as Computation Fluid Dynamics (CFD) may be required
- Source for relevant **failure and ignition data**

- Do you understand how your system works?
- Are you **fully** aware of the risk involved?
- Are you aware of incidents history relating to the technology?

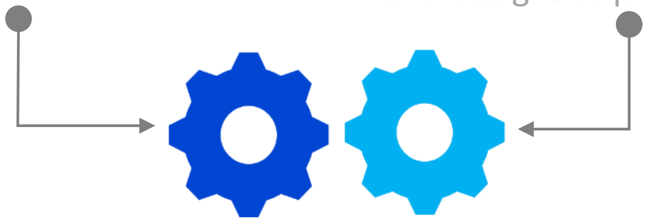
Accident Prevention Policy & Robust Management System

Safety & Health Management System

Systems in place to ensure measures are robust

Human Factors

Competency, performance and designs to prevent errors



Scope

- Established **personnel competency requirements** in oil and chemicals industry
- **Regular SHMS audits** to ensure effectiveness
- Designs focused on **minimising human errors**

Other Considerations

- Workforce needs to be trained in **risks and unique properties** associated with new technologies
- Insufficient competent personnel can **weaken SHMS**

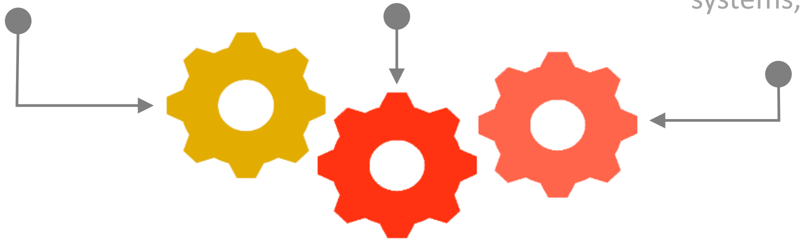
- Are all stakeholders equipped with the necessary knowledge to effectively manage hazards?
- Is the organisation aware of safety implications of design or procedural changes?
- Can the design address potential human errors? Can the system drive positive human behaviour?

Adequate Safe and Reliable Measures

Process Safety
Redundancy, diversity, layout, containment, relief, protection from excursions

Mechanical
Containment integrity, construction verification, maintenance procedures

Electrical Control & Instrumentation
Safety-related control systems, ignition control



Scope

- Evaluate **hierarchy of controls** to manage foreseeable hazards
- Demonstrate that the facility has been designed to **appropriate standards**
- Design **control measures** to protect against excursions beyond design conditions
- **Maintenance strategy** for equipment, instruments and controls

Other Considerations

- How to ensure safety is not compromised where design of novel technology is not covered by published codes and standards
- **Inherently safer design** and **automated interventions** should be implemented, where practicable
- **Materials selection** should be appropriate for conditions

- Are adequate controls and redundant instruments installed to monitor excursions and predict escalations?
- How to ensure safe process in the absence of established standards?

Adequate Emergency Response

Emergency Response

Plans and resources for emergency, and plans for de-inventorising

Scope

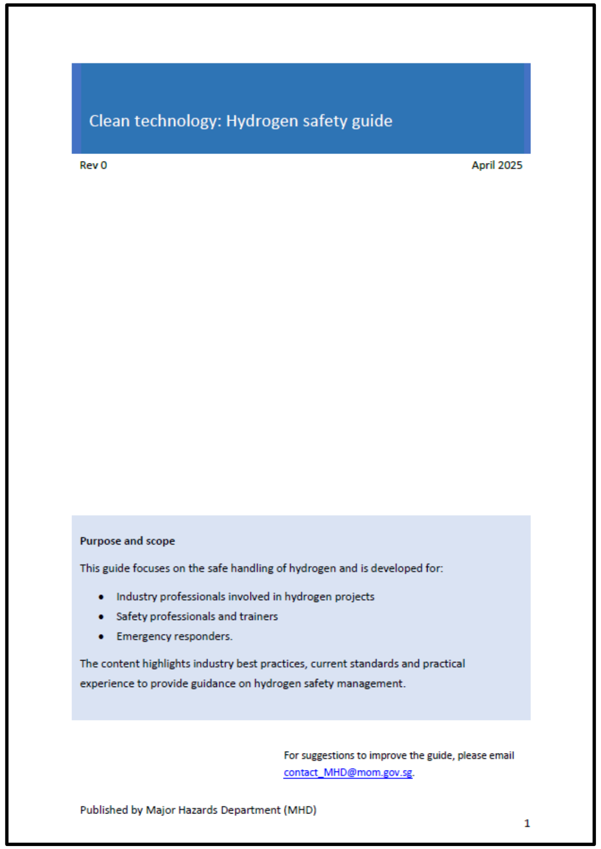
- Identify **fixed and mobile equipment** that help mitigate consequences of major accidents
- Ensure **sufficient personnel with appropriate skills and competencies** to respond during emergencies

Other Considerations

- Emergency response strategy should be **specific and based on characteristics of materials**:
  - **Hydrogen** – how to effectively **detect leaks and/or fires**
  - **Ammonia** – how to effectively **mitigate dispersion of gas cloud**

- Whether emergency response personnel are trained to handle the unique hazards associated with low carbon fuels, particularly hydrogen or ammonia?

Ensuring Safe Cleantech Adoption



Clean technology: Hydrogen safety guide

Rev 0 April 2025

Purpose and scope

This guide focuses on the safe handling of hydrogen and is developed for:

- Industry professionals involved in hydrogen projects
- Safety professionals and trainers
- Emergency responders.

The content highlights industry best practices, current standards and practical experience to provide guidance on hydrogen safety management.

For suggestions to improve the guide, please email contact_MHD@mom.gov.sg.

Published by Major Hazards Department (MHD)

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Hydrogen Safety Guide

Involvement in Workgroups & Projects

Contributing to safer designs across:

1. Hydrogen Refuelling Stations
2. Methanol Bunkering Processes
3. Ammonia/Hydrogen Power Plant Designs
4. Batteries Storage System Design

Standards & Publications

- **Published Hydrogen Safety Guide** and actively involved in standards development for **Ammonia Bunkering**

MHD participated in overseas trips to keep up with cleantech development, identify areas of improvement in work processes, and explore networking opportunities

China (23-27 Jun 2025)

Study trip led by MHD focusing on ammonia and hydrogen developments *(with JTC, URA, SCDF, NEA, EMA, MPA)*

Japan (25-28 Nov 2025)

Study trip organised by EMA focusing on use and design of ammonia-related equipment facilities

UK & Finland (20-24 Oct 2025)

Study trip led by SME PEO focusing on regulator best practices *(with NEA, SCDF)*

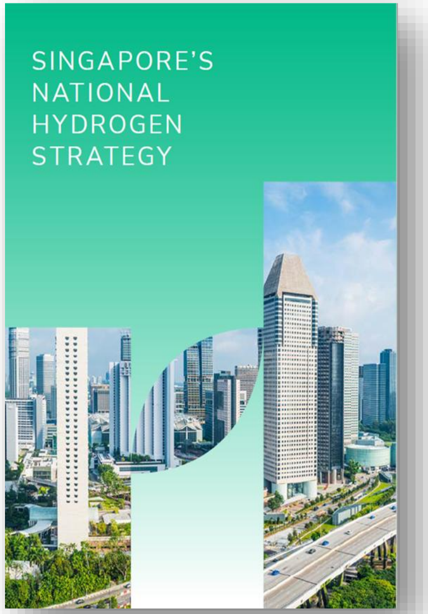
France (28-30 Oct 2025)

Sharing of case study with the OECD Working Party on Chemical Accident

MOM is committed to support Singapore's cleantech transition and enable industry to innovate safely to prevent major accidents

- MHD will continue to encourage the industry to develop their understanding of risks and challenges presented by new cleantech (e.g. electrolysers, hydrogen fuel cells, solid-state metal hydrides)
- We will partner with industry and academia to monitor the cleantech landscape and identify relevant cleantech standards to be developed
- MHD is evaluating:
  - ✓ The health and safety impact of new cleantech
  - ✓ How system integration for cleantech can be carried out safely and competently
  - ✓ New tools or approaches that can change the way we provide safety advices for planning authorities

Source: Hygreen Energy



Key Takeaways

Adoption of low carbon emitting technologies and use of low carbon fuels offer a scalable decarbonisation pathway.

Important to understand the hazard and safety implications of scaled up deployment of low carbon fuels, i.e. hydrogen and ammonia.

The WSH Act and its subsidiary legislation set out the legal framework for ensuring safety and health of persons in workplaces deploying low carbon emitting technologies

Principles of Safety Case can be used to guide assessment of risk associated with adoption of low carbon emitting technologies and fuels

Ministry of Manpower

Thank you