Report of the Pro-Tem Committee for Hydrogen and Hydrogen Carriers

Jointly prepared by

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February 2025

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EXECUTIVE SUMMARY

This report presents the outcomes of the Pro-Tem Committee (PTC) on Standards for Hydrogen and Hydrogen Carriers, formed in September 2023 under the Chemical Standards Committee (CSC) of the Singapore Standards Council (SSC). The committee's mission was to explore the development of hydrogen-related standards in response to Singapore's national hydrogen strategy, which aims to achieve net-zero emissions by 2050.

Background and Objectives

Singapore's National Hydrogen Strategy, announced in October 2022, outlines the potential of low-carbon hydrogen as a major decarbonization pathway as part of Singapore's efforts to achieve net zero emissions by 2050. Transport, power and industrial sectors are the top contributors, accounting for more than 95% of emissions in Singapore. The strategy identifies the potential pathways and application of hydrogen in decarbonising these sectors. Standards and Conformance (S&C) can play a crucial role to support Singapore's transition to a more sustainable hydrogen economy.

Committee Activities

The PTC held multiple meetings, beginning in October 2023, involving stakeholders from government, industry, academia, and trade associations. Four subgroups (SGs) were established to study the hydrogen-related standardisation needs required for the sectors identified under Singapore's national hydrogen strategy and to support the infrastructure along the hydrogen value chain:

SG 1: Hydrogen usage in transportation sectors (airport, seaport and land transport),

SG 2: Hydrogen usage in power generation sector (ammonia, 30% hydrogen blended fuel),

SG 3: Industrial applications (e.g. chemical reactions, production of low carbon fuel such as hydrogen and sustainable aviation fuels (SAF), and furnaces), and

SG 4: Hydrogen infrastructure to support transmission, distribution and storage (ship from source to storage and distribution; potentially through pipelines).

Broadly, each subgroup conducted an exploratory study of its assigned industry and centered their research efforts and discussions on three key themes:

- Plans & Interests of the Government, Regulators and Sector,
- Hydrogen application in industry sub-sectors and the quality and carbon intensity of the hydrogen required, and
- Existing standards, potential gaps and the timeline of implementation required.

Findings and Recommendations

The committee identified near-, medium-, and long-term areas for standard development:

- **Near-term**: Standards for hydrogen transmission, fuel cell-powered vehicles, and carbon intensity methodologies.
- **Medium-term**: Standards for low-carbon hydrogen in power generation and hydrogen handling processes.
- **Long-term**: Standards for the use of hydrogen carriers like ammonia and methanol.

The committee recommended the formation of a National Mirror Committee (NMC) to represent Singapore in the international standardisation work of ISO/TC 197 on hydrogen technologies. The NMC would ensure Singapore's interests in the global hydrogen economy and explore greenhouse gas (GHG) accounting methodologies for hydrogen.

Conclusion

The PTC successfully fulfilled its objectives, providing a roadmap for future hydrogen standard development. The committee recommends further industry engagement and a study mission to assess hydrogen deployment in other countries. Upon disbandment, stakeholders interested in advancing hydrogen standards are encouraged to continue efforts with Enterprise Singapore and related standards development organisations.

1.0 Introduction

National Hydrogen Strategy

Singapore has committed to achieving net zero emissions by 2050, as part of our contribution to global climate action[1]. As a small and densely populated city-state, the country faces significant limitations in harnessing alternative energies. We have limited land for solar deployment, and do not have access to wind and hydropower at a meaningful scale. Hence, to support this net zero goal, the Ministry of Trade and Industry (MTI) launched the National Hydrogen Strategy in October 2022 to guide our efforts harnessing hydrogen as a low-carbon solution for Singapore.

Transport, power and industrial sectors are the top contributors, amounting for more than 95% of the primary emissions in Singapore. Hence, the strategy identifies the potential pathways and application of hydrogen in decarbonising these sectors.

Low-carbon hydrogen can play an important role to decarbonise Singapore's power sector, given our limited ability to generate renewable energy domestically. Utility-scale Combined Cycle Gas Turbines (CCGTs) that can combust a blend of hydrogen and natural gas are already available. Singapore has announced its commitment to support the introduction of the minimum 30% hydrogen-compatible requirement for all new and repowered powerplants from 2024, with the ability to be retrofitted to support 100% hydrogen deployment in the future, when the technology matures.

Low-carbon hydrogen is also a pathway for mitigating industrial emissions and enabling sustainable production. As a feedstock for multiple industrial processes, demand for low-carbon hydrogen is expected to increase as companies decarbonise and transition towards the making of sustainable projects such as biofuels and synthetic fuels. Low-carbon hydrogen also presents an option for the industry to decarbonise heat, power and steam generation by replacing fossil fuels in burners and co-generation plants.

Besides reducing domestic emissions, low-carbon hydrogen can be a key decarbonisation solution for the maritime and aviation sectors. As a global shipping and air hub, Singapore can play an important role in supporting this transition. In the maritime sector, hydrogen-based fuels such as ammonia are expected to play a prominent role in the sector's multi-fuel transition. On the aviation front, low-carbon hydrogen can contribute to the production of Sustainable Aviation Fuels and in the longer term possibly directly as a fuel. In the near term, there is potential to be used in the fuel calls for airside ground vehicles as well as heavy vehicles in the port operations.

Singapore has recognised the importance of long-term planning and the need for a conducive regulatory environment to facilitate the adoption of low-carbon hydrogen. For example, to prepare for longer-term deployment, the government has planned to work with the industry to study the safety requirements to gradually build up the necessary infrastructure along the hydrogen value chain.

[1] SG Green Plan 2030

Standards & Conformance in Hydrogen

Standards & Conformance (S&C)[2] is thus crucial to support our transition to a more sustainable hydrogen economy. The adoption of international hydrogen standards and development of new Singapore standards where needed addresses potential public health and safety risks associated with production, storage, delivery and use of hydrogen. S&C can also help establish clear definitions of low-carbon hydrogen which will allow Government and industry to have a common language to set aside thresholds, which would make Singapore's requirements vis-à-vis the global value chain. As we experiment with new use-cases and prepare the necessary infrastructure and our workforce for the development of a broader hydrogen economy, standards would also minimise the risk to local communities and assist the industry in securing the social license to operate.

However, the existing regulatory system was not intentionally designed to cater for a hydrogen-based economy, nor facilitate large-scale hydrogen uptake. Hence, it is vital for us to identify S&C gaps to be filled to assure regulators of the safe expansion of infrastructural and research projects in support of the national hydrogen strategy.

2.0 Formation of the Hydrogen Pro-Tem Committee

Under the purview of the Chemical Standards Committee (CSC), a PTC for hydrogen and hydrogen carriers comprising of members from industry and trade associations, government agencies, and research institutes, was formed in September 2023 to:

1. Conduct an in-depth evaluation to assess the prospects of developing standard(s) related to hydrogen for the industries. The PTC would specifically examine:
    - Industry trends (e.g. national plans, industry initiatives etc.),
    - Industry gaps/challenges/needs (i.e. problem statements),
    - Industry capabilities/infrastructures to support standardisation efforts (e.g. mature technology, guidelines, permits),
    - Benefits/impact that standardisation can bring about to stakeholders (e.g. promote safety, training needs etc.), and
    - Identify lead organisations who are committed to promote the adoption of this standard.

[2] Standards are published documents that set out specifications for products, processes, performances or services, while conformance is the process of judging whether a particular product, process or service meet said standards or comply with a regulation.

2. Share consolidated findings with CSC for their decision making regarding:
    - Singapore's involvement in international work carried out under ISO/TC 197 "Hydrogen technologies",
    - New standard(s) to be developed by Standards Committee, and
    - The need to embark on a study mission, to support standards identification and development.

This report aims to outline the PTC's findings on existing S&C gaps across the low-carbon hydrogen value chain that are key to the successful implementation of the national hydrogen strategy and its recommendations for S&C development going forward. The list of PTC participants can be found in Annex II.

2.1 PTC Structure & Discussion Topics

To facilitate in-depth discussions and conduct a thorough gap analysis, the PTC organised itself into four subgroups (SGs) representing key industries relevant to hydrogen-use:

1. SG 1: Hydrogen usage in transportation sectors (airport, seaport and land transport),

2. SG 2: Hydrogen usage in power generation sector (ammonia, 30% hydrogen blended fuel),

3. SG 3: Industrial applications (e.g. chemical reactions, production of low carbon fuel such as hydrogen and SAF, and furnaces). and

4. SG 4: Hydrogen infrastructure to support transmission, distribution, and storage (ship from source to storage and distribution, potentially through pipelines).

Broadly, each subgroup conducted an exploratory study of its assigned industry and centered their research efforts and discussions on three key themes:

1. Plans & Interests of the Government, Regulators and Sector,

2. Hydrogen application in industry sub-sectors and the quality and carbon intensity of the hydrogen required, and

3. Existing standards, potential gaps and the timeline of implementation required.

3.0 Findings & Analysis

Table 1 below outlines a summary of the findings and identified gaps reported by each Sub-Group (SG). For more detailed information, please refer to subsections 3.1 to 3.5.

Table 1: Summary of Findings

Sub-Group Name	Findings & Identified Gaps
SG 1: Transportation sectors (airport, seaport & land Transport	• Hydrogen as an energy vector is a longer-term interest; ○ Hydrogen use-cases in Singapore's airport & seaport are limited to smaller-scale deployment, such as hydrogen fuel cells (HFC) for harbour crafts and airside ground vehicles, where standards can support implementation. ○ Electric Vehicles are of higher priority for land transport than HFC vehicles. • Some existing guidelines and developments as possible reference: ○ Singapore's Technical Reference on Hydrogen Refuelling Station (HRS) [Ongoing]. ○ Relevant standards under ISO/TC 197 on Hydrogen Technologies, such as ISO 14687 on Hydrogen fuel quality — Product specification.
SG 2: Power Generation	• Standards may be required for hydrogen and ammonia power plants ○ [Hydrogen] Near-term priority to help achieve at least 30% blended hydrogen compatibility, and move towards 100% in the future (for boiler, gas turbine)[3]. ○ [Ammonia] Energy Market Authority (EMA) and Maritime Port Authority of Singapore (MPA) are evaluating proposals from consortia to provide low- or zero-carbon ammonia solutions for power generation and bunkering. • Where relevant, S&C can be developed to ensure the safe implementation and quality specifications of hydrogen and ammonia in the above developments.

[3] Singapore has publicly announced its commitment to support the introduction of the minimum 30% hydrogen-compatible requirement for all new and repowered powerplants from 2024, with the ability to be retrofitted to support 100% hydrogen deployment in the future, when the technology matures (EDB, 2024)

SG 3: Industrial Applications	• Standards for four hydrogen industrial processes identified as important: 1. Hydrogen as a combustion fuel for process heaters/furnaces. 2. Hydrogenation to produce Sustainable Aviation Fuel (SAF). 3. Hydrogen as feedstock for chemical reactions. For example, Carbon Capture Utilisation (CCU), production of methanol, possible production of renewable ammonia, etc. 4. Production of low-carbon hydrogen. For example, through Steam Methane Reforming (SMR) and/or Autothermal Reforming (ATR). • Local chemical companies assessed the need for hydrogen-related standards to be developed as unlikely, as many would deem their own internal procedures and existing regulatory licenses and permits as sufficient safeguards.
SG 4: Hydrogen Infrastructure	• Standards for liquefied-hydrogen (L-H_2) storage and transportation not a priority due to high cost to set up large-scale storage infrastructure based on existing assessments. • There could be operational concerns like finding the land space required to build and house the required infrastructure (e.g storage or buffer tanks) for the blending of hydrogen at the site of the end-user. • There is no need for standards covering gaseous-hydrogen (G-H_2) operating conditions since companies often utilise their own corporate design specifications, codes and/or standards as seen for many years in Jurong Island. • A standard covering the transmission of hydrogen via pipeline networks would be useful, especially to aid regulation. • For G-H_2 applications, three main areas were considered: a. Blending i. End-users prefer to blend hydrogen at site. However, due to land constraints, bulk storage of hydrogen at site for blending might be needed. Standards may be required to provide assurance on these storage units.

	ii. It is difficult to track the green credentials of the imported hydrogen blended at source, standards could be developed to mitigate risks and facilitate interoperability. b. Transmission (from source or storage to application) i. While standards such as ASME B31.12, IGEM/TD/1 Supplement 2, CEN/TS 17977:2023 and API standards exists overseas, there are no local standards in Singapore. ii. Guidance on the type of material, maintenance and material integrity of pipelines and safety considerations need to be adapted to suit Singapore's needs. iii. A standard for transmission codes on how underground pipelines could be set up and maintained could also be developed. c. Combustion i. Little need for standards in G-H2 operating conditions as there are established processes within Jurong Island currently in use.
Horizontal across all SGs	• There is a need to develop globally agreed methodology for calculating hydrogen's carbon intensity, to ensure consistency and transparency. • The ongoing development of ISO 19870-1 'Methodology for determining the greenhouse gas emissions Part 1: Emissions associated with the production of hydrogen up to production gate', was assessed to relevant for Singapore's participation.

3.1 SG 1: Hydrogen usage in transportation sectors (airport, seaport and land transport)

In the transportation sector, the use of hydrogen as an energy vector for mass adoption is assessed to be a longer-term interest.

For land transport in Singapore, there are trials for hydrogen-powered light commercial vehicles, although limited relative to the plans in place for the use of electric vehicles (EVs). To support pilot trials and refuelling operations, Singapore is also developing a technical reference on HRS.

For airport and seaport uses, the main application of hydrogen in the near-term appears limited to HFC heavy vehicles operating within the ports' boundaries, rather than to the wider deployment of hydrogen-fuelled airplanes or oceangoing vessels. This includes the exploration of using HFC for harbour crafts and prime movers, and airside ground vehicles.

Some existing international standards were also identified and will be assessed on their applicability to Singapore's context. For example:

- ISO 14687 on hydrogen fuel quality which covers hydrogen purity and water content which are key parameters for HFC deployment, and
- Other relevant standards under ISO/TC 197 that support land transportation.

3.2 SG 2: Hydrogen usage in power generation sector (ammonia, 30% hydrogen blended fuel)

The government agencies (through MTI and EMA) and industry players within the energy sector in the PTC, have focused discussions around minimum 30% blended hydrogen fuel in the near-term, with the goal of using 100% hydrogen in the future. This is to support EMA's introduction of the minimum 30% hydrogen-compatible requirement for all new and repowered powerplants from 2024, with the ability to be retrofitted to support 100% hydrogen deployment in the future, when the technology matures. Local regulators are also referencing USA's NFPA codes for safety evaluations of these powerplants.

Concurrently, the EMA and the MPA are in the process of selecting a lead developer, who will pilot the use of ammonia on Jurong Island for power generation and bunkering. Specifically, a 100% ammonia-fired turbine will be piloted.

Additionally, it was acknowledged that quality specifications for hydrogen and ammonia will defer based on their applications.

Therefore, where required, S&C can be developed to ensure (i) the safe implementation of hydrogen or ammonia combustion, and (ii) quality requirements for varying hydrogen and ammonia applications.

3.3 SG 3: Industrial applications (e.g. chemical reactions, production of low carbon fuel such as hydrogen, SAF, and furnaces)

Standards in four hydrogen industrial processes were identified as important:

1. Hydrogen as a combustion fuel for process heaters/furnaces,
2. Hydrogen use for hydrogenation to produce Sustainable Aviation Fuel (SAF),
3. Hydrogen as feedstock for chemical reactions. For example, CCU, production of methanol, possible production of renewable ammonia, etc, and
4. Production of low-carbon hydrogen. For example, through Steam Methane Reforming (SMR) and/or ATR.

However, local chemical companies feedbacked that the need for hydrogen-related standards to be developed is unlikely. Given that it is common for refining or petrochemical companies to handle hydrogen and its carriers (e.g Liquid Organic Hydrogen Carriers (LOHC), ammonia) either as a process feed or as a byproduct, many would deem their own internal procedures, and existing licenses and permits, as sufficient safeguards.

3.4 SG 4: Hydrogen infrastructure to support transmission, distribution, and storage (ship from source to storage and distribution, potentially through pipelines)

The PTC agreed for the scope of SG 4's discussion to be within the boundaries of Singapore, i.e. after hydrogen has been imported and transported to the shores of Singapore. The following assessments pertaining to the S&C for hydrogen infrastructures across the local supply-chain were made:

- While the high cost of large scale L-H_2 storage is of concern, its ability to be stored and transported within ISO tanks like other cryogenic gases (e.g. Nitrogen) is well established, making standards for L-H_2 less pressing.

- To support G-H_2 application, there are three main areas for consideration:
  a. Blending
     i. Due to varying needs defined by hydrogen application, there is an industry preference for end-users to blend hydrogen at site. However, this methodology is limited by land constraints, where space is required to build storage or buffer tanks to support on-site blending. Therefore,

standards may be required to provide assurance on bulk storage of hydrogen at site for blending.

ii. Alternatively, there may be a need for hydrogen blending to take place at source. However, it is difficult to track the green credentials of the imported hydrogen blended at source, standards could be developed to mitigate risks and facilitate interoperability.

b. Transmission (from source or storage to application)

i. While there are existing standards such as ASME B31.12, IGEM/TD/1 Supplement 2, CEN/TS 17977:2023 and API standards, there are no local standards in Singapore which may be required to address local context such as local requirements for transmission of different blended hydrogen for different applications, as well as the potential need for pipelines to run through residential areas. Therefore, guidance on the type of material (e.g. carbon steel, stainless steel, etc.), maintenance and material integrity of pipelines (e.g. corrosion against corrosive substances contaminated hydrogen, damage prevention, etc.) and safety considerations might need to be adapted to suit Singapore's needs.

ii. Further, a standard for transmission codes detailing how underground pipelines could be set up and kept from damage and corrosion could be developed.

c. Combustion

i. There is little need for standards in G-H2 operating conditions as there are established processes within Jurong Island, where each company refers to their own corporate design specifications, codes and/or operating procedures.

3.5 Horizontal across all SGs

All subgroups agreed that carbon intensity of hydrogen was important, and there is a need to develop globally-agreed methodology for calculating hydrogen's carbon intensity, to ensure consistency and transparency.

The ongoing development of ISO 19870-1, Methodology for determining the greenhouse gas emissions Part 1: Emissions associated with the production of hydrogen up to production gate, was assessed to be relevant for Singapore's participation at ISO.

4.0 Conclusion & Recommendations

The PTC recommends a phased implementation plan to address the identified gaps through S&C moving forward. The plan comprises of three stages**: (1) Near-term, (2) Medium-term and (3) Long-term actions.**

(1) Near-term Actions

In the immediate term, the PTC recommends to embark on developing / adopting:

1. A standard on transmission of gaseous H2 and/or 30% H2 blended fuel via pipelines.
2. A standard on the operation of H2 fuel cell powered vehicles (e.g. land operations in air and seaports as well as harbour crafts).
3. A standard on carbon intensity (i.e. ISO 19870-1 developing under ISO/TC 197). and
4. A new standard on “Guidelines for hydrogen facilities design, materials selection, operations, storage, and distribution”. This standard would serve as a ‘one-stop’ reference material for Singapore that captures relevant existing standards for hydrogen across industry sectors, either as Technical Reference (TR) or Workshop Agreement (WA).

(2) Medium-term Actions

In the medium-term, the PTC recommends developing:

1. A standard on the usage of low carbon hydrogen for power generation, including the retrofitting of equipment, and
2. A process standard that includes the handling of hydrogen.

(3) Long-term Actions

In the long run, the PTC recommends developing:

1. A standard relating to local utilization of hydrogen carriers (e.g. LOHC, Ammonia, Methanol)[4], and
2. A standard relating to the utilisation of liquified hydrogen.

[4] Beyond methanol and ammonia bunkering which CSC is currently developing.

To support the monitoring and implementation of PTC's recommended plans, a National Mirror Committee (NMC) for ISO TC 197 will be formed under CSC.

The proposed scope of the NMC, in addition to the near-, medium- and long-term actions, is to participate in international standards development work under the ISO/TC 197 on Hydrogen Technologies, which includes topics such as GHG accounting on Hydrogen, L-H2, LOHC, and Ammonia. This is in line with Singapore's approach to pivot away from colour-coded terminology towards classification by emissions level instead.

To ensure continual applicability and responsiveness of the recommendations, the NMC will continue to monitor ongoing and future technological and industry developments that may require a re-prioritisation of the plans above. For example, in response to new developments, some middle or long-term actions may require short-term and immediate attention instead.

ANNEX I – List of Abbreviations

ATR	Autothermal Reforming
CCU	Carbon Capture Utilisation
CSC	Chemical Standards Committee
EMA	Energy Market Authority
EV	Electric Vehicals
G-H_2	Gaseous-hydrogen
GHG	Greenhouse Gas
HFC	Hydrogen Fuel Cells
HRS	Hydrogen Refuelling Station
ISO	International Standards Organisation
L-H_2	Liquefied-hydrogen
LOHC	Liquid Organic Hydrogen Carriers
MPA	Maritime Port Authority of Singapore
MTI	Ministry of Trade and Industry
NFPA	The National Fire Protection Association
NMC	National Mirror Committee
PTC	Pro-Tem Committee
S&C	Standards and Conformance
SAF	Sustainable Aviation Fuels
SG	Subgroup
SMR	Steam Methane Reforming
TC	Technical Committee
TR	Technical Reference
WA	Workshop Agreement

ANNEX II – Acknowledgments

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