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Accelerating the Implementation of the National Green Hydrogen Mission

Assessment of Standards to Enable the Ecosystem

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The Council on Energy, Environment and Water (CEEW) is one of Asia's leading not-for-profit policy research institutions and one of the world's leading climate think tanks. **The Council uses data, integrated analysis, and strategic outreach to explain — and change — the use, reuse, and misuse of resources**. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public. CEEW has been extensively involved in research on pathways to net-zero emissions and the required investments.

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The Council's major contributions include: The 584-page *National Water Resources Framework Study* for India's 12th Five Year Plan; the first independent evaluation of the *National Solar Mission*; India's first report on global governance, submitted to the National Security Adviser; irrigation reform for Bihar; the birth of the Clean Energy Access Network; work for the PMO on accelerated targets for renewables, power sector reforms, environmental clearances, *Swachh Bharat*; pathbreaking work for the Paris Agreement, the HFC deal, the aviation emissions agreement, and international climate technology cooperation; the concept and strategy for the International Solar Alliance (ISA); the Common Risk Mitigation Mechanism (CRMM); critical minerals for *Make in India*; modelling uncertainties across 200+ scenarios for India's low-carbon pathways; India's largest multidimensional energy access survey (ACCESS); climate geoengineering governance; circular economy of water and waste; and the flagship event, Energy Horizons. It recently published Jobs, Growth and Sustainability: A New Social Contract for India's Recovery.

The Council's current initiatives include: A go-to-market programme for decentralised renewable energy-powered livelihood appliances; examining country-wide residential energy consumption patterns; raising consumer engagement on power issues; piloting business models for solar rooftop adoption; developing a renewable energy project performance dashboard; green hydrogen for industry decarbonisation; state-level modelling for energy and climate policy; reallocating water for faster economic growth; creating a democratic demand for clean air; raising consumer awareness on sustainable cooling; and supporting India's electric vehicle and battery ambitions. It also analyses the energy transition in emerging economies, including Indonesia, South Africa, Sri Lanka and Vietnam.

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Contents

The development and harmonisation of standards is a pre-requisite for a global hydrogen economy.

Image: iStock

Executive summary

Green hydrogen is in the early stages of deployment worldwide. As of August 2022, 38 countries, including the European Union (EU), were developing or had ratified policies on green hydrogen[175]. The trading of green hydrogen, its derivative fuels, and related technologies are expected to significantly increase, given the mounting pressure to meet climate goals and the lack of access to renewable energy in many countries. The lack of codes and standards has been consistently recognised as a major hindrance to the large-scale deployment of any horizon technology. In order to support the growth of a hydrogen economy, governments, research institutions, and international bodies are working in conjunction to harmonise codes, standards, and procedures related to the hydrogen value chain.

The development of standards for green hydrogen will increase industry confidence in its uptake

India has set a target of producing 5 million tonnes per annum (MTPA) of green hydrogen by 2030 through the recently launched *National Green Hydrogen Mission*[176]. Rapid scaling up of green hydrogen projects in India would require the development of a favourable ecosystem, and a single window clearance for green hydrogen projects would be a key component. In this regard, the development and harmonisation of hydrogen standards would play a critical role in making it for businesses to enter the green hydrogen market. In addition, since India aims to be a global hub for green hydrogen in the coming decades, the synchronisation of standards across the value chain with global export markets is of the utmost importance.

A. Gap assessment of hydrogen standards in India

Our report provides a comprehensive overview of the existing standards relating to green hydrogen in India. Further, the report also compares the Indian standards with those in countries such as Australia, Canada, Germany, Japan, South Korea, the United States (US), and the United Kingdom (UK) across components of the green hydrogen value chain. The comparison identifies the gaps in existing standards in India across the hydrogen value chain and recommends alternatives for adoption. The comparison enables the identification of standards that are popular worldwide, so that they may be adopted in India after due diligence.

B. Key recommendations

The missing links in standards related to the hydrogen value chain and the alternatives for adoption are summarised schematically in ES Figure 1. The gaps in standards are categorised according to the various stages of the value chain – namely, production, storage, transportation, applications, and dispensation. The key recommendations are given in what follows.

Hydrogen production

- The IS 16509:2020 standard for electrolytic hydrogen production does not cover solid oxide electrolysers (SOECs), which are expected play a significant role in the coming decades. This should be updated to include the requirements defined in the outline for the UL LLC 2264A standard.

- The IS 16512 (Part 1):2016 standard for hydrogen production through hydrocarbon reforming does not include production through alternative means such as natural gas or biomass pyrolysis. India should proactively develop standards for these technologies as they could be the bridge between the transition from grey to green hydrogen.

India lacks standards for hydrogen transport through pipelines, fuel cell modules and refueling stations

Hydrogen storage

- The IS 7285:Part 1:2018 standard for gaseous hydrogen storage defines standards for cylinder sizes only up to 400 litres. India can consider expanding the standard to include larger cylinder sizes, as the demand for hydrogen is expected to increase in the near future.
- India currently does not have standards defined exclusively for bulk storage of liquid hydrogen. India should develop and adopt standards such as CGA P-12, NFPA 55 and EIGA Doc 06/19.

Hydrogen transport

- Currently, India does not have standards for dedicated hydrogen pipelines. It should consider adopting standards such as the ASME B31.12-2019 or CGA G-5.6 to allow the safe transport of hydrogen in bulk. The adopted standard should include steel pipes for hydrogen transport and other alternatives such as modified natural gas infrastructure repurposed for hydrogen transport.
- India also does not have standards for metal hydride storage and the transport of hydrogen. It can adopt the prescribed ISO 16111:2018 standard after due diligence.
- India currently does not have standards for maritime transport of hydrogen. India can adopt the IGC code/MSC.420 after due diligence.

Hydrogen applications

- India must adopt standards such as the ISO 19882:2018 or develop its own standard for thermally activated pressure relief valves, which form an integral part of hydrogen-propelled vehicles.

- India lacks standards for fuel-cell modules (IEC 62282-3-100:2019 – stationary fuel cells; IEC 62282-5-100:2018 – portable fuel cells; and IEC 62282-6-100:2010 – micro fuel cells), fuel-cell-based aircraft (SAE AIR 6464), and fuel-cell-based railway locomotives (IEC 63341 (Parts 1-3)). Since fuel cells are one of the primary routes for energy conversion using hydrogen, it is imperative that such standards are adopted or developed soon.

- Currently, there are no standards governing hydrogen-fuelled internal combustion engines (ICEs). India should take the lead in developing the same.

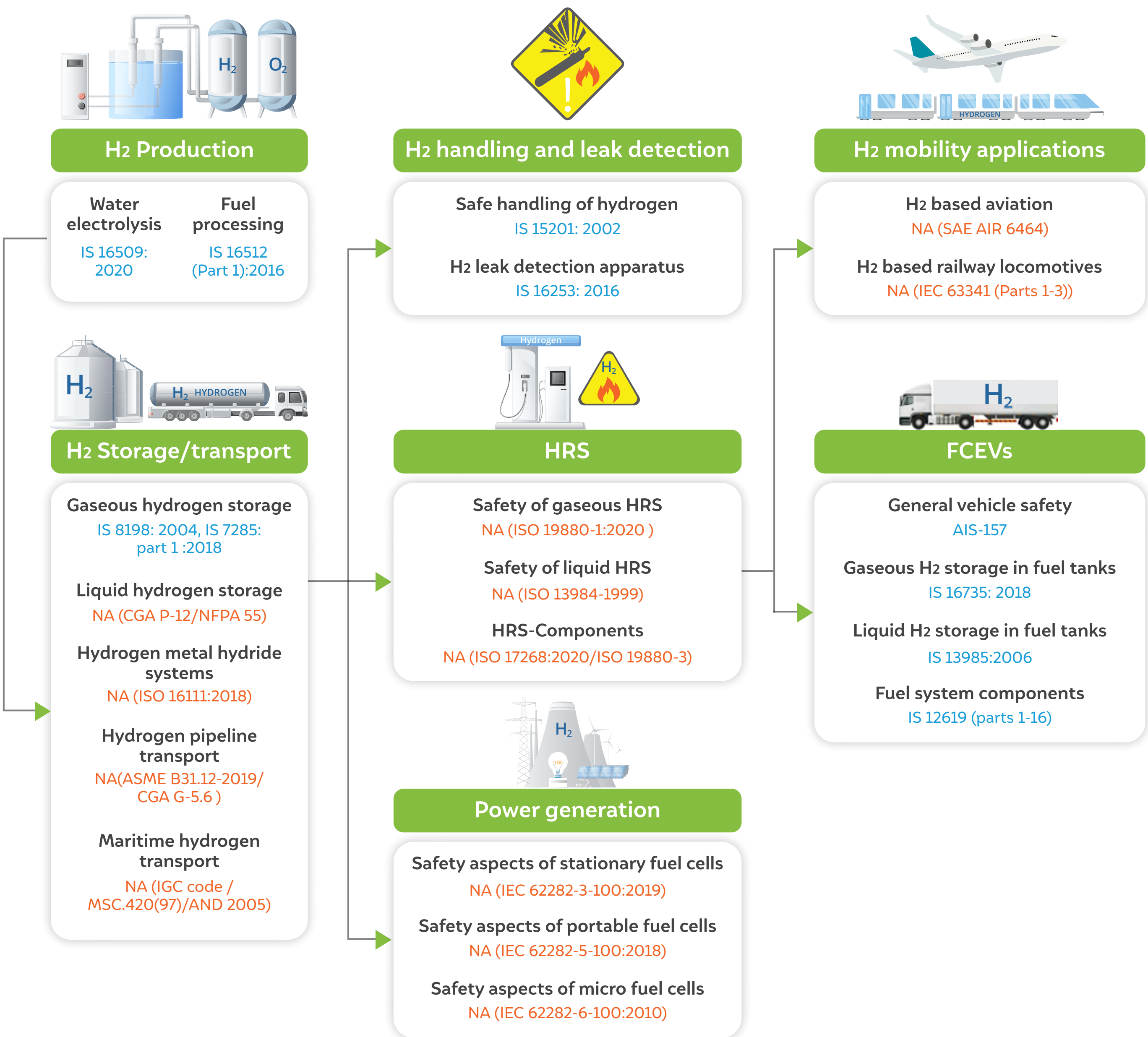
- There are no standards defining the operational parameters or design specifications of equipment for the safe use of hydrogen for process heat applications. India should proactively develop them in order to accelerate the use of hydrogen as a green fuel in industries.

Hydrogen dispensation

- India currently does not have any standards for hydrogen refuelling stations. The ISO 19880-1:2020 or CSA/ANSI HGV 4.9:20 standards for gaseous hydrogen dispensation and the ISO 13984-1999 standard for liquid hydrogen dispensation can be adopted. The standards related to hydrogen dispensation for end users need to match domestic requirements and climatic conditions.

ES Table 1 details the hydrogen safety standards in India, covering various components of the value chain, and suggests alternatives to existing standards; it also recommends standards in cases where there are none. In addition, the detailed commentary compares the status of the standards in countries such as Australia, Canada, Germany, Japan, South Korea, the UK, and the US.

Figure ES1 Missing links in the hydrogen value chain in India



Source: Authors' compilation

Note: The colour of the text represents whether Indian safety standards are present. **Blue** indicates that indigenous standards have been developed, whereas **orange** denotes that indigenous standards are not available and indicates possible alternatives for India to adopt.

Table ES1 Summary of gap assessment of hydrogen standards in India

No.	Component	Indian standard (IS)	Alternatives	Comments
		Hydrogen production		
1.	Electrolytic hydrogen production technologies	IS 16509:2020[29]	UL LLC 2264A Edition[173] NFPA 2[120]	The Indian standard, adopted from the ISO 22734:2019[87], covers proton exchange membrane (PEM), alkaline electrolysers, and anion electrolyte membrane electrolysers (AEM) but does not cover solid oxide electrolyser cells (SOECs). The Underwriters Laboratories (UL) outline includes specifications for SOECs that can be adopted in India after due diligence. The ISO (International Organisation for Standards) standard has also been adopted by Australia, Canada, Germany, Japan, South Korea, the UK, and the US. The IS standard can be updated with the ISO/AWI 22734-1[87] (under development) that focuses on general requirements, test protocols, and safety requirements.
2.	Hydrocarbon reforming	IS 16512 (Part 1): 2016[28]	NFPA 2	The Indian standard is a modified adoption of the ISO 16110-1:2007[98] standard and was reaffirmed in 2021. This ISO standard has also been adopted with modifications by Australia, Canada, Germany, Japan, South Korea, the UK, and the US. The ISO 16110-2:2010[86] standard that defines test protocols for feedstock-based hydrogen production could also be adopted by India. The IS 16512 (Part 1):2016 standard currently adopted for feedstock-based hydrogen production technologies does not define the requirements and protocols for efficient resource use and effluent management. India should bridge this gap by including it in the existing standards. It should be noted that there are no standards for hydrogen production through alternative means such as natural gas or biomass pyrolysis. India should be proactive and develop standards for the same.
		Hydrogen storage (gaseous/liquid)		
3.	Gaseous hydrogen storage	IS 7285:Part 1:2018[31] (reaffirmed in 2022)	ISO 19881:2018[84] (Land vehicle fuel containers) ASME STP/PT-003-2005[169] STP-PT-014-2008[167] NFPA 55[119]	India aims to be a hydrogen hub. Consequently, the storage standards should comply with requirements across the globe. India can also consider adopting the best features of other standards, such as those by American Society of Mechanical Engineers (ASME) and National Fire Protection Association (NFPA). In addition, the IS 7285: Part 1:2018 defines standards for only up to 400 litres. India can explore expanding the standards to cover larger cylinder sizes.
4.	Liquid hydrogen storage	-	EIGA Doc 06/19[60] NFPA 55 CGA P-12	India currently does not have standards defined exclusively for bulk storage of liquid hydrogen. India should develop and adopt standards such as CGA P-12, NFPA 55 and EIGA Doc 06/19. In addition, an adequacy assessment should be carried with globally used standards.
5.	On-board hydrogen storage for fuel cell electric vehicles (FCEVs)	IS 16735:2018[25]	ISO 19881:2018	The IS 16735:2018 is a derivative of the ISO 19881:2018. Australia, Canada, Germany, Japan, the Republic of Korea, the UK, and the US have also adopted the relevant ISO standards (with modifications in some instances).

No.	Component	Indian standard (IS)	Alternatives	Comments
	Hydrogen transportation			
6.	Compressed hydrogen storage for transport	IS 8198:2004 (reaffirmed in 2019)	ISO 19881:2018	The IS 8198:2004 is applicable to the storage and transport of gaseous hydrogen. However, based on the description, it is unclear if the IS 8198:2004 is a derivative of the ISO 19881:2018. The ISO 19881:2018 standard has been adopted as a modified version by Australia, Canada, Germany, Japan, South Korea, the UK, and the US.
7.	Liquid hydrogen storage for transport - land vehicle fuel tanks	IS 13985:2006[33] (reaffirmed in 2021)	EIGA Doc 06/19 ISO 13985:2006 NFPA 55	The Indian standard IS 13985:2006 is derived from the ISO 13985:2006 and defines standards for transportable liquid hydrogen fuel tanks. Countries such as Australia, Canada, Germany, Japan, South Korea, the UK, and the US have adopted the same ISO standard.
8.	Hydrogen transportation through pipelines	-	ASME B31.12-2019[68] EIGA Doc 121/14[59] ISO 19880-1:2020 CGA G-5.6[38]	There are no Indian standards for hydrogen pipelines. Germany, South Korea, Australia, and Japan also do not have standards for hydrogen pipelines. The US and UK have adopted the ASME B31.12-2019. India can consider adopting a standard that incorporates the best practices from various existing standards for hydrogen pipeline transport. The ASME is expected to update the existing standard to include steel pipes for the transport of gaseous hydrogen and India can consider adopting the updated standard after due diligence.
9.	Metal hydride storage of hydrogen	-	ISO 16111:2018[105]	India can adopt the prescribed ISO standard for metal hydride storage after due diligence. Standards for this purpose have been adopted with modifications by Australia, Canada, Germany, Japan, the Republic of Korea, the UK, and the US.
10.	Maritime transport of hydrogen	-	IGC code/MSC.420[97]	India currently does not have standards maritime transport of hydrogen. India can adopt the prescribed alternatives after due diligence.
	Fuel system components for FCEVs			
11.	FCEV fuel system components	IS/ISO 12619-1[26] (parts 1-16)	CSA HPIT 1-2015[35] (for hydrogen trucks) SAE J2579_201806[128] (for on-road vehicles)	The IS/ISO 12619-1 is a derivative of the ISO 12619 (part 1–16):2017[81]. The ISO standard has been adopted by Australia, Canada, Germany, Japan, the UK, and the US. Other alternatives include the CSA HPIT 1-2015 (for on-board fuel storage and handling systems).
12.	Thermally activated pressure relief devices for compressed hydrogen	-	ISO 19882:2018[94]	India must adopt or develop a standard for thermally activated pressure relief valves. Australia, Canada, Germany, the Republic of Korea, the UK, and the US have adopted the ISO 19882:2018 standards.

No.	Component	Indian standard (IS)	Alternatives	Comments
	Hydrogen refuelling stations			
13.	Gaseous hydrogen dispensing stations	-	ISO 19880-1:2020[92] (general requirements) CSA/ANSI HGV 4.9:20[136] ISO 17268:2020[95] (connection devices)	There are no Indian standards for hydrogen refuelling stations, though refuelling connection devices follow the IS 17268:2020 standard (which is a derivative of ISO 17268:2020). Standards for hydrogen dispensation to end users need to match domestic requirements and climatic conditions and should be designed to be easily scalable. Australia, Canada, Germany, Japan, Korea, the UK, and the US have adopted standards related to gaseous hydrogen fuelling stations. India could follow suit by adopting a standard that complies with some or all of the specifications prescribed.
14.	Liquid hydrogen dispensing stations	-	ISO 13984-1999[101]	
15.	Components of hydrogen refuelling station	IS 17268:2020	ISO 17268:2020 (connection devices) ISO 19880-3 (valves) J2600_201510[123] (connection devices) J2601/3_201306[124] (fuelling protocol)	
	Fuel-cell-powered vehicles			
16.	Safety aspects of FCEVs	AIS-157[20] AIS-137 (Parts 1-8)[118]	ISO 23273:2013 SAE J2578_201408[127] EC 79/200[170] GTR-13[174]	The interoperability of safety aspects of FCEVs is crucial for the import and export of FCEVs or their components. Currently, except for Japan, several countries, including Germany (ISO 23273[52]), India (AIS-157), the US (ISO 23273:2013[10]), the UK (ISO 23273:2013[6]), Australia (ISO 23273:2013[142]), South Korea (KS R ISO 23273-2), and Canada (ISO 23273:2013[158]), have adopted the ISO standard.
17.	Fuel-cell installations for industrial trucks	-	IEC 62282-4-102:2017[72]	Australia, Germany, Japan, the UK, and the US have adopted identical or modified versions of the IEC 62282-4-102:2017 standard. India can also adopt the IEC standard after due diligence.
18.	Hydrogen quality for end-use applications	IS 16061:2021[24]	DOE FCEV[171] SAE J2719_202003[126]	The Indian standard is a derivative of the ISO 14687:2019[85]. Other countries – such as Australia and South Korea – have also adopted derivatives of the ISO standard. For mobility applications, the Indian standards can be cross-checked with the DOE FCEV standards for the safe operation of fuel cells.
	Distributed hydrogen use			
19.	Combustion of hydrogen for process heat	-	-	Currently, there are no standards defining the operational parameters and design specifications of equipment for the safe use of hydrogen for process heat applications. India should be proactive in developing the same.
	Hydrogen-fuelled internal combustion engines (ICEs)			
20.	Hydrogen-fuelled ICEs	-	-	Currently, there are no standards governing hydrogen-fuelled ICEs. India should take the lead in developing standards for hydrogen-fuelled ICEs.

No.	Component	Indian standard (IS)	Alternatives	Comments
	Hydrogen-based aviation			
21.	Hydrogen fuel-cell aircraft	-	SAE AIR 6464[125]	India can adopt the SAE AIR 6464 for hydrogen fuel-cell aircraft. This standard has so far been adopted only by the US.
	Hydrogen-based railways			
22.	Hydrogen-based railway locomotives	-	IEC 63341 (Parts 1-3)[71]	Except for the UK (BS EN IEC 63341), no other country has adopted standards for hydrogen-based railway locomotives. India should adopt the IEC standard after conducting feasibility studies.
	Portable fuel cells			
23.	Safety aspects of portable fuel cells	-	IEC 62282-5-100:2018[73]	Countries such as Australia, Canada, Germany, Japan, the UK, and the US have adopted a modified version of the IEC 62282-5-100:2018 standard. India can adopt the IEC standard after due diligence.
	Stationary fuel cells			
24.	Safety aspects of stationary fuel cells	-	IEC 62282-3-100:2019[79]	Australia, Canada, Germany, Japan, South Korea, the UK, and the US have adopted the IEC 62282-3-100:2019 standard. India can also adopt this standard after due diligence.
25.	Safety standards pertaining to micro fuel cells	-	IEC 62282-6-100:2010[82]	Canada, Germany, the Republic of Korea, the UK, and the US have adopted the IEC 62282-6-100:2010 standard. India can adopt this standard after due diligence.
	General hydrogen safety			
26.	Safety in handling hydrogen	IS 15201:2002[32] (reaffirmed in 2014)	ISO/TR 15916:2015[89] NFPA 2 OSHA 1910.103[92]	Countries such as Australia, Germany, Japan, South Korea, and the UK have adopted either identical or modified versions of the ISO/TR 15916:2015 standard, whereas Canada (CAN/BNQ-1784-000/2022[158]), the US (OSHA 1910.103), and India have developed their own.
27.	Leak detection apparatus	IS 16253:2016[27] (reaffirmed in 2021)	ISO 26142:2010[96]	India along with countries such as Australia, Canada, Japan, the UK, and the US have adopted modified versions of the ISO 26142:2010 standard.

Source: Authors' compilation

The development of hydrogen standards will kick-start the implementation of the *National Green Hydrogen Mission.*

Image: iStock

1. Introduction

India has set a target of producing five million tonnes per annum of green hydrogen by 2030[176]. Coherence in safety standards will enable manufacturers, sellers, customers, trade organisations, and regulators to rapidly scale up the green hydrogen ecosystem and facilitate the exchange of technologies and fuels. India's National Green Hydrogen Mission seeks to establish the country as a green hydrogen production hub. The key to implementing such a policy mission at scale are standards, codes, and protocols that are applicable to the entire hydrogen value chain. Safety standards will be instrumental in ensuring single-window clearance of all green hydrogen projects in the country.

Developing and adapting standards for the green hydrogen value chain will be key to implementing the *National Green Hydrogen Mission*

Safety standards are typically designed to safeguard the well-being of the people, processes, and equipment involved in any given industry. They not only prevent the occurrence of hazardous events during the life cycle of the concerned product or process, but also determine the quality of the product itself. There are statutory or advisory bodies which publish these standards. These bodies confirm that the standards are updated in accordance with industry trends and, at times, also verify enforcement. In India, the Bureau of Indian Standards (BIS) is responsible for setting standards for the green hydrogen economy. Globally, there are statutory or advisory bodies such as the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), and the American Society of Mechanical Engineers (ASME), among others, which develop and publish these standards for use. These bodies, listed in Table 1, create consensus-based, market-relevant, consistent standards that provide a structure for the stakeholders involved.

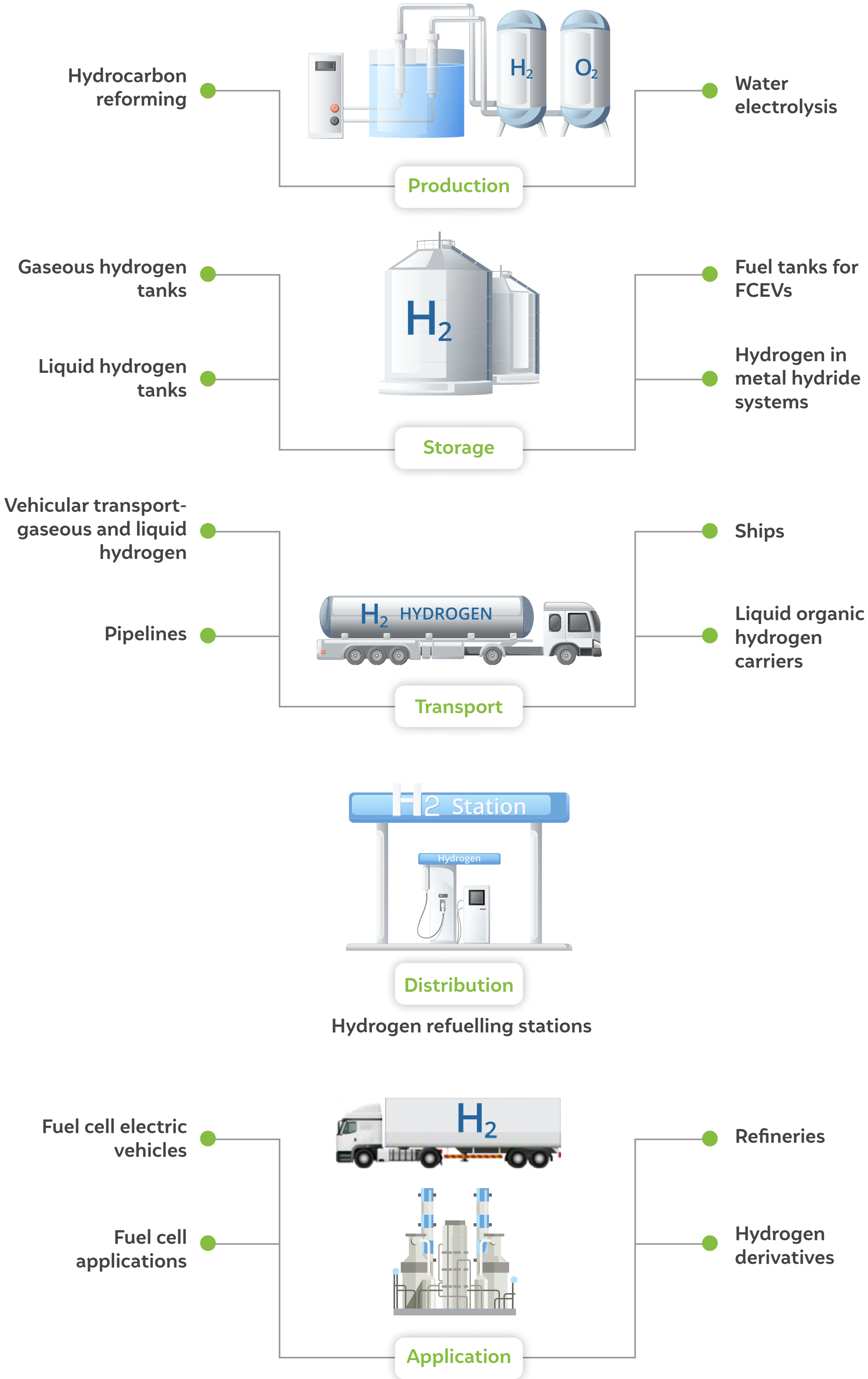
Figure 1 shows the green hydrogen value chain. The hydrogen value chain can be broadly split into five main components: hydrogen production, storage, transportation, distribution, and consumption. The inherent physical and chemical properties of hydrogen allow multiple pathways for its production, transportation, storage, and use. It can be produced through electrolysis or by reforming feedstock fuels, and stored and transported in gaseous, liquid, or metal hydride form. As the global demand for hydrogen fuel is expected to increase considerably in the coming decades, the need for adequate standards is greater than ever. To assess the current requirements for the safe handling of hydrogen in India, this report compares Indian and global standards across the hydrogen value chain. It identifies gaps in existing standards in India and recommends alternatives for adoption. The paper compares hydrogen safety standards in India with those in countries such as Australia, Canada, Germany, Japan, South Korea, the US and the UK. The comparison highlights standards that are popular worldwide so that they may be considered for adoption in India after due diligence.

Table 1 A large number of national and international bodies are developing standards related to hydrogen and its applications

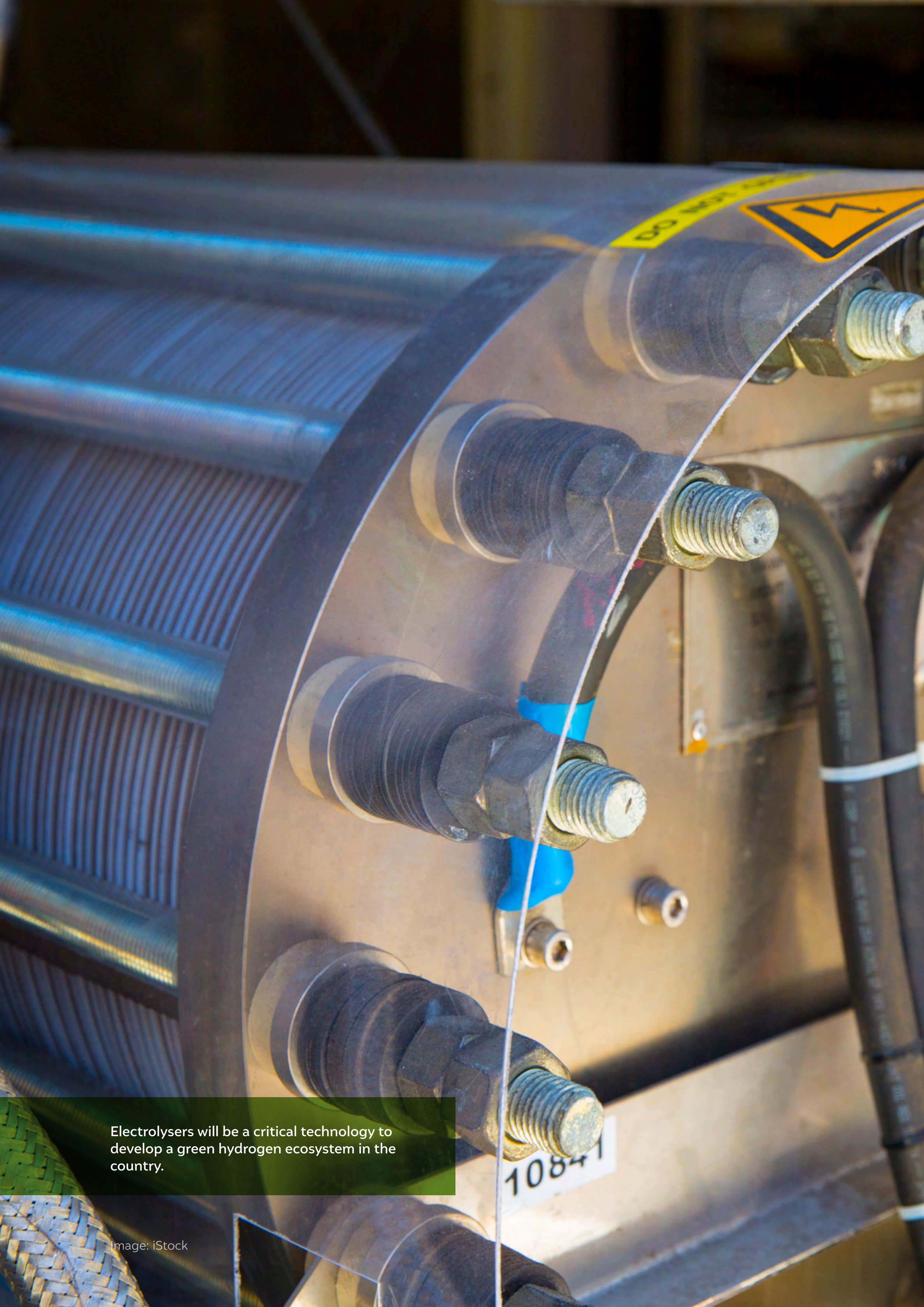
No.	Standard	Jurisdiction	Description
1.	American National Standards Institute (ANSI)	USA	The ANSI is a not-for-profit organisation that develops voluntary, consensus-based standards and codes for products, systems, services, and personnel in the United States.
2.	American Petroleum Institute (API)	Global	The API sets global technical standards for the oil and gas industry to enhance environmental, health, safety, and personnel performance.
3.	American Society of Mechanical Engineers (ASME)	Global	The ASME creates standards worldwide for diverse engineering disciplines such as power plants, elevators, construction equipment, piping, etc.
4.	American Society for Testing and Materials (ASTM)	Global	The ASTM defines standards for test methods, specifications, and regulations for products and services across the globe.
5.	Bureau of Indian Standards (BIS)	India	The BIS is responsible for setting and maintaining standards in India and falls under the purview of the Ministry of Consumer Affairs, Food and Public Distribution, Government of India.
6.	Automotive Research Association of India (ARAI)	India	The ARAI is a cooperative industrial research association of the automotive of the automotive industry, which is affiliated with the Ministry of Heavy Industries, Government of India.
7.	CSA Group (CAN/SA)	USA, Canada, Europe, and Asia	The CSA Group formulates standards across a wide range of areas, including construction and infrastructure, electronics, environment and natural resources, etc.
8.	Compressed Gas Association (CGA)	USA, Canada	The CGA develops specifications and safety standards pertaining to industrial gases, primarily in North America.
9.	United States Department of Energy (DOE)	USA	The DOE is an executive arm of the US government that oversees the national energy policy and mandates standards for topics under its jurisdiction.
10.	European Industrial Gases Association (EIGA)	European Union	The EIGA sets and enforces technical standards for the production and distribution of industrial, medical, and food gases, particularly in the European Union.
11.	International Electrotechnical Commission (IEC)	Global	The IEC is an international organisation that develops and publishes standards for electrical, electronic, and related technologies.
12.	International Organisation for Standards (ISO)	Global	The ISO is a global coalition of national bodies that develops standards to facilitate the trade and exchange of products, processes, and services worldwide.
13.	National Fire Protection Association (NFPA)	Global	The NFPA is an international non-profit organisation that develops standards and safety protocols to eliminate the chance of fire and electrical and related hazards.
14.	Occupational Safety and Health Administration (OSHA)	USA	A wing of the United States Department of Labour, OSHA directs standards for employee safety in the construction, maritime, and industrial sectors.
15.	Society of Automotive Engineers (SAE)	Global	The SAE is a US-based organisation that develops standards for aerospace, automotive, and commercial vehicles.
16.	Underwriters Laboratories (UL)	Global	The UL is a safety organisation that assesses and formulates safety standards for testing, manufacturing, and performance of products globally.

Source: Authors' compilation

Figure 1 Hydrogen value chain



Source: Authors' analysis

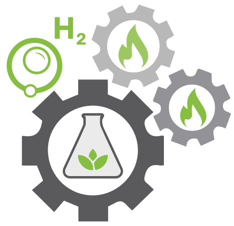


Electrolysers will be a critical technology to develop a green hydrogen ecosystem in the country.

Image: iStock

2. Hydrogen production

Hydrogen can be produced in multiple ways, using renewable electricity, fossil fuels, biomass, or nuclear energy. Depending on the production pathway, hydrogen is categorised as grey, blue, green, turquoise, and pink. Grey hydrogen is produced by conventional processes such as steam methane reforming or coal gasification; Blue hydrogen is also produced by steam methane reforming or coal gasification, but combined with carbon capture.; green hydrogen is produced through water electrolysis using renewable electricity; turquoise hydrogen is produced through natural gas pyrolysis; and pink hydrogen is produced by water electrolysis using electricity produced by nuclear power plants. However, the two main production pathways are hydrocarbon reforming (or gasification) and water electrolysis., as can be seen in Figure 2.



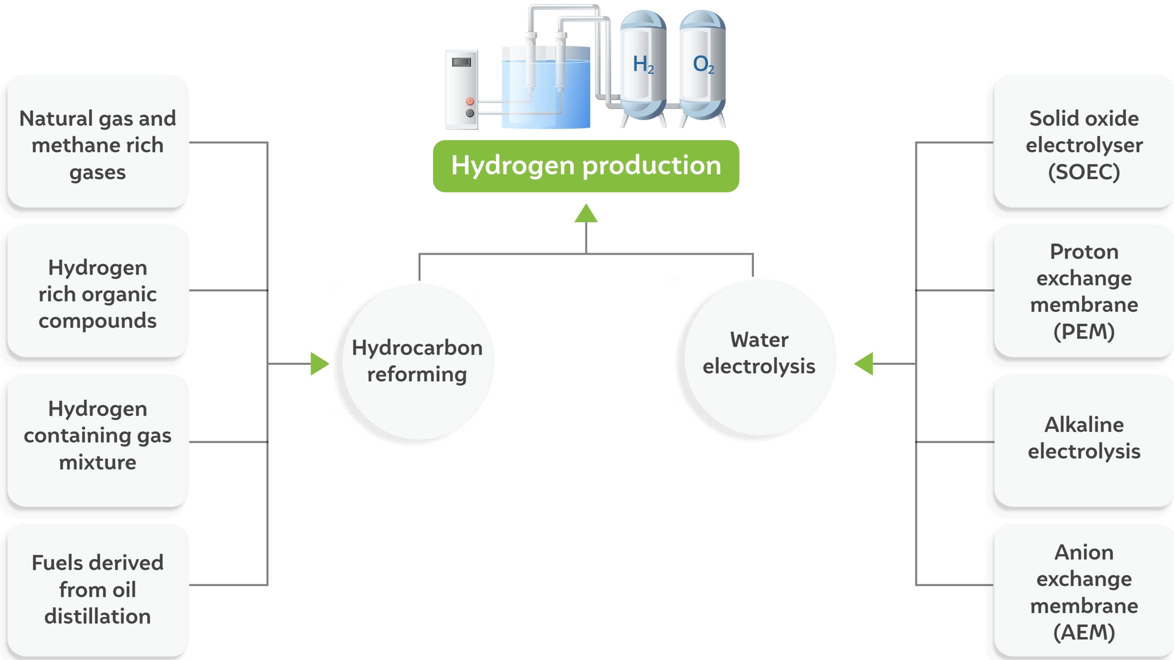
India should develop standards for hydrogen production through alternative paths such as natural gas or biomass pyrolysis

2.1 Standards for hydrogen production

Hydrogen production standards exist for both the hydrocarbon reforming and electrolytic production pathways. The ISO 16110-1:2007 standard is the primary standard for hydrogen produced from feedstock fuels such as natural gas, diesel, liquefied petroleum gas (LPG), coal mine gas, and renewable sources such as biomass. The standards in countries such as India (domestically termed IS 16512 (Part 1):2016), Australia (AS 16110.1:2020[134]), the Republic of Korea (KS B ISO 16110-1[117]), and the UK (BS ISO 16110-1:2007[1]) are derivate of ISO 16110-1:2007.

The predominant standard that governs hydrogen production from water electrolysis is the ISO 22734:2019 standard, as listed in Table 2. The wide scope of this standard encompasses the manufacturing, safety, and performance characteristics of hydrogen production through an electrolyser. It also covers hydrogen generators used for industrial, commercial, and residential purposes. The ISO is now updating this standard (currently under development as the ISO/AWI 22734-1), which will then also cover general requirements, test protocols, and safety standards for electrolysers.

Figure 2 Hydrogen is produced primarily through electrolysis and hydrocarbon reforming



Source: Authors' compilation

As indicated in Table 3, India (IS 16509:2020), Australia (AS 22734:2020[130]), and the UK (BS ISO 22734:2019[64]) have directly adopted or have used modified versions of the ISO 22734:2019 standard for hydrogen production through electrolysis. The ISO standard covers proton exchange membrane (PEM) electrolysers, alkaline electrolysers, and anion electrolyte membrane (AEM) electrolysers. However, from the description, it is unclear if the ISO standard also covers upcoming technologies such as solid oxide electrolyser cells (SOECs). The Underwriters Laboratories (UL) standard (UL LLC 2264A, Edition 2) for electrolytic hydrogen seems more comprehensive. It covers hydrogen generation through various electrolyser technologies, including solid oxide electrolysers. It also describes the codes for installing hydrogen generators in accordance with the NFPA 70 and NFPA 2 hydrogen codes. The outline of this code also aligns with the ISO 22734:2019 standard to improve harmonisation across the globe.

Our assessment indicates that India does not have a standard that defines the specifications for the purification of hydrogen produced from hydrocarbon reforming. Further, India can adopt the ISO/TS 19883:2017[103] standard that prescribes the requirements for stationary and portable pressure swing adsorption (PSA) purification systems. In addition, India (IS 16061:2021), along with Australia (AS ISO 14687:2020[132]) and the Republic of Korea (KS B ISO 14687[111]), has adopted the ISO 14687:2019 standard for minimum quality specifications for the use of PEM stationary and vehicular applications. The ISO 16110-2:2010 standard defines test protocols for performance measurement of hydrogen generation through hydrocarbon reforming. However, the standard to measure the performance of electrolysers used for hydrogen production (ISO/AWI 22734-1) is still under development. India, after due diligence, can adopt the ISO/AWI 22734-1 standard post its development and notification by the ISO.

Table 2 Standards related to hydrogen production

No.	Issuing body	Standard	Description
			Feedstock-based hydrogen production technologies
1.	ISO	ISO 16110-1:2007	This standard is applicable to hydrogen production using hydrocarbon fuels such as natural gas, diesel, and LPG as well as other hydrogen-rich compounds such as methanol, coal mine gas, and renewable sources such as biomass.
2.	AS KS BS	AS 16110.1:2020 KS B ISO 16110-1 BS ISO 16110-1:2007	The Australian (AS), Korean (KS), and British (BS) standards are derivatives of the ISO 16110-1:2007 and are applicable to hydrogen production using hydrocarbon fuels (including biomass).
3.	IS	IS 16512 (Part 1): 2016	The Indian standard is also an adoption of the ISO 16110-1:2007 and is applicable to hydrogen production using hydrocarbon fuels, including biomass.
4.	ISO	ISO/TS 19883:2017	This ISO standard outlines the safety measures, design requirements, commissioning procedures, and operational guidelines for pressure swing adsorption (PSA) systems used in hydrogen purification for industrial and commercial applications, including stationary and skid mounted (portable) systems.
5.	AS	SA TS 19883:2020[29]	The AS standard is a derivative of the ISO/TS 19883:2017 and is applicable to hydrogen purification systems.
6.	NFPA	NFPA 2	The NFPA standard establishes comprehensive safeguards for for the generation, installation, storage, piping, use, and handling of hydrogen in compressed gas or cryogenic liquid form.
			Electrolytic hydrogen production technologies
7.	ISO	ISO 22734:2019	This standard defines the construction, safety, and performance requirements of PEM, AEM, and alkaline water electrolysers for industrial, commercial, and residential use. It is not applicable to hydrogen generation using reversible fuel cells and oxygen produced as a by-product of hydrogen generation.
8.	UL	UL LLC 2264A, Edition 2	The UL outline covers the safety requirements for hydrogen generation using PEM, AEM, SOEC, or aqueous acid or base electrolysers. The UL standard also defines safety procedures for installing hydrogen generation systems according to the NFPA 2 and NFPA 70.
9.	AS BS	AS 22734:2020 BS ISO 22734:2019	These standards are a derivative of the ISO 22734:2019 and are applicable to water electrolysers (AEM, PEM, or alkaline electrolyser).
10.	NFPA	NFPA 2	This standard establishes safeguards for the generation, installation, storage, piping, use, and handling of hydrogen in compressed gas or cryogenic liquid form.
11.	IS	IS 16509:2020	The Indian standard is a derivative of the ISO 22734:2019 and is applicable to hydrogen generation using water electrolysis for industrial and commercial applications.
			Miscellaneous
12.	ISO	ISO 16110-2:2010	This standard codifies the performance measurement of hydrogen generators using hydrocarbon reforming, with a production capacity of less than 400 m3/h under defined conditions.
13.	AS	AS ISO 16110.2:2020[133]	This standard is a derivative of the ISO 16110-2:2010 and outlines the procedures for testing the performance of hydrogen generators using feedstock fuels.
14.	EIGA	EIGA Doc 122/18[58]	This standard comprehensively defines the environmental impacts of the entire hydrogen value chain with respect to energy consumption for generation (feedstock-based generation and electrolytic generation), transportation, storage, and purification.
15.	EIGA	EIGA Doc 155/21[57]	This is a compilation of the best available technologies for the steam methane reforming process for plant sizes greater than 10,000 Nm3/h. It exhaustively defines the process parameters, best available technologies, and emission protocols (air and water) associated with each process and the sub-processes of steam methane reforming in hydrogen production. In addition, it also describes protocols for the management of resources (such as water), by-products, and waste generated during the process.

Source: Authors' compilation

Table 3 Hydrogen production standards categorised by issuing country

No.	Primary standard	Australia	India	South Korea	United Kingdom	Japan	Canada	Germany	United States
1.	Hydrogen generators using hydrocarbon reforming ISO 16110-1:2007	AS 16110.1: 2020	IS 16512:Part 1:2016	KS B ISO 16110-1	BS ISO 16110-1:2007	ISO 16110-1:2007[106]	ISO 16110-1:2007[137]	ISO 16110-1[44]	ISO 16110-1:2007[6]
2.	Hydrogen generators using PEM or alkaline electrolysis ISO 22734:2019[47]	AS 22734:2020	IS 16509:2020	-	BS ISO 22734:2019	ISO 22734: 2019[107]	ISO 22734: 2019[138]	ISO 22734: 2019[45]	ISO 22734:2019[7]

Original standard   Modified adoption   Direct adoption

Source: Authors' compilation

2.2 Gaps in hydrogen production standards

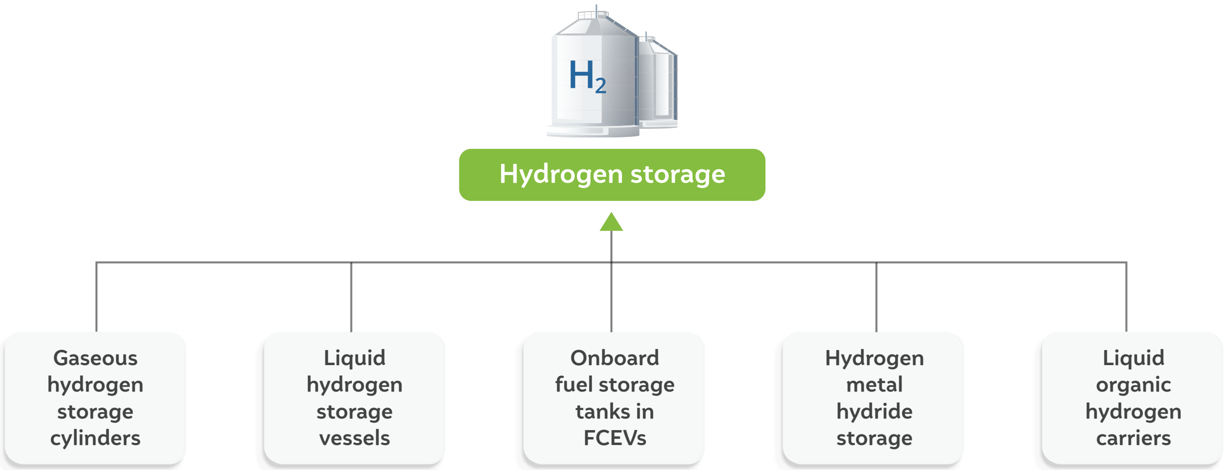
- It is essential to note that there are no standards for hydrogen production through other alternative means such as natural gas or biomass pyrolysis. India should be proactive and develop standards for these methods since these alternative methods could be a bridge between grey and green hydrogen.
- The Indian standard is a modified adoption of the ISO 22734:2019[87]. However, although it covers PEM, AEM, and alkaline water electrolysers, it does not cover SOECs.
- The current standards adopted for feedstock-based hydrogen production technologies do not define requirements and protocols for efficient resource use and effluent management.

3. Hydrogen storage

Gaseous hydrogen tube trailers use high-pressure steel or composite cylinders to store and transport hydrogen.

Hydrogen storage will be critical to manage intermittency of renewables like wind and solar. Figure 3 shows the various hydrogen storage pathways. Hydrogen can be stored phsysically (in tanks and cylinders) or chemically (energy carriers). Gaseous and liquid hydrogen are stored and transported in tanks and cylinders. It can also be stored in metal hydride compounds that absorb and release hydrogen under specific thermodynamic conditions. Chemical carriers of hydrogen include liquid organic hydrogen carriers (LOHCs), ammonia, and methanol. LOHCs are effective alternatives to conventional storage solutions as the hydrogen chemically bonds to a stable organic liquid carrier, reducing the need for compression and making the transport of hydrogen more cost-efficient. Ammonia and methanol are green hydrogen derivatives that find applications across various industries and are discussed in subsequent sections.

Figure 3 There are multiple hydrogen storage pathways, based on capacity, transport distance, and application



Source: Authors' compilation

3.1 Standards for hydrogen storage

The standards for hydrogen storage, as shown in Table 4, provide guidelines for the construction and usage of hydrogen storage systems. Organisations such as the ISO (ISO 11114-4:2017[104]) and the ASME (ASME STP/PT-003-2005) have developed standards for storing gaseous hydrogen. Further, the ISO (ISO 13985:2006) and the EIGA (EIGA Doc 06/19) have standards for liquid hydrogen storage. The NFPA (NFPA 55) standard covers both gaseous and liquid hydrogen storage. Currently, India (IS 7285:Part 1:2018[31]), along with Australia (ISO 11114-4:2017), Canada (ISO/DIS 15399[152]), and Germany (DIN EN ISO 19884[41]), has standards for storage of gaseous and liquid hydrogen storage derived from the ISO standard (ISO 13985:2006). However, it is worth mentioning that Germany still uses standards (DIN EN ISO 19884) that the ISO has since withdrawn (ISO/FDIS 19884). In addition, the IS 7285:Part 1:2018 defines standards for only up to 400 litres. India can explore revising the standard for larger cylinder sizes.

All countries considered in this analysis have adopted standards for the on-board storage of hydrogen as a fuel for FCEVs. However, Canada and the UK still prescribe the ISO/TS 15869:2009 standard, which has already been withdrawn and updated with the ISO 19881:2018. Countries such as Australia, Germany, and the US have adopted the ISO 19881:2018 standard. Apart from the above standards, the Compressed Gas Association (CGA) has developed a set of standards for hydrogen storage in gaseous and liquid forms. The CGA H-3[39] prescribes standards for cryogenic hydrogen storage, and the CGA PS-34[36] defines standards for hydrogen storage and dispensation in general. The CGA has also developed standards such as the CGA H-1 and CGA H-2 for metal hydride–based hydrogen storage systems. They provide guidelines for service conditions and for classifying and labelling such storage systems. India also has standards (IS 16735:2018) for on-board storage of compressed hydrogen gas as fuel in FCEVs.

Table 4 Hydrogen storage standards

No.	Issuing body	Standard	Description
			Storage vessels and cylinders (gaseous hydrogen)
1.	ISO	ISO 11114-4:2017	This standard specifies the test methods for the selection of seamless steel for storing hydrogen and hydrogen-containing embrittling gas in cylinders of size up to 3000 litres.
2.	ISO	ISO 16964:2019	This standard defines the specification and testing requirements for high-pressure flexible hose assemblies applicable to use in gas cylinders, bundles of cylinders, and trailers. It also defines the pressure and temperature range of these flexible hose assemblies, which operate under a pressure of up to 1000 bar and a temperature range of -40^{0}C to +65^{0}C. However, this standard is not applicable to flexible rubber and plastic hose assemblies used for welding, cutting, and other related processes of up to 45 MPa (450 bar), for use with medical gas systems for commercial use, and for liquid petroleum gas cylinders.
3.	ISO	ISO 7539-11:2013	This standard defines the testing procedures for investigating the susceptibility of the metal, including alloys,to hydrogen embrittlement and hydrogen-assisted cracking.
4.	ISO	ISO 9587:2007	This standard defines the stress relief requirements for high strength steel to reduce their susceptibility to hydrogen embrittlement in pretreatment, electroplating, autocatalytic plating, chemical conversion and phosphating processes. This is only applicable to steels whose properties are not affected after heat treatment at temperature a range of 19^0-23^{0}C.
5.	ISO	ISO 9588:2007	This standard specifies the procedure to reduce susceptibility of hydrogen embrittlement that can occur during surface finishing processes. The heat treatment process defined ,reduces the risk of embrittlement for iron and steel.
6.	ASME	ASME STP/PT-003-2005	This standard defines the design, manufacturing, and testing aspects of all pressurised hydrogen storage tanks, transportation piping, and pipelines up to 15,000 psi. It also reviews existing codes and standards and develops data for service experience, leak tightness performance, surface conditions for piping, etc.
7.	AS	STP-PT-014-2008	This standard defines the design, safety, and testing standards for composite storage cylinders for hydrogen applications. It includes extensive testing procedures such as failure modes, effect analysis, cyclic fatigue, and stress rupture tests and also accounts for field service issues.
8.	IS	IS 7285:Part 1:2018	This standard defines the specifications for the material, design, and manufacturing processes for refillable normalised or tempered seamless steel gas cylinders of water capacities from 0.5 litres up to and including 400 litres for compressed, liquefied, and dissolved gases.
9.	IS	IS 8198:2004	This standard covers the code of practice for filling, inspecting, testing, maintaining, and use of portable steel cylinders for the storage and transportation of hydrogen gas and high-pressure liquefiable gases in cylinders exceeding 500-ml water capacity.
10.	DIN	DIN EN ISO 19884	This standard defines specifications for cylinders and tubes used for stationary storage of gaseous hydrogen. This German standard is a derivative of the ISO 19884 standard that has been withdrawn and is no longer used.
11.	CGA	CGA PS-34	This CGA standard describes requirements for hydrogen storage, use, and dispensation.
			Storage vessels and cylinders (liquid/cryogenic hydrogen)
12.	EIGA	EIGA Doc 06/19	This document outlines the layout, design, operational parameters, and safety standards for stationary storage and bulk transportation of liquid hydrogen through tankers and tank containers by road, sea, and rail to fixed storage users. This standard does not apply to portable tanks such as pallet tanks and liquid cylinders.

No.	Issuing body	Standard	Description
13.	ISO	ISO 13985:2006	This standard defines the construction and testing requirements for refillable fuel tanks for liquid hydrogen used in land vehicles. It is specifically applicable to fuel tanks that are permanently attached to the vehicle.
14.	IS BS KS	IS 13985:2006 BS ISO 13985:2006[22] KS B ISO 13985[70]	These standards outline the construction and testing requirements for refillable liquid hydrogen fuel tanks used in land vehicles and are derivatives of ISO 13985:2006
15.	NFPA	NFPA 55	This code provides the safety guidelines for the installation, storage, use, and handling of compressed gas and cryogenic fluids in stationary and portable cylinders and tanks.
16.	CGA	CGA H-3	This standard is applicable to liquid hydrogen storage tanks with allowable working pressures of up to 175 psi.
17.	CGA	CGA P-41	This standard defines the specifications for the location, installation, and operation of bulk storage systems in enclosures where reduced airflow can create an oxygen-deficient or oxygen-enriched atmosphere. This standard is applicable only for bulk cryogenic storage systems, not for compressed gas storage systems.
18.	CGA	CGA P-17	This standard defines the specifications for the general design and minimum criteria for underground installation of liquid hydrogen storage tanks.
19.	CGA	CGA H-5	This standard defines the specifications for the safe design, installation and use of bulk hydrogen supply systems that include gaseous/cryogenic hydrogen storage tanks (above or below ground), vaporisers , valves, piping, cryogenic pumps and compressors, monitoring and control systems. This standard specifies requirements for supply systems upto 15,000 psi of gaseous hydrogen and 5000 scf of liquid hydrogen.
	On-board hydrogen storage for FCEVs		
14.	ISO	ISO 19881:2018	This document defines material, design, manufacturing, and marking standards for fuel tanks carrying fuel-cell-grade compressed gaseous hydrogen. This standard is applicable to on-board fuel containers for use in light-duty vehicles, heavy-duty vehicles, and industrial-powered trucks.
15.	IS	IS 16735:2018	This standard specifies the requirements for refillable cylinders (metal and composite) of capacity less than 500 litres and intended for on-board storage of compressed hydrogen gas or hydrogen gas blends to be used as a fuel in automotive vehicles.
	Miscellaneous		
16.	EIGA	EIGA Doc 100/03/E[61]	This comprehensive document provides guidelines for the testing of portable high-pressure hydrogen cylinders and vessels that are applicable for use individually, in a bundled form, and on trailers.

Source: Authors' compilation

Table 5 Hydrogen storage standards categorised by issuing country

No.	Primary standard	Australia	Canada	Germany	India	South Korea	United Kingdom	United States
1.	Storage vessels and cylinders (gaseous hydrogen) ISO 19881:2018	AS ISO 19881:2020	*ISO/DIS 15399	*DIN EN ISO 19884	IS 7285:Part 1:2018	KS B ISO 19881	BS ISO 19881:2018	ISO 19881:2018[8]
2.	Storage vessels and cylinders (liquid/ cryogenic hydrogen/ On-board) ISO 13985:2006	ISO 13985: 2006[140]	ISO 13985: 2006[154]	ISO 13985[47]	IS 13985:2006	KS B ISO 13985	BS ISO 13985:2006	ISO 13985:2006
3.	On-board hydrogen storage for FCEVs ISO 19881:2018	ISO 19881:2018[139]	*ISO/TS 15869: 2009[153]	ISO 19881[46]	IS 16735:2018	KS B ISO 19881	DD ISO/TS 15869:2009	ISO 19881:2018

Original standard   Modified adoption   Direct adoption

Source: Authors' compilation

Note: *Direct/modified adoption of an outdated ISO standard

3.2 Gaps in standards for hydrogen storage

- It is not clear whether the IS 8198:2004 is an original standard or a derivative of ISO. However, since India aims to be a hydrogen hub, storage standards should comply with requirements across the globe. India can also consider adopting the best features of other standards such as those by ASME and NFPA.
- The Indian standards can be made more stringent by conducting an adequacy assessment and comparing them with standards such as the EIGA Doc 06/19 and NFPA 55.

Hydrogen transportation is critical for achieving the targets set in NGHM as major demand nodes of hydrogen are far away from locations with good RE potential.

Image: iStock

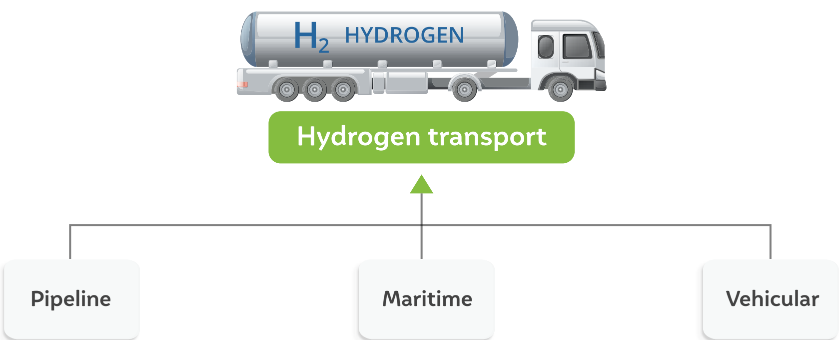
4. Hydrogen transportation

Hydrogen can be transported in different ways depending on the volume to be moved. For bulk transport, dedicated pipelines to areas of demand can be deployed, while for smaller volumes, storage tanks mounted on vehicles can be used. The mode of transport also depends on other factors such as the delivered cost of hydrogen, distance, climatic conditions, and most importantly, the state of hydrogen (i.e., whether it is in gaseous, liquid, or cryogenic form).

4.1 Standards for hydrogen transportation

The ASME B31.12-2019 standard outlines the requirements for pipeline transportation of gaseous hydrogen. The US and the UK have adopted the ASME B31.12-2019 for the transportation of gaseous and liquid hydrogen in pipelines. The ASME standard comprehensively describes the material, welding, testing, and operation requirements of pipelines. It also details requirements for the maintenance of transport pipelines and the design, construction, and testing of industrial piping systems. Similarly, the CGA G-5.6 and EIGA Doc 121/14 standards outline the specifications for the safe design, operation, and maintenance of transmission and distribution of pure hydrogen and hydrogen-blended gases through pipelines. The gap analysis also indicates that India, along with Australia, Germany, Canada, and the Republic of Korea, needs to have standards for hydrogen pipelines. Therefore, it should adopt a standard that amalgamates the best practices of all the existing standards on hydrogen pipelines. The ASME is expected to update the existing the ASME B31.12-2019 standard to include steel pipes for the transport of gaseous hydrogen. India should therefore adopt the updated standard after due diligence. It is worth mentioning that the ISO 19880-1:2020 standard specifies requirements for hydrogen pipelines as part of the delivery systems for hydrogen refuelling stations. However, there is ambiguity about whether this is applicable to purpose-built pipelines for transporting hydrogen. A deeper understanding of this standard is required through adequacy assessment.

Figure 4 Pathways for transport of hydrogen



Source: Authors' compilation

International standards such as the ISO 19881:2018 define the materials, design, and manufacturing requirements of storage containers carrying fuel-cell-grade compressed gaseous hydrogen for land vehicle operation. This standard is specific to containers which are permanently attached, with a water capacity of 1000 litres and an upper working pressure limit of 70 MPa. India has developed and adopted the IS 8198:2004 standard that outlines protocols for hydrogen transport. However, it is not clear whether the Indian standard is a derivative of the ISO 19881:2018. Other countries – such as the Republic of Korea (KS B ISO 19881[114]), Australia (ISO 19881:2018), Germany (ISO 19881), the UK (BS ISO 19881:2018[21]), and the US (ISO 19881:2018) – have adopted modified versions of the ISO standard. Hydrogen storage in metal hydrides is particularly useful as it can then be transported in solid form and retrieved under specific thermodynamic conditions. The ISO 16111:2018 standard is the only one of its kind that defines the material, design, construction, and testing requirements for metal hydride assemblies exclusively meant for hydrogen storage and transportation. India should adopt this standard after carrying out the required modifications for domestic requirements.

Table 6 Hydrogen transportation standards

No.	Issuing body	Standard	Description
1.	ASME	ASME B31.12-2019	This comprehensive document includes standards for the design, construction, operation, and maintenance of piping in gaseous and liquid hydrogen service and gaseous hydrogen pipelines. It includes guidelines for material fabrication, material selection, welding, installation, and testing of hydrogen piping and pipelines.
2.	EIGA	EIGA Doc 121/14	This extensive document defines the design, construction, and operational requirements of hydrogen pipelines. It also includes granular aspects of pipelines such as metal compatibility, valve equipment, venting and pressure relief systems, safety management systems, etc.
3.	EIGA	CGA G-5.6	This document defines the standards for the safe design, operation, and maintenance of transmission and distribution systems for pure hydrogen and hydrogen-blended gases in hydrogen pipelines in the temperature range of -40 ^{0}C to 175 ^{0}C and pressure range of 1 MPa to 21 MPa. This standard includes specific guidelines for the transmission of ultra-high-purity hydrogen.
4.	DoT	DoT 49 CFR 170-192[172]	This US Department of Transportation (DOT) standard outlines the regulations for transporting flammable gases in pipelines. It includes the requirements for the materials, pipe design, welding, joining, and corrosion control as well as the testing protocols for the pipeline infrastructure.
	On-board hydrogen storage for transporting hydrogen		
5.	ISO	ISO 19881:2018	This standard defines the material, design, manufacturing, and marking requirements for storage containers carrying fuel-cell-grade compressed gaseous hydrogen for land vehicle operation. This is specific to containers that are permanently attached with a capacity of 1000 litres of water and an upper working pressure limit of 70 MPa.
6.	ISO	ISO 13985:2006	This standard specifies the manufacturing requirements for liquid hydrogen refillable fuel tanks used in land vehicles. It also defines the testing methods required to ensure safety. It is only applicable to fuel tanks intended to be permanently attached to land vehicles.
7.	KS BS	KS B ISO 19881 BS ISO 19881:2018	These Korean and British standards are derivatives of the ISO 19881:2018, for hydrogen storage tanks specifically transported by land vehicles.
8.	ISO	ISO 16111:2018	This standard specifies the material, design, construction, and testing requirements of transportable reversible metal hydride gas storage systems with a maximum developed pressure limit of 25 MPa. It also includes guidelines for the service parameters, design specifications, etc. for storage systems.

No.	Issuing body	Standard	Description
			Maritime transport of hydrogen
9.	MSC	IGC code / MSC.420(97)	The IGC code provides an international standard for the safe bulk carriage of liquefied gases. It applies to shipping vessels, irrespective of their storage capacity, including vessels of less than 500 gross tonnage, which are equipped to carry liquefied gases having a vapour pressure exceeding 2.8 bar absolute, at a temperature of 37.8 ºC.

Source: Authors' compilation

Note: *Direct/modified adoption of an outdated ISO standard

Table 7 Hydrogen transportation standards categorised by issuing country

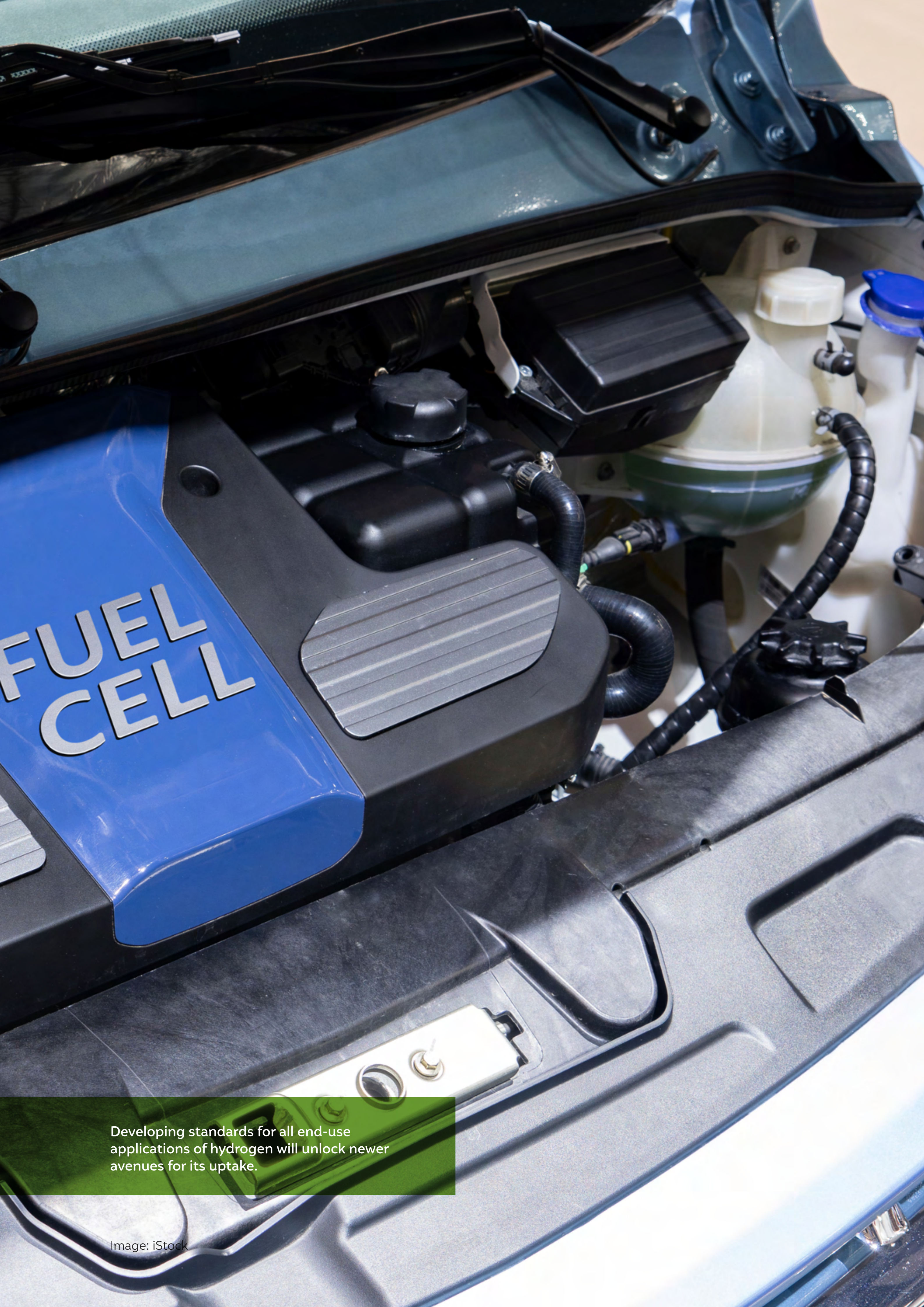
No.	Primary standard	Australia	Canada	Germany	India	South Korea	United Kingdom	United States
1.	Hydrogen pipelines ASME B31.12-2019	-	-	-	-	-	ASME B31.12-2019	ASME B31.12-2019
2.	On-board gaseous storage vessels for transport ISO 19881:2018	ISO 19881:2018	ISO 19881:2018	ISO 19881	IS 8198:2004 (reaffirmed in 2019)	KS B ISO 19881	BS ISO 19881:2018	ISO 19881:2018
3.	On-board liquid storage vessels for transport ISO 13985:2006	ISO 13985: 2006[141]	ISO 13985:2006	ISO 13985[48]	IS 13985:2006	KS B ISO 13985	BS ISO 13985:2006	ISO 13985:2006[9]
4.	Hydrogen storage for transporting hydrogen – reversible metal hydride ISO 16111:2018	AS ISO 16111:2020	ISO 16111: 2018[156]	ISO 16111	-	ISO 16111:2018	ISO 16111:2018	ISO 16111:2018
5.	Liquid organic hydrogen carriers (LOHCs)	-	-	-	-	-	-	-

Original standard **Modified adoption** **Direct adoption**

Source: Authors' compilation

4.2 Gaps in standards for hydrogen transportation

- The IS 8198:2004 standard is valid for the storage and transport of gaseous hydrogen. However, from the description, it is unclear whether the IS 8198:2004 is a derivative of the ISO 19881:2018.
- There are no Indian standards for hydrogen pipelines. Germany, South Korea, Australia, and Japan also do not have standards for hydrogen pipelines.
- India does not have standards for metal hydride storage of hydrogen, while countries such as Australia, Canada, Germany, Japan, Korea, the UK, and the US have adopted the prescribed ISO standard.



Developing standards for all end-use applications of hydrogen will unlock newer avenues for its uptake.

Image: iStock

5. Hydrogen applications

Hydrogen is used in fuel-cell-based vehicles, trucks, buses, forklifts, aircraft, railways and as a stationary fuel. In addition, it is also used to produce derivatives such as ammonia, methanol, etc. Another upcoming distributed use of hydrogen is as an alternative feedstock fuel in emission-intensive industries such as steel, cement, fertilisers, etc. The following section discusses the standards related to these applications in detail.

5.1 Standards for hydrogen-powered vehicles, fuel cells, and distributed use

The standards related to hydrogen applications are listed in Table 8. Globally, the most popular standards related to hydrogen-powered vehicles are formulated by the ISO. The Bureau of Indian Standards (IS standards for short) has adopted existing ISO standards such as the ISO 12619 (domestically termed as IS/ISO 12619-1) and ISO 23828:2022 (domestically termed as IS 23828:2013[34]) for fuel system components and performance measurement of fuel-cell-powered road vehicles. However, India lacks standards for fuel cells, FCEVs in general, and fuel-cell-based aircraft and hydrogen-propelled railway locomotives. Countries such as Canada, Japan, Australia, the UK, and the US have proactively adopted some or all of the standards related to the aforementioned areas. India also lacks standards for essential safety components – such as thermally activated pressure relief valves (as defined by the ISO 19882:2018), for use in compressed hydrogen fuel containers of FCEVs. India should therefore explore the adoption of standards such as the ISO 23273:2013 and SAE J2578_201408 that outline the safety, design, construction, operation, and maintenance aspects of FCEVs. In addition, India should also explore adopting standards such as the CSA HPIT 1-2015 (which include standards for heavy-duty industrial vehicles) and SAE J2579_201806 (which defines the design, construction, and operational requirements for on-road vehicles). It is essential to mention that these standards can be domestically adopted after a thorough study to match local needs and conditions.

Table 8 Standards related to hydrogen-powered vehicles

No.	Issuing body	Standard	Description
	On-board hydrogen fuel system for consumption in FCEVs		
1.	ISO	ISO 12619	This standard applies to compressed gaseous hydrogen (CGH2) and hydrogen/natural gas (H2/NG) blends fuel system components intended for use in vehicles defined by the ISO 3833:1977 standard. It does not apply to liquid hydrogen fuel tanks, fuel containers, etc.
2.	IS BS	IS/ISO-1 12619 BS ISO 12619-1:2014[66]	These standards are derivatives of the ISO 12619 and are applicable to CGH2 and H2/NG blends fuel system components, such as gas-tight housing and ventilation hoses.

No.	Issuing body	Standard	Description
3.	ISO	ISO 19882:2018	This standard applies to gaseous hydrogen/thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers that adhere to the ISO 19881, IEC 62282-4-101, ANSI HGV 2, CSA B51 Part 2 standards. These fuel containers are used in commercial and industrial FCEV vehicles.
4.	KS BS	KS B ISO 19882[115] BS ISO 19882:2018[63]	These Korean and British standards are derivatives of the ISO 19882:2018 and define standards for thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers.
5.	CSA	CSA HPIT 1-2015	This standard establishes the basic requirements for the material selection, design, manufacturing, and testing of compressed hydrogen gas fuel system components (such as valves, pressure gauges, filters etc.), refillable containers used in industrial trucks, or other heavy-duty industrial applications.
	Fuel cells		
6.	SAE	SAE J2579_201806	This standard defines the design requirements, construction and operational parameters, and maintenance requirements for hydrogen fuel storage and handling systems for on-road land vehicles.
7.	SAE	SAE J3089_201810[122]	This standard provides the test methods for evaluating the hydrogen sensors used in FCEVs.
8.	ISO	ISO 23273:2013	This standard defines the safety requirements of gaseous hydrogen–powered fuel-cell vehicles. It also includes standards benchmarking the quality of fuel for the same purpose.
9.	KS	KS R ISO 23273-2	This standard is a derivative of the ISO 23273-2:2006 and deals with the safety aspects of FCEVs. It is based on an outdated ISO standard, which has since been revised to the ISO 23273:2013.
	Overall FCEVs		
10.	SAE	SAE J2578_201408	This standard relates to the overall design, construction, operation, and maintenance of FCEVs. It defines safety aspects for the integration of the fuel-cell system with the fuel storage system.
11.	AIS	AIS-157	This Indian Automotive Industry (AIS) standard is applicable to compressed gaseous hydrogen–fuelled fuel-cell vehicles. It is applicable to FCEVs manufactured by original equipment manufacturers (OEMs) and not for retrofitted or converted fuel-cell vehicles.
12.	AIS	AIS-137 (Parts 1-8)	This AIS standard defines the testing procedure for assessing safety requirements and for measuring the conformity of production. It includes the testing procedure for other fuels apart from hydrogen-like LPG, NG/bio-methane, and flex-fuel H_2/NG.
13.	EC	EC 79/200	This European Commission standard specifies the requirements for hydrogen-powered vehicles, including the safety specifications in case of impact and electrical safety. It also specifies the design parameters of hydrogen components and the systems used in hydrogen-powered motor vehicles.
14.	GTR	GTR-13	This Global Technical Regulations (GTR) standard covers the general requirements of all the systems and components of a fuel-cell vehicle. It defines the safety, design, and performance requirements of the fuel system and the storage of compressed hydrogen.
	Hydrogen quality for fuel cells		
15.	DOE	DOE FCEV	This extensive report includes standards and protocols for maintaining hydrogen fuel quality, particularly for PEM fuel cells used in road vehicles. It also includes extensive testing standards for PEM-based FCEVs.
16.	ISO	ISO 14687:2019	This document specifies the minimum quality requirements of hydrogen fuel for utilisation in vehicular and stationary applications that deploy PEM fuel cells.

No.	Issuing body	Standard	Description
17.	IS AS KS	IS 16061:2021 AS ISO 14687:2020 KS B ISO 14687[116]	These standards are derivatives of the ISO 14687:2019 and specify the minimum quality requirements for hydrogen used in vehicular and stationary applications.
18.	SAE	SAEJ2719_202003	This standard specifies the requirements for hydrogen fuel quality for commercially used proton exchange membrane (PEM) fuel cells in vehicles.
	Performance measurement of vehicular fuel-cell modules		
19.	ISO	ISO 23828:2022	This standard specifies the protocols for measuring the energy consumption and driving range of fuel-cell passenger cars and light-duty trucks that use compressed hydrogen.
20.	IEC	IEC 62282-4-102:2017	This standard covers the performance test methods for gaseous hydrogen and direct methanol-fuelled fuel cells, specifically for industrial trucks. It applies to DC fuel-cell power systems with an output voltage of less than 150 V.
21.	IEC	IEC 62282-4-101:2022	This standard defines the safety requirements of fuel-cell power systems designed for use in electrically powered industrial trucks. They are intended for use in industrial vehicles powered by gaseous hydrogen and methanol fuel-cell power systems.
22.	IS	IS 23828:2013	This standard is a derivative of the ISO 23828:2013 and covers the measurement of energy consumption and range of FCEVs (passenger vehicles and light-duty trucks).
	Hydrogen-based aviation		
23.	SAE	SAE AIR 6464	This standard defines the technical requirements for the integration of proton exchange membrane (PEM) fuel-cell systems, fuel storage, fuels (gaseous/liquid hydrogen), fuel injection, and electrical systems with the aircraft.
24.	SAE	EUROCEA / AIR 6464	This standard outlines the safety guidelines for hydrogen fuel cells in aircraft. It defines the technical specifications for the safe integration of PEM-based fuel-cell modules, fuels (compressed hydrogen/liquid), fuel storage, fuel injection, and electrical systems.
	Hydrogen-based railways		
25.	IEC	IEC 63341 (Parts 1-3)	This series of standards define the safety, design, performance requirements, and testing methods for fuel-cell-powered railway locomotives.
	Hydrogen-based shipping		
26.	ADN	ADN 2005	The European Parliament defines the specifications for international carriage of dangerous good like hydrogen and hydrogen containing compounds.

Source: Authors' compilation

The IEC is the primary international body responsible for creating and implementing standards related to fuel cells, among other areas. The IEC 62282 code is the most comprehensive standard related to the safety, performance assessment, installation, and balance of plant systems associated with fuel cell systems. Table 9 lists the safety standards associated with portable, stationary fuel-cell modules and micro fuel cells. Parts 2 and 3 of this standard (listed as IEC 62282-2-100:2020[2] and IEC 62282-3-100:2019[3] respectively) define safety specifications for the design, construction, operation, and testing procedures of stationary fuel cell modules. Similarly, part 5 (listed as IEC 62282-5-100:2018) defines the safety specifications for portable fuel cells, and part 6 (termed as IEC 62282-6-100:2010[74]) outlines the specifications for wearable micro fuel cells. Countries such as Germany and the European Union have proactively adopted these standards to facilitate their commercial adoption.

Fuel cells are, in simple terms, power plants that convert chemical energy (from fuels such as hydrogen, ammonia, and methanol) into electrical energy. They are gaining traction as decades of ongoing research is coming to fruition. Typically, supply chains for complex systems such as this involve designs and components that are distributed across manufacturing hubs around the globe. Consequently, the harmonisation of standards, with necessary tweaks to match local conditions, is essential for the early commercialisation of fuel cells. Table 9 compares the standards related to fuel-cell safety. India lags particularly in the development and adoption of standards for fuel cells, while countries such as Australia, Canada, Germany, Japan, the UK, and the US have all adopted the relevant standards (the IEC 62282 series). India should consider adopting this series of standards after conducting the requisite feasibility studies.

It is important to note that currently, there are no standards that exclusively prescribe the safety and operational requirements for hydrogen combustion for process heat applications. Since hydrogen has the potential to replace fossil fuels in the production of process heat for industrial applications, India, along with other international standardisation bodies, should develop standards for hydrogen combustion and related apparatus for process heat applications.

Table 9 Standards related to hydrogen-powered fuel cells

No.	Issuing body	Standard	Description
			Portable fuel-cell modules
1.	IEC	IEC 62282-5-100:2018	This document defines standards for the construction, safety, and test requirements of portable fuel-cell power systems intended for electricity production. It is applicable to AC and DC portable fuel cell power systems with output voltages of up to 600 V (for AC) or 850 V (for DC), for indoor and outdoor use.
2.	ANSI	ANSI/FC 3-2004 (R2017)[5]	This standard applies to AC/DC portable fuel-cell power systems with a rated output voltage not exceeding 600 V, for commercial, industrial, and residential indoor and outdoor use.
			Stationary fuel-cell modules
3.	IEC	IEC 62282-2-100:2020	This standard provides safety specifications for the construction, operation, and testing of fuel-cell modules under standard and non-standard conditions. It is specific to conditions that can be hazardous to the environment the fuel cell is installed in.
4.	IEC	IEC 62282-3-100:2019[80]	This standard is applicable to the safety and testing of stationary, self-contained fuel-cell power systems which generate electricity through electrochemical reactions. It is applicable to fuel-cell systems with a wide variety of fuel inputs such as hydrogen, natural gas, methane-rich gases derived from renewable (biomass) or fossil-based sources, landfill gas, digester gas, and coal mine gas.
5.	NFPA AS	NFPA 853121 AS 62282.2.100:2022[135]	This standard defines the fire prevention and protection protocols for the safety of facilities that use stationary fuel-cell systems of all capacities. This Australian standard, which is a derivative of the IEC 62282-2-100:2020, defines the safety requirements for fuel-cell modules.
			Micro fuel cells
6.	IEC	IEC 62282-6-100:2010	This standard covers the safety aspects of wearable or easily transportable micro fuel cells that do not provide a DC output greater than 60 V.
7.	DIN EN	DIN EN 62282-6-100 IEC 62282-6-100:2010/AMD1:2012	These German and European standards are derivatives of the IEC 62282-6-100:2010.

Source: Authors' compilation

Table 10 Standards related to hydrogen-powered vehicles categorised by issuing country

No.	Primary standard	Australia	Canada	Germany	India	Japan	South Korea	United Kingdom	United States
	On-board hydrogen fuel system								
1.	Compressed gaseous hydrogen (CGH_2) and hydrogen/natural gas (H_2/NG) blends fuel system (general requirement) ISO 12619	ISO 12619-1:2014[150]	ISO 12619-1:2014[166]	ISO 12619-1[56]	IS/ISO 12619-1	ISO 12619-1:2014	-	BS ISO 12619-1: 2014	ISO 12619-1:2014[18]
2.	Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers ISO 19882:2018	ISO 19882: 2018[146]	ISO 19882: 2018[163]	ISO 19882[53]	-	ISO 19882: 2018108	KS B ISO 19882	BS ISO 19882:2018	ISO 19882: 2018[15]
	Overall FCEVs								
3.	General safety of fuel-cell vehicles ISO 23273:2013	ISO 23273: 2013[142]	ISO 23273:2013	ISO 23273[52]	AIS-157	-	KS R ISO 23273-2	ISO 23273: 2013[68]	ISO 23273: 2013[10]
4.	Fuel-cell installations in industrial trucks/forklifts IEC 62282-4-101:2022	IEC 62282-4-101[144]	IEC 62282-4-101:2022[159]	IEC 62282-4-101:2022[77]	-	JIS C 62282-4-101	-	IEC 62282-4-101:2022[69]	IEC 62282-4-101 Ed. 2.0 b:2022[11]
	Fuel cells								
5.	Fuel-cell safety (portable fuel cells) IEC 62282-5-100:2018	IEC 62282-5-100:2018[148]	IEC 62282-5-100:2018[160]	IEC 62282-5-100:2018[50]	-	JIS C 62282-5-100	-	BS EN IEC 62282-5-100:2018 – TC	IEC 62282-5-100:2018[78]
	Performance measurement of vehicular fuel-cell modules								
6.	Fuel-cell road vehicles — energy consumption measurement ISO 23828:2022	ISO 23828: 2013[151]	ISO 23828: 2008[157]	ISO 23828[51]	IS/ISO 23828: 2013[34]	-	-	BS ISO 23828:2013	ISO 23828: 2022[13]
	Hydrogen-based aviation								
7.	Hydrogen fuel-cell aircraft safety guidelines	-	-	-	-	-	-	EUROCEA / AIR 6464	SAE AIR 6464-2013
	Hydrogen-based railways								
8.	Hydrogen-based railway locomotives IEC 63341 (Parts 1-3)	-	-	-	-	-	-	BS EN IEC 63341	-

Original standard   Modified adoption   Direct adoption

Source: Authors' compilation

Table 11 Standards for hydrogen-powered stationary fuel cells categorised by issuing country

No.	Primary standard	Australia	Canada	Germany	India	Japan	United Kingdom	United States
1.	Fuel-cell power systems – fuel-cell modules (stationary fuel cells) IEC 62282-3-100:2019	AS 62282.3.300:2021	IEC 62282-3-100:2019	DIN EN IEC 62282-3-100	-	JIS C 62282-3-100:2019	IEC 62282-3-100:2019	IEC 62282-3-100:2019
2.	Micro fuel cells IEC 62282-6-100:2010	-	IEC 62282-6-100:2010[161]	DIN EN 62282-6-100[40]	-	-	IEC 62282-6-100:2010/AMD1:2012[62]	IEC 62282-6-100:2010

Original standard Modified adoption Direct adoption

Source: Authors' compilation

5.2 Gaps in standards for hydrogen applications

- India currently does not have standards for thermally activated pressure relief devices for compressed hydrogen. In contrast, Australia, Canada, Germany, the Republic of Korea, the UK, and the US have adopted the ISO 19882:2018 standard.
- India does not have standards for fuel cell installations for industrial trucks. Australia, Germany, Japan, the UK, and the US have adopted identical or modified versions of the IEC 62282-4-102:2017 standard.
- Currently, there are no standards governing hydrogen-fuelled ICEs. India should take the lead in developing standards for this.
- India does not have standards for hydrogen-based aviation and hydrogen-based railway locomotives. The US has adopted the SAE AIR 6464 for hydrogen-based aviation, whilst standards for railway locomotives have only been adopted by the UK by way of the BS EN IEC 63341 standard.
- India also has gaps in standards for the safety aspects of portable fuel cells, stationary fuel cells, and micro fuel cells. Countries such as Australia, Canada, Germany, Japan, the UK, and the US have adopted the relevant IEC standards (IEC 62282-5-100:2018, IEC 62282-3-100:2019, and IEC 62282-6-100:2010, respectively).
- There are no standards defining the operational parameters and design specifications of equipment for the safe use of hydrogen for combustion of hydrogen for process heat.

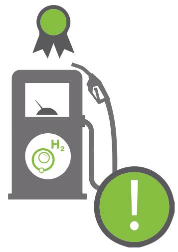
6. Hydrogen dispensation

Refuelling stations are key to enabling the commercial use of hydrogen for mobility applications.

This section highlights the standards and codes developed for the dispensation of hydrogen through hydrogen refuelling stations and is summarised is Table 12. The ISO 19880-1:2020 is one of the most extensive, covering numerous facets of hydrogen delivery such as gaseous hydrogen compression, purification systems (where required), pumps and vaporisers, pre-cooling devices, and dispensing systems. Australia (AISO 19880-1:2020), Japan (ISO 19880-1:2020), the UK (BS ISO 19880-8:2019+A1:2021), and the US (ISO 19880-1:2020) have adopted modified versions of this ISO standard. Germany, on the other hand, has developed its own standard (DIN EN 17127[43]) for hydrogen dispensation.

6.1 End use infrastructure of hydrogen value chain

End use infrastructure like hydrogen refueling stations are a crucial part of the hydrogen value chain. They are essential for decarbonising the mobility sector and will enable the adoption of fuel cell based vehicles. This section identifies gaps in standard for gaseous and liquid hydrogen refueling stations and recommends standards that India can adopt.



India does not have standards for hydrogen refueling stations while most developed countries have adopted ISO standards

The Republic of Korea has modified and adopted the same ISO standard as KS B ISO 19880 series. However, since we cannot access a translation of part 1 of this modified standard, it has not been included in this compilation. The SAE prescribes the J2601/3_201306 standard for motorcycles, forklift trucks, trams, trains, and fluvial and marine applications. Since this standard is widely applicable and India does not have standards for dispensing gaseous hydrogen, it may consider adopting this standard after due diligence.

The CSA/ANSI HGV 4.9:20 standard defines the requirements for the design, installation, operation, and maintenance of fuelling stations. Australia, Canada, Germany, Japan, South Korea, the UK, and the US have adopted a modified version of the ISO 13984-1999 that outlines the requirements for liquid hydrogen refuelling stations. However, this standard will be superseded by a newer version (ISO/AWI 13984). India can adopt the same after conducting a feasibility study. The country-wise comparison is show in Table 13.

Refuelling stations also require supplementary components designed specifically for hydrogen dispensation. ISO 17268:2020 is the predominant standard describing the design, safety, and operational characteristics of refuelling connection devices such as receptacles, nozzles, and communication hardware for a working pressure limit of 70 MPa. It has also been adopted by countries such as the Republic of Korea and Germany. India can follow suit, particularly since in this case, the above-listed countries are at the forefront of commercial FCEV manufacturing.

Table 12 Standards for hydrogen dispensation

No.	Issuing body	Standard	Remarks
	Gaseous hydrogen dispensing station		
1.	ISO	ISO 19880:2020 (parts 1–9)	This is one of the most extensive standards that covers many aspects of hydrogen delivery, such as gaseous hydrogen compression, purification systems (where required), pumps and vaporisers, pre-cooling devices, and dispensing systems. These dispensing stations include those that cater to light-duty hydrogen-powered road vehicles as well as heavy-duty vehicles such as buses and trucks. This generic standard is widely applicable.
2.	KS AS	KS B ISO 19880-5[113] AS 19880.3:2020[19]	These standards are derivatives of the ISO 19880-5:2019 and define the specifications for dispenser hoses and hose assemblies (applicable to fuel systems and industrial applications).
3.	DIN	DIN EN 17127	This German standard outlines the protocols for outdoor hydrogen refuelling points dispensing gaseous hydrogen.
4.	CSA	CSA/ANSI HGV 4.9:20	This standard cover specifications for the design, installation, operation, and maintenance of fuelling stations, particularly for land vehicles.
5.	SAE	J2601/3_201306	This extensive standard covers hydrogen fuel dispensation exclusively for industrial vehicles (such as forklifts, tractors, and pallet jacks). It also covers granular aspects such as refuelling connection devices, vehicle fuelling system manufacturers, and other infrastructure required by dispensing stations.

No.	Issuing body	Standard	Remarks
	Liquid hydrogen dispensing station		
6.	ISO	ISO 13984-1999 (reaffirmed in 2021)	The international standard is for the design and installation of liquid hydrogen dispensing stations.
	Components of hydrogen refuelling station		
7.	ISO	ISO 17268:2020	It is applicable to compressed hydrogen land vehicle refuelling connection devices such as receptacles, nozzles, and communication hardware for a working pressure limit of 70 MPa.
8.	IS	IS 17268:2020	This standard is identical to the ISO 17268:2020 standard and is applicable to refuelling connection devices in on-road vehicles.
9.	KS	KS B ISO 17268[112]	This standard is a derivative of the ISO 17268:2006 and defines the specifications for compressed hydrogen surface vehicle refuelling connection devices.
10.	DIN	DIN EN ISO 17268[42]	This standard is derived from the outdated ISO 17268:2012, which defined standards for refuelling connection devices for gaseous hydrogen land vehicles.
11.	AS	AS 19880.3:2020[129]	This Australian standard is a derivative of the ISO 19880-3:2018.
12.	SAE	J2600_201510	This standard defines the design criteria and testing protocols for refuelling/ dispensing connectors, nozzles, and receptacles.
13.	EN	BS EN 17127:2020[65]	This British standard, which is a derivative of the ISO 19880-1:2020, defines the guidelines for the dispensation of gaseous hydrogen through fuelling stations for fuel cell electric vehicles (FCEVs).

Source: Authors' compilation

Table 13 Hydrogen dispensation standards categorised by issuing country

No.	Primary standard	Australia	Canada	Germany	India	Japan	South Korea	United Kingdom	United States
1.	Gaseous hydrogen dispensing station ISO 19880:2020 (parts 1-9)	ISO 19880-1:2020[145]	ISO 19880-1:2020[162]	DIN EN 17127	-	ISO 19880-1:2020[110]	KS B ISO 19880-5	BS ISO 19880-8: 2019+A1: 2021	ISO 19880-1:2020[142]
2.	Liquid hydrogen dispensing station ISO 13984-1999 (reaffirmed in 2021)	ISO 13984: 1999[149]	ISO 13984: 1999[165]	ISO 13984[55]	-	ISO 13984:1999	KS B ISO 13984	ISO 13984: 1999[23]	ISO 13984: 1999[17]
3.	Components of hydrogen refuelling stations ISO 17268:2020	ISO 17268: 2020[147]	ISO 17268:2020	DIN EN ISO 17268	-	-	-	BS EN ISO 17268: 2020	ISO 17268: 2020[12]

Original standard   Modified adoption   Direct adoption

Source: Authors' compilation

6.2 Gaps in standards for hydrogen dispensation

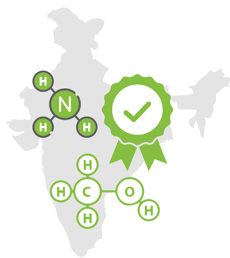
India does not have any standards for gaseous and liquid hydrogen refuelling stations. Australia, Canada, Germany, Japan, South Korea, the UK, and the US have adopted the ISO standards related to gaseous and liquid hydrogen fuelling stations.

Green hydrogen uptake can also be in the form of fuels like ammonia and methanol.

Image: iStock

7. Other fuels

Ammonia plays a crucial role in the fertiliser and chemical industries. Similarly, methanol plays a vital role in the manufacturing of paints, plastics, and chemicals and is expected to be used as a source of energy in the future. The emissions footprint of these globally traded commodities has recently come under scrutiny. Currently, natural gas is the primary source of hydrogen required for ammonia and methanol production. However, green hydrogen is expected to replace fossil fuel–based generation of hydrogen. Consequently, it is vital to conduct a gap analysis to assess the standards related to the safe handling of these chemicals.

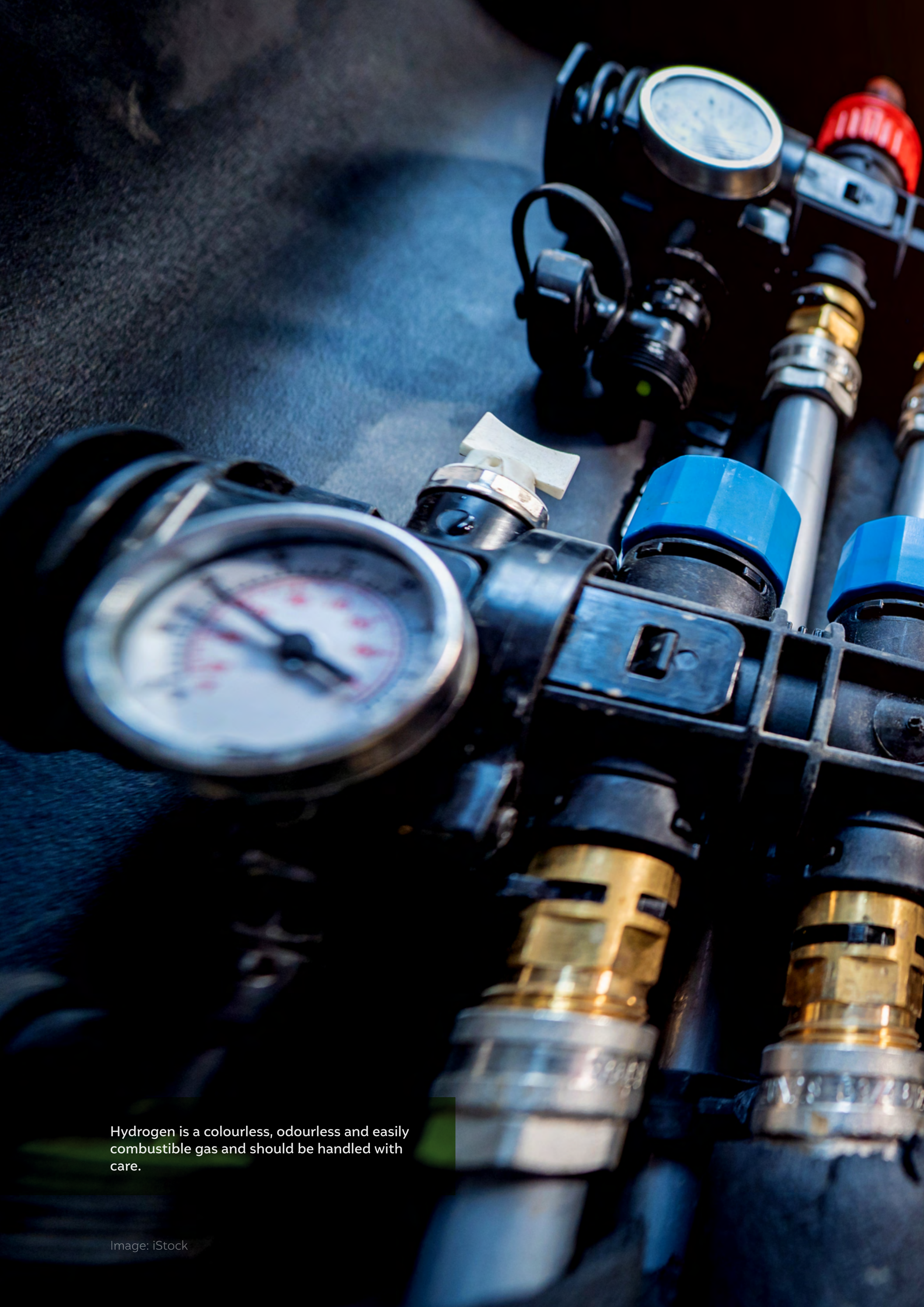


Green ammonia and methanol are globally traded commodities and India already has standards for them

Countries such as Australia (AS 2508.3.011), Japan (JIS K 1501:2005), and the US (CGA G-2.1) have established safety standards for the storage and handling of methanol. India too has defined the IS 7444:1974 standard that describes the properties of methanol and associated hazards due to its mishandling. It also extensively includes essential information on the storage, safe handling, packing, labelling, disposal of waste, and cleaning and repair of containers used for methanol storage.

Similarly, Australia and the US have established standards related to the safe handling of ammonia (termed AS/NZS 2022:2003 and ANSI/CGA G-2.1-2014, respectively). India has also established standards for the safe handling of liquid and anhydrous ammonia as well as protocols for its sampling and testing for industrial use. India has developed and adopted the IS 4IS 517544:2000 (reaffirmed in 2017) standard that defines the safety standards and protocols for handling anhydrous ammonia and the IS 8198:Part 7:1988 that specifies the filling, inspection, testing, and maintenance standards for liquefied ammonia cylinders. In addition, India has also established standards for sampling ammonia for industrial applications (IS 662).

Given that ammonia and methanol are already globally traded commodities, safety standards are not expected to be a major bottleneck in scaling up trade in these green hydrogen derivatives. The literature review indicates that most countries already have standards and guidelines for handling these chemicals. Therefore, it is expected that the trade in green fuels will continue unhindered in the future.



Hydrogen is a colourless, odourless and easily combustible gas and should be handled with care.

Image: iStock

8. Hydrogen safety

The storage and handling of hydrogen pose a safety threat. Consequently, robust safety measures and standards are vital. Table 14 lists the various standards for hydrogen safety and its detection.

Table 14 General hydrogen safety standards

No.	Issuing body	Standard	Remarks
			General hydrogen safety
1.	IS	IS 15201: 2002	This Indian standard was reaffirmed in 2014 and describes the physical and chemical properties of hydrogen and the prevention of hazards related to its use. It also includes essential information on the storage, handling, labelling, and transportation of hydrogen.
2.	ISO	ISO/TR 15916:2015	This standard outlines the safety concerns, hazards, and risks associated with hydrogen stored in gaseous, liquid, or hydride form.
3.	NFPA	NFPA 2[75]	This code is applicable to safety aspects related to hydrogen production, storage, transfer, and use for various applications.
4.	OSHA	OSHA 1910.103	This comprehensive standard defines the specifications for the safety relief devices used across the hydrogen value chain.
5.	CGA	CGA P-12[37]	This standard defines the general guidelines about the transportation, storage, safe handling, and safe use of the cryogenic liquids commonly used by industry. It is applicable to cryogenic and refrigerated liquid users, shippers, carriers, distributors, and equipment designers.
6.	CSA	ANSI/CSA CHMC 1-2014	This standard defines test methods for evaluating the metal compatibility with compressed hydrogen applications.
7.	AIAA	ANSI/AIAA G-095A-2017	This standard defines the specifications related to the design, building and use of hydrogen systems. It also specifies the requirements for storage, leak detection, and transportation of hydrogen as well as a review of emergency procedures during hazards related to hydrogen.
			Hydrogen detection and venting apparatus
6.	ISO	ISO 26142:2010	This standard specifies the performance and test methods for hydrogen detection apparatuses designed to measure hydrogen concentrations (specifically in stationary applications). It defines parameters such as precision, response time, stability, measuring range, selectivity, and poisoning for the detection system. This standard is used for certification purposes.
7.	IS	IS 16253:2016	This Indian standard, which was reaffirmed in 2021, is a derivative of the ISO 26142:2010.
8.	CGA	CGA G-5.5[4]	This standard provides the minimum requirements for the safe design, installation, and operation of systems used for venting gaseous and liquid hydrogen to the atmosphere as part of manual and automatic venting for system pressure control.

Source: Authors' compilation

Across the globe, various standards address the safety aspects of each level of the hydrogen value chain (see Table 15). Australia, Germany, the Republic of Korea, and the UK have subscribed to modified versions of the ISO/TR 15916:2015 standard that provides safety guidelines for the use of hydrogen in various forms. Canada and the US, on the other hand, have adopted standards such as the CAN/BNQ-1784-000/2022 and OSHA 1910.103, which are broadly similar in scope to the ISO standard.

The Indian standard for general hydrogen safety is the IS 15201:2002 or the 'hydrogen code of safety'. This indigenously developed standard establishes guidelines regarding the handling and storage of hydrogen in both gaseous, liquid and hydrides forms. It also codifies preventive measures for hazards related to hydrogen, including training for personnel who handle hydrogen and hydrogen-reliant equipment, among other provisions. To keep it widely applicable, this standard deliberately excludes safety standards for the production phase of hydrogen and the operation of hydrogen manufacturing facilities. India also has standards relating to hydrogen detection for stationary applications. This standard, domestically termed as IS 16253:2016, is a derivative of the ISO 26142:2010 standard.

Table 15 General hydrogen safety standards as categorised by countries

No.	ISO standard	Australia	Canada	Germany	India	South Korea	United Kingdom	United States
1.	General hydrogen applications (gaseous/ liquid forms and hydrides) ISO/TR 15916:2015	ISO/TR 15916: 2015[143]	CAN/ BNQ-1784-000/2022	ISO/TR 15916[49]	IS 15201:2002	KS B ISO 15916	PD ISO/TR 15916:2015	OSHA 1910.103
2.	Hydrogen detection apparatus ISO 26142:2010	AS-26142-2020	ISO 26142: 2010[164]	ISO 26142[54]	IS 16253:2016 (derivative of ISO)	-	BS ISO 26142:2010	ISO 26142:2010[16]

Original standard   Modified adoption   Direct adoption

Source: Authors' compilation

9. Recommendations and conclusions

Developing and enforcing safety standards are of prime importance to increase hydrogen uptake.

In essence, the standardisation of components, infrastructure, and practices throughout the hydrogen value chain should ensure safety, interoperability, and convenience. In the era of shrinking carbon space, hydrogen is set to be a globally traded commodity. We propose the following recommendations for the various elements of the hydrogen value chain.

9.1 Hydrogen production

- The Indian standard for electrolysers (IS 16509:2020) is a derivative of the ISO 22734:2019. However, the ISO standard is being updated as the ISO/AWI 22734-1, with the inclusion of performance measurement of hydrogen production through electrolysis. India could update its standard in accordance with the changes made in the updated ISO standard.

- The existing ISO 22734:2019 standard covers electrolyser technologies such as alkaline, AEM and PEM. However, it does not cover upcoming technologies such as SOECs. The UL LLC 2264A[99] outline, however, has a broader scope, including SOECs. India should therefore consider including the specifications prescribed in this standard.
- The IS 16512 (Part 1):2016 standard – currently adopted for feedstock-based hydrogen production technologies – does not define the requirements and protocols for efficient resource use and effluent management. India should bridge this gap by addressing these issues in the existing standard. including it in the existing standards.
- India should also consider developing standards for hydrogen production through alternative pathways – such as natural gas pyrolysis or biomass pyrolysis – which are expected to be the transitionary technologies to green hydrogen production.

India can adopt the updated ISO standard ISO/AWI 22734-1 for electrolytic hydrogen production, which includes performance measurement standards

9.2 Hydrogen storage

- India has adopted standards such as the IS 7285:Part 1:2018 and IS 13985:2006 for gaseous and liquid hydrogen storage, respectively. However, an adequacy assessment should be carried out to ensure that existing Indian standards remain globally relevant. In this context, India should consider incorporating additional specifications included in standards such as the ASME STP/PT-003-2005, STP-PT-014-2008 and NFPA 55 in its standards to strengthen the safety aspects related to storage. In addition, the IS 7285:Part 1:2018 defines standards for cylinder capacities only up to 400 litres. India can explore expanding the standard to cover larger cylinder sizes.
- India currently does not have standards defined exclusively for bulk storage of liquid hydrogen. India should develop and adopt standards such as CGA P-12, NFPA 55 and EIGA Doc 06/19.

9.3 Hydrogen transportation

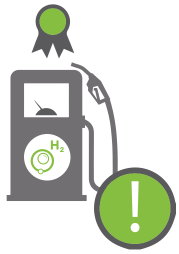
- The gap analysis indicates that India, along with countries such as Australia, Germany, Canada, and the Republic of Korea, does not have standards for hydrogen pipelines. Therefore, it should adopt a standard that amalgamates the best practices and codes as described by organisations such as the ASME (ASME B31.12-2019), CGA (CGA G-5.6), and the US Department of Transport (DoT 49 CFR 170-192). The ASME is expected to update the existing ASME B31.12-2019 standard to include steel pipes for the transport of gaseous hydrogen, and India should adopt the updated standard after due diligence.
- India also does not have standards related to transportable metal hydride–based storage systems such as the ISO 16111:2018. India could adopt the same after due diligence.
- India currently does not have standards for maritime transport of hydrogen. India can adopt the IGC code/MSC.420 after due diligence.

9.4 Hydrogen dispensation

- India currently does not have standards for hydrogen refuelling stations. In contrast, countries such as Australia, Japan, the Republic of Korea, the UK, and the US have adopted a modified version of the ISO 19880-1:2020 (for gaseous hydrogen) and ISO 13984-1999 (for liquid hydrogen). India should follow suit and adopt the above-mentioned standards, including requirements for refuelling infrastructure as defined in standards such as the ISO 19880-3 (valves) and J2601/3_201306 (fuelling protocols). The adoption of standards related to dispensation is a precursor to the commercial use of FCEVs.

9.5 Hydrogen-powered vehicles, fuel cells, and other applications

- Globally, the standards formulated by the ISO and the IEC for hydrogen-powered vehicles and fuel cells are widely used by countries such as Canada, Japan, Australia, the UK, and the US. India also has adopted ISO standards for fuel systems components (IS/ISO 12619) and performance measurement of fuel-cell-powered land vehicles (IS 23828). However, India lacks standards for fuel-cell modules (where the existing standards include the IEC 62282-3-100:2019 (stationary fuel cells), IEC 62282-5-100:2018 (portable fuel cells), and IEC 62282-6-100:2010 (micro fuel cells)), fuel-cell-based aircraft (where the existing standard is SAE AIR 6464), and fuel-cell-based railway locomotives (where the existing standard is IEC 63341 (Parts 1-3)). Since fuel cells are one of the primary routes for energy conversion using hydrogen, standards related to them have to be adopted or developed soon.
- Currently, there are no standards governing hydrogen-fuelled ICEs. India should take the lead in developing standards for the same.
- There are no standards governing the operational parameters or design specifications of equipment for the safe use of hydrogen for process heat applications. India should be proactive in developing the same to accelerate the use of hydrogen as a green fuel in industries.



India currently does not have standards for hydrogen refueling stations. The ISO 19880-1:2020 standard can be adopted after due diligence

9.6 Conclusion

This study shows that there are gaps in standards across the hydrogen value chain, such as in production, storage, transport, dispensation, and utilisation. The comparison showcases popular standards across each component of the value chain, categorised according to organisations developing them and the countries adopting them. The prerequisite to adopting these existing standards would be an adequacy assessment, especially in areas where multiple standards exist globally and have not yet been adopted in India. Such an exercise would yield the development of domestic standards that would be in line with global best practices. Research and development (R&D) related to hydrogen and hydrogen-allied technologies are currently underway across industry, government, and academia, with collaboration often extending beyond national boundaries. Therefore, it is imperative that the global R&D community collaborates in creating and adopting common standards for the faster adoption of hydrogen in the energy mix. A common hydrogen standards framework will increase access to low-carbon technologies. India should lead the effort to harmonise standards across the hydrogen value chain both domestically and globally, in order to realise the vision set out in the *National Green Hydrogen Mission*.

Endnotes

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Acronyms

AEM	Anion electrolyte membrane
CGH_2	Compressed gaseous hydrogen
FCEV	Fuel cell electric vehicle
GTR	Global technical regulations
H_2/NG	Hydrogen/Natural gas
HRS	Hydrogen refuelling station
ICE	Internal combustion engine
LOHC	Liquid organic hydrogen carrier
LPG	Liquefied petroleum gas
MTPA	million tonnes per annum
NGHM	National Green Hydrogen Mission
PEM	Proton exchange membrane
SAF	Sustainable aviation fuel
SOEC	Solid oxide electrolyser cell

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