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Energy Forum

STUDY AND RECOMMENDATIONS FOR DEVELOPMENT OF INTERNATIONALLY COMPATIBLE GREEN HYDROGEN STANDARDS IN INDIA

Report by:

PMANIFOLD Advancing Net-Zero Markets
IIT Madras
Royal HaskoningDHV Enhancing Society Together

On behalf of:

GOVERNMENT OF INDIA
MINISTRY OF NEW AND RENEWABLE ENERGY

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About this Report

This comprehensive report has been meticulously prepared as part of the PtX hub's visionary initiative, "Study and Recommendations for Internationally Compatible Standards for Green Hydrogen in India." This report was commissioned by the Indo-German Energy Forum (IGEF) and jointly implemented by the renowned Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the Ministry of New and Renewable Energy (MNRE), Government of India.

The overarching objective of this project is to meticulously identify and address existing gaps within the regulatory framework, standards, and certifications encompassing the green hydrogen, green ammonia, and green methanol value chain in India. Through rigorous global benchmarking and a detailed analysis of the Indian standardization ecosystem, this study aims to provide robust and strategic recommendations for bridging these identified gaps. The ultimate aim is to catalyse the development of a resilient Indian green hydrogen value chain.

This report is structured around three foundational pillars, each crucial to the comprehensive understanding and effective implementation of a standardized and sustainable green hydrogen industry:

- **Regulations:** This section delves into the existing regulatory landscape and identifies key areas where enhancements and adaptations are needed to align with international best practices. The recommendations put forth in this report aim to create an enabling environment for the growth and optimal functioning of the green hydrogen sector in India.
- **Standards:** By thoroughly assessing and comparing the Indian standardization ecosystem with global benchmarks, this study aims to identify gaps and propose harmonized standards that will promote interoperability, quality assurance, and seamless integration within the green hydrogen value chain. These proposed standards will provide a solid foundation for industry stakeholders to uphold excellence and drive innovation.
- **Certifications:** This segment focuses on the crucial aspect of certifications, which play a pivotal role in establishing credibility and facilitating market acceptance. By evaluating existing certification processes and their alignment with international norms, this report presents recommendations for enhancing and streamlining certification frameworks to ensure reliability and instil confidence in green hydrogen-related activities.

With its in-depth analysis and strategic recommendations, this report strives to guide policymakers, industry players, and stakeholders towards building a vibrant, sustainable, and globally competitive green hydrogen industry in India. It is envisioned that the implementation of these recommendations will propel India towards a greener, more resilient future, while fostering international collaboration and harmonization within the broader energy transition landscape.

Acknowledgement

We gratefully acknowledge the support and contributions received during the execution of the project "Study and recommendations for internationally compatible green hydrogen standards in India," commissioned by IGEF under the PtX Hub. This undertaking would not have been possible without numerous individuals and organisations' unwavering support and collaboration.

First and foremost, we extend our heartfelt appreciation to the dedicated team at GIZ for entrusting us with this significant project and providing invaluable guidance throughout its duration. Their expertise and assistance were instrumental in making critical decisions and shaping the project's outcome.

We also want to express our sincere gratitude to our esteemed consortium partners, whose expertise and contributions have significantly enriched the project. Royal HaskoningDHV played a pivotal role in compiling international standards, ensuring that our recommendations align with global best practices. Likewise, IIT Madras's efforts in compiling Indian standards have been crucial to creating recommendations tailored to the unique context of India.

Furthermore, we are immensely grateful to MNRE for their generous support in supplying us with the necessary data and information that were indispensable to our research and analysis. The guidance and reviews provided by esteemed organizations such as CII, FICCI, SIAM, ARAI, BIS, TÜV Nord, and Plugpower have also been invaluable in shaping our interim results and ensuring their relevance and accuracy.

Lastly, we would like to acknowledge the collective efforts of all individuals and entities who have contributed to this project, directly or indirectly. Your collaboration, feedback, and insights have been deeply appreciated and have played a significant role in the successful execution of this endeavour.

Together, through our combined efforts, we have taken substantial strides towards establishing internationally compatible green hydrogen standards in India. We remain committed to driving sustainable practices and fostering an environment conducive to the growth of the hydrogen industry.

Contents

List of Figures

List of Tables

List of Abbreviations & Acronym

ADR	Agreement concerning the International Carriage of Dangerous Goods by Road
AEM	Anion Exchange Membranes
AFID	Alternative Fuels Infrastructure Directive
AFIR	Alternative Fuels Infrastructure Regulation
ANSI	American National Standards Institute
ARAI	Automotive Research Association of India
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AT	Acoustic Emission Testing
ATR	Autothermal Reforming
AWI	Approved Work Item
BIL	Bipartisan Infrastructure Law
BIS	Bureau of Indian Standards
BPVC	Boiler, Pressure & Vessel Code
CCS	Carbon Capture & Storage
CCUS	Carbon Capture, Utilisation, and Storage
CEA	Central Electricity Authority
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CERC	Central Electricity Regulatory Commission
CGA	Compressed Gas Association
CHMC	Compressed Hydrogen Materials Compatibility
CHPS	Clean Hydrogen Production Standard
CII	Confederation of Indian Industry
CMVR	Central Motor Vehicle Rules
CNG	Compressed Natural Gas
CO2	Carbon Dioxide
CO2e	Carbon Dioxide Equivalent
CoC	Chain of Custrody
CPCB	Central Pollution Control Board
CSA	Canadian Standards Association
CTU	Central Transmission Utility
DNV	Det Norske Veritas
DOE	Department of Energy
EC	European Commission
ECHA	European Clean Hydrogen Alliance
EIGA	European Industrial Gases Association
EPA	Environmental Protection Agency
EPACT	Energy Policy Act
EPO	European Patent Office
EU	European Union
FCEVs	Fuel Cell Electric Vehicles
FICCI	Federation of Indian Chambers of Commerce & Industry
GAR	Gas Applications Regulations
GH2	Green Hydrogen
GHG	Greenhouse Gas
GHP	Green Hydrogen Policy
GIA	Global Industry Alliance
GO	Guarantees of Origin
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GTR	Global Technical Regulations
GW	Gigawatt
H2PA	Hydrogen Production Analysis
HPGSA	High-Pressure Gas Safety Act
ICE	Internal Combustion Engine
ICS	International Chamber of Shipping
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IGEF	Indo Germand Energy Forum
IGF	Code International Code of Safety for Ships using Gases or other Low-flashpoint Fuels
IMDG	Code on International Maritime Dangerous Goods
IMO	International Maritime Organization

IMPCA	International Methanol Producers and Consumers Association
IPCEI	Important Projects of Common European Interest
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
IPs	International Patents
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
ISCC	International Sustainability and Carbon Certification System
ISO	International Standardization Organization
JARI	Japanese Automobile Research Institute
JIS	Japanese Industry Standards
JISC	Japanese Industrial Standards Committee
JPEC	Japanese Petroleum Energy Centre
JPY	Japanese Yen
JSA	Japanese Standards Association
LCA	Life Cycle Assessments
LCOE	Levelized Cost of Electricity
LNG	Liquefied Natural Gas
MAE	Modal Acoustic Emission
MARAD	Maritime Administration
METI	Ministry of Economy, Trade, & Industry
MNRE	Ministry of New & Renewable Energy
MoCA	Ministry of Civil Aviation
MOEFCC	Ministry of environment, Forest, and climate Change
MoP	Ministry of Power
MoPNG	Ministry of Petroleum and Natural Gas
MoPSW	Ministry of Ports, Shipping, and Waterways
MoRTH	Ministry of Road Transport and Highways
MoU	Memorandum of Understanding
MPa	Megapascal
MSC	Maritime Safety Committee
MT	Million Tons
MTPA	Million Tons per Annum
MWh	Megawatt-hour
NFPA	National Fire Protection Agency
NGEU	NextGenerationEU
NGHM	National Green Hydrogen Mission
NH3	Ammonia
NHEM	National Hydrogen Energy Mission
NIST	National Institute of Standards and Technology
Nm3	Normal Cubic Meter
OPS	Onshore Power Supply
PEM	Proton Exchange Membrane
PESO	Petroleum and Explosives Safety Organization
PNGRB	Petroleum and Natural Gas Regulatory Board
PRD	Pressure Relief Device
PtX	Power-to-X
R&D	Research and Development
RE	Renewable Energy
RED	Renewable Energy Directive
RFNBO	Renewable Liquid and Gaseous Fuels of Non-Biological Origin
RLF	Renewable and Low Carbon Fuels
SAE	Society of Automotive Engineers
SERC	State Electricity Regulatory Commission
SIAM	Society of Indian Automobile Manufacturers
SMR	Steam Methane Reforming
SOLAS	Safety of Life at Sea
STU	State Transmission Utility
TC	Technical Committees
TEN-T	Trans-European Transport Network
TERI	The Energy and Resources Institute
UN	United Nations
UNECE	United Nations Economic Commission for Europe
US	United States
USD	United States Dollar
WTO	World Trade Organization

Introduction

The need for sustainable development and the fight against climate change has become a global concern. As countries aim to achieve climate neutrality, ***Green Hydrogen**, and its derivatives* has emerged as a key solution to reduce carbon emissions in hard-to-abate sectors such as heavy industry, shipping, aviation, heavy-duty transport, and long duration storage of renewable energy. India, with its ambitious targets for becoming a net zero economy by 2070, is actively seeking to develop a robust green hydrogen value chain.

1.1 Background and Purpose of the Report

India has pledged to cut its emissions to net zero by 2070. While renewable energy is key for this transformation, some hard-to-abate sectors cannot yet directly electrify to become climate neutral. The Power-to-X (PtX) technology can fill this gap by converting green electrons generated by renewable electricity into green fuel. One of the most important green fuels is green hydrogen which is produced by water electrolysis. With India's relatively cost-competitive[1] renewable energy generation ecosystem along with future capacity addition plans and promising growth forecasts, green hydrogen will play a pivotal role in the larger decarbonization chain. Figure 1 highlights that the levelized cost of electricity (LCOE) for both wind (around 25 USD/MWh) and solar (around 33 USD/MWh) falls in the lower limit of the global LCOE range.

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[1] Harnessing Green Hydrogen, NITI Aayog, 2022

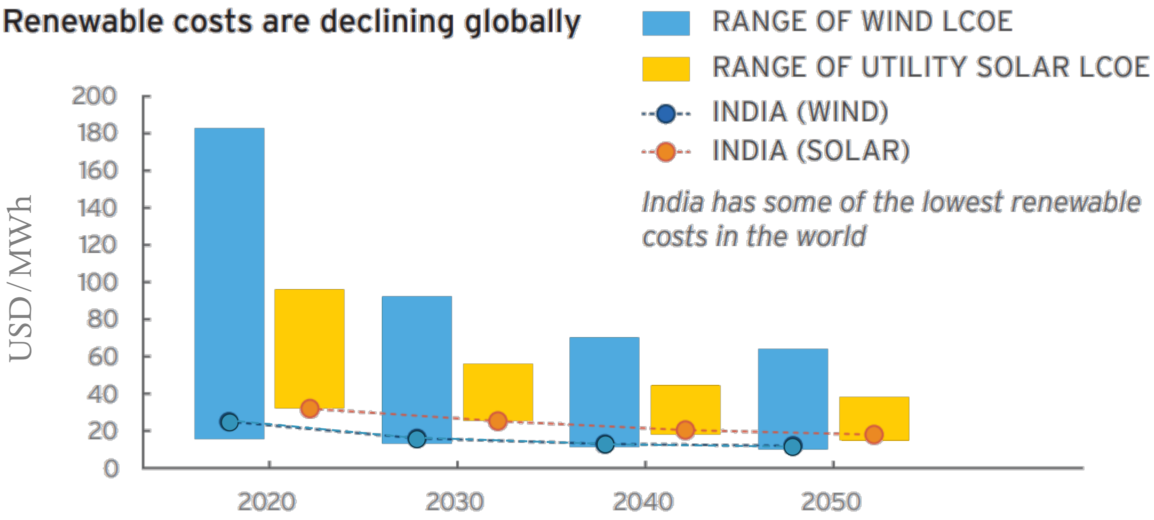

Figure 1: LCOE India vs LCOE global range[1]

The National Green Hydrogen Mission (NGHM) launched in 2023 facilitates the transition from fossil fuel-based feedstocks to green hydrogen. To achieve the target of producing five million tonnes (Mt) of green hydrogen per annum by 2030[2] and become a production and export hub for the fuel, numerous steps, and developments across the green hydrogen value chain are being envisaged. One critical requirement would be to develop and adopt a well-defined set of regulations, standards, and certifications across the green hydrogen, green ammonia, and green methanol value chain. These standards and certifications should ensure safety, interoperability, and compatibility of equipment and products, enabling seamless adoption and deployment of green hydrogen technologies.

This report aims to identify existing gaps in Indian regulations, standards, and certifications and provide recommendations/ strategies for the development and adoption of green hydrogen/ green ammonia/ green methanol standards and certifications in India. The report will be useful for policymakers, industry stakeholders, and regulatory bodies in India to develop a roadmap for the implementation of green hydrogen and its derivatives in the country.

1.2 Scope and Methodology

To accomplish the above objectives, a detailed review of Indian and international regulations, standards, and certification has been conducted. The study focuses on the value chain for green hydrogen, and its derivatives (green ammonia, and green methanol), including production, transformation, storage & transportation, and end-use application. The scope of the study is limited to regulations, standards, and

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[2] National Green Hydrogen Mission, MNRE, 2023

certifications related to the safety, interoperability, and compatibility of equipment and products across the value chain.

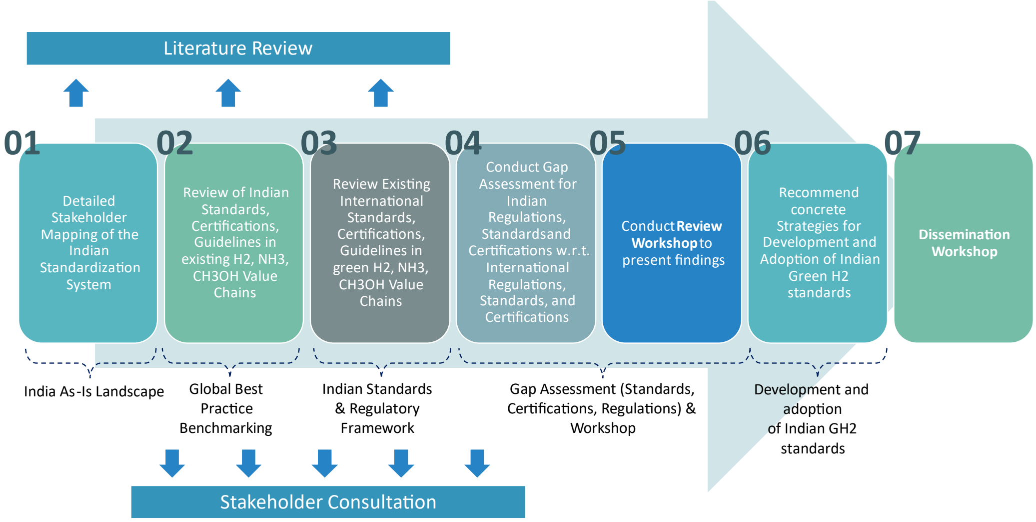

Figure 2: Methodology followed in the study

The methodology followed for this report involves a combination of primary and secondary research methods as shown in Figure 2. Primary research involves stakeholder consultations with government agencies, industry experts, academia, standardization bodies, and regulators in India to understand the current state and future requirements for green hydrogen standards and certifications. Secondary research consists of extensive review of existing literature[3], data sources, and case studies of best practices in other countries (EU, US, and Japan). The case studies of best practices in other countries form the basis to identify strategies and recommendations for the development and adoption of green hydrogen standards and certifications in India.

This report includes comparative studies to provide a comprehensive view and understanding of the existing gaps in the standards across the value chain, which are further detailed under each section. The following chapters provide an overview of green hydrogen and its derivatives, and the value chain. It also presents the existing Indian regulations, standards, and certifications and compares them with international regulations, standards, and certifications. Finally, the report provides recommendations and strategies for the development and adoption of green hydrogen standards and certifications in India.

1.3 Value Chain

The development of a robust green hydrogen value chain is critical for achieving India’s climate goals and promoting sustainable development. For this study, various

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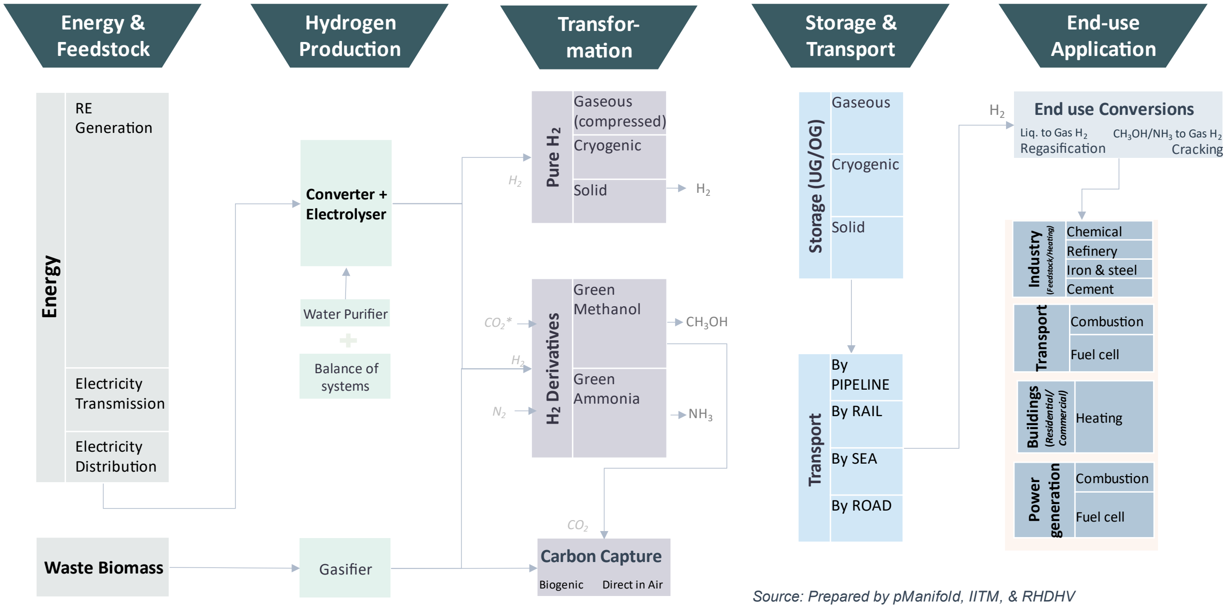
[3] Existing literature includes academic articles, technical reports, and government publications related to GH2 and its derivatives

stages are considered in the hydrogen value chain starting from energy and feedstock use to end-use applications as shown in Figure 3. This report considers two derivatives of hydrogen, i.e., Methanol & Ammonia. Both of them are preferred as energy carriers for hydrogen due to their high energy density, existing infrastructure utilization, easy handling and storage, global availability, and renewable potential. Moreover, Methanol offers versatility as it can be directly used as fuel and is widely used in various industries. While ammonia primarily serves as a hydrogen carrier, it can also be used as fuel. However, challenges such as toxicity, safety concerns, and potential emissions need to be addressed for their wider adoption.



Source: Prepared by pManifold, IITM, & RHDHV

** Either directly captured or through sustainable biomass route*

Figure 3: Green hydrogen value chain

CHAPTER 2 Global Best Practices for Green Hydrogen and Derivatives

2.1 Introduction

The term green hydrogen is used to describe hydrogen that meets specific sustainability criteria. However, there is no universally accepted definition for green hydrogen yet. According to Velazquez and Dodds 2020, "*green*" hydrogen is explained in various ways in literature, such as "*from any renewable source*" (State of California), "*from any renewable source with an explicit mention to low GHG intensity*" (CertifHy, TÜV SÜD), or "*from any renewable source or any other net zero carbon energy through carbon capture & storage (CCS) and/or emission offsets*" (Government of Australia).[4] The definition of *renewable hydrogen* is relatively more standardized, as it specifically limits the of pathways to renewable sources that are eligible.

To establish an effective green hydrogen economy, it will be crucial to incorporate the necessary technical components, which should be clearly outlined in a standard, regulation, and certification design. A standard is a technical document that provides guidelines, rules, or definitions for a specific material, product, process, or service.[5] It serves as a consensus-based and replicable method for achieving a particular objective. Standards are developed through collaborative efforts involving various stakeholders, such as manufacturers, consumers, and regulators. These stakeholders work together to establish common specifications and procedures that align with business requirements, meet consumer demands, and ensure appropriate levels of public safety.[6]

European Union (EU), Japan, and the United States (US) are taking lead in the green hydrogen transition.[7] In a joint study of the International Energy Agency (IEA) and the European Patent Office (EPO), global patent data on hydrogen innovation technologies was studied to gather a comprehensive up-to-date analysis. According to the data depicted in Figure 4, the report found that global patenting in hydrogen technologies is led by the EU and Japan, accounting for 28% and 24% respectively of all international patents (IPs) filed during the specified period. The US closely follows with 20% of all patents related to hydrogen.[8] Of these patents in the 2011-2020 period, the largest number accounted for was in hydrogen production technologies.

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[4] Green hydrogen characterisation initiatives: Definitions, standards, guarantees of origin, and challenges - ScienceDirect

[5] "What is a standard?" - European Standards - CEN-CENELEC (cencenelec.eu)

[6] ISO - Standards

[7] EPO - Hydrogen patents shift towards clean technologies with Europe and Japan in the lead

[8] Hydrogen Innovation Patents Technology

Even though most of the hydrogen is still produced using fossil fuels, the patenting data indicates a movement in favor of low-emission methods like electrolysis. The automotive industry has long been the focus of hydrogen's end-use applications, with Japan serving as the main driving force. These statistics highlight the significant contributions made by the EU, Japan, and the US in the field of hydrogen technology and their role as leading countries. Hence, these three countries will be investigated to assess their best practices in green hydrogen regulation, standardization, and certification. The general principles of hydrogen regulation should be clear and enable cross-border transport.

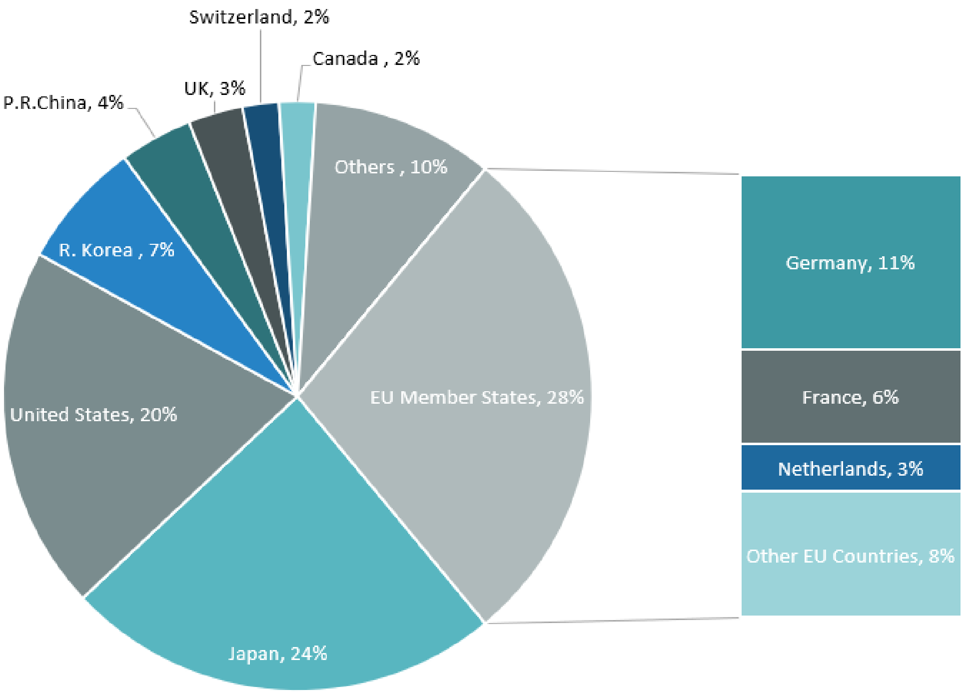

Figure 4: Leading countries for hydrogen patents, 2011-2020

According to the International Renewable Energy Agency (IRENA), four key regulatory foundations are essential when it comes to green hydrogen:[9]

- National hydrogen strategy: Each country should establish its hydrogen ambitions, including targets and the required support mechanisms. This strategy will serve as a reference point for private investment and financial institutions, providing clarity on the country's hydrogen development plans.
- Policy priorities: Green hydrogen can be utilized in various applications. Policymakers should prioritize and concentrate on the applications that offer the highest value and align with the country's specific goals and resources.

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[9] Making the breakthrough: Green hydrogen policies and technology costs (irena.org)

- Guarantees of origin: The carbon emissions associated with hydrogen production and transportation should be accurately reflected in its life cycle. Origin schemes should incorporate transparent emission labelling for hydrogen and its derived products. This labelling will enhance consumer awareness and create incentives for carbon reduction.
- Governance system and enabling policies: As green hydrogen becomes more widespread; policies should address its integration into the energy system.

By implementing these four pillars, countries can establish a robust framework to drive the growth and adoption of green hydrogen as a sustainable energy carrier. This section of the report delves into various aspects of green hydrogen, starting with an examination of regulations in the EU, US, and Japan. It then transitions to a discussion on technical standards, covering international standardization bodies as well as specific standards adopted by the EU, USA, and Japan. Lastly, it explores the importance of green hydrogen certification, green ammonia, and green methanol within these regions, highlighting the best practices of the certification frameworks in place in the EU, USA, and Japan.

2.2 Green Hydrogen Regulations

As the demand for green hydrogen continues to grow as shown in Table 1, it becomes essential to establish robust regulations to guide its development and deployment. In the EU for instance, according to the REPowerEU Plan the demand for renewable hydrogen in Europe will increase to 20 Mt per year in 2030.[10] In the US, the Department of Energy (DOE) states in their National Clean Hydrogen Strategy that the projected demands reach 10 Mt by 2030, 20 Mt per year by 2040, and 50 Mt per year by 2050, presenting significant strategic opportunities.[11] In Japan, the Ministry of Economy, Trade and Industry, (METI) in collaboration with other ministries and agencies, formulated the "Green Growth Strategy through Achieving Carbon Neutrality in 2050". That states an introduction of up to 3 Mt of hydrogen in 2030 and approximately 20 Mt in 2050.[12] Similarly, India's NGHM targets production of at least 5 Mt green hydrogen by 2030 while various studies have estimated demand for 2035 and 2050.

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[10] REPowerEU (europa.eu)

[11] DOE National Clean Hydrogen Strategy and Roadmap (energy.gov)

[12] 02_hydrogen.pdf (meti.go.jp)

Table 1: Green hydrogen demand expected for different regions from their strategy roadmaps

Region	2030	2040	2050
EU	20 Mt	-	53Mt
US	10 Mt	20 Mt	50 Mt
Japan	3 Mt	-	20 Mt
India	5 Mt		27 Mt

As mentioned earlier, the regulatory foundation in each of the countries can be categorized into four key pillars, each addressing crucial aspects of green hydrogen implementation. With these four pillars—national hydrogen strategy, policy priorities, guarantees of origin, and governance system with enabling policies—countries can create a robust regulatory framework to promote the sustainable growth and utilization of green hydrogen.

2.2.1 EU

EU's hydrogen strategy:

The EU's hydrogen strategy and REPowerEU plan have introduced an inclusive framework aimed at facilitating the adoption of renewable and low-carbon hydrogen. This framework plays a crucial role in the EU's decarbonization efforts by providing a cost-effective solution and reducing reliance on imported fossil fuels. The EU strategy on hydrogen (COM/2020/301) was adopted in 2020. The strategy proposes policy action points in five key areas as shown in Figure 5.

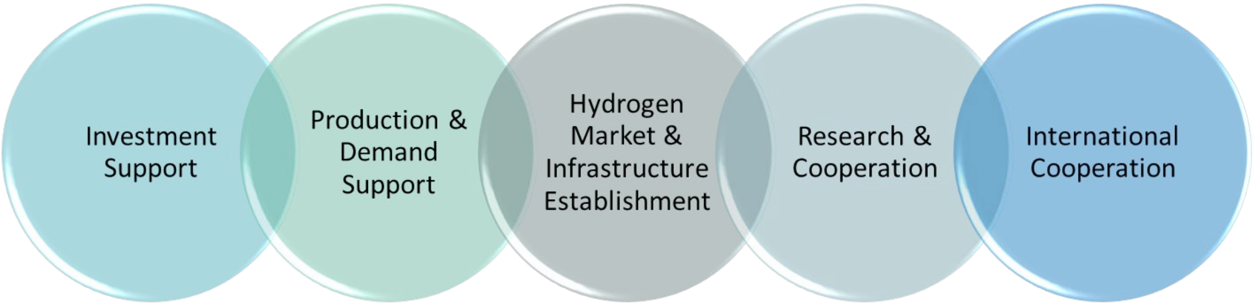

Figure 5: Five key area action points of the EU Strategy on hydrogen

The Fit-for-55 package, introduced in July 2021, has presented a series of legislative proposals that transform the European hydrogen strategy into a concrete policy framework at the European level. Its objective is to align the EU's climate and energy legislative framework with the goal of achieving:

1. climate neutrality by 2050 and,
2. reducing net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels.

It includes establishing targets for the adoption of renewable hydrogen[13] in industry and transportation by 2030. One of the measures of Fit-for-55 is FuelEU, aimed at reducing GHG emissions in shipping by promoting the use of renewable and low-carbon fuels (RLF). FuelEU will apply to vessels above 5,000 GT traveling to and from EU ports. The key requirements include GHG intensity reduction targets, mandatory onshore power supply (OPS) for ships at berth, and provisions for different types of voyages. The provisional agreement on FuelEU has been reached, and it is expected to be formally adopted and enter into force in 2025. As part of the Fit-for-55 the Alternative Fuels Infrastructure Directive (AFID) is undergoing revision and transformation into a Regulation (AFIR). The goal of AFIR is to make sure that Member States adopt comparable GHG reduction strategies, and that insufficient infrastructure does not obstruct the adoption of RLF. AFIR collaborates with the Trans-European Transport Network (TEN-T) and the FuelEU Maritime Law to create regulations for alternative fuel infrastructure in EU Member States. The critical dates for national policy framework submission by January 2025 and the eventual implementation of mandatory OPS from 2025 to 2030 have an influence on EU ports and Member States. In addition to technical OPS criteria, AFIR contains guidelines for LNG bunkering, hydrogen, methanol, and ammonia. To build an integrated transportation network, TEN-T concentrates on enhancing important roads, railways, inland waterways, airports, seaports, and inland ports. The TEN-T network is properly covered by AFIR's regulations for renewable and low-carbon fuels. When AFIR is implemented, Member States are required to update their policy frameworks which has an impact on ports and ship operators who must make investments in OPS infrastructure and long-term fuel-mix strategy. The AFIR provisional agreement has been achieved and is anticipated to be fully ratified and come into effect once the necessary approvals have been received. Additionally, the Hydrogen and decarbonized gas market package (COM/2021/803 final and COM/2021/ 804 final) proposes measures to facilitate the development of dedicated hydrogen infrastructure and create an efficient hydrogen market.

Policy priorities:

In Europe, the Renewable Energy Directive (RED) governs the production and promotion of renewable energy. RED I (2009) contained binding minimum national targets[14] for the consumption of renewable energy by 2020 by all member states but has been replaced in 2018 by RED II. The existing RED ll establishes an EU-wide target of a 32%[15] share of renewable energy in the total energy consumption of the

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[13] Renewable hydrogen can be obtained via electrolysis using renewable electricity to split water into hydrogen and oxygen and is referred to as 'renewable fuels of non-biological origin' (RFNBO) - Hydrogen (europa.eu)

[14] Targets for individual member states function as binding baseline levels (Spain 20%)

[15] Will be revised upwards in 2023; 38 – 40% RES is needed to reach the 55% GHG target

EU by 2030. However, in March 2023, the Council and Parliament adapted the RED II revision to raise the share of EU's renewable energy as shown in Table 2.

Table 2: Agreed EU Targets in provisional agreement of March 2023 [16]

Overall energy consumption	Transport	Industry
Must be reduced to 42.5% compared to 1990 by 2030 with an additional 2.5% indicative top that would allow reach to 45%	• 5.5% for advanced biofuels (mostly from non-food-based feedstocks) and RFNBOs (mostly renewable H_2 and H_2-based synthetic fuels). There is a minimum need of 1% of RFNBOs in the percentage of renewable energies supplied to the transport sector in 2030. • A binding target of 14.5% GHG savings target from the use of renewables by 2030 • Or a binding share of at least 29% of renewables within the final consumption of energy in the transport sector by 2030	• Increase their use of renewable energy annually by 1.6%. • 42% H2 used from RFNBOs[17] by 2030 and 60% by 2035. • Discount for industry under 20% if: ○ the member states' national contribution to the binding overall EU target meets their expected contribution ○ share of hydrogen from fossil fuels consumed in the member state is not more than 23% in 2030 and 20% in 2035

The reached provisional political agreement will follow the next steps before it enters into force, see Figure 6[18]. Within the agreement, there are provisions for expediting permitting processes concerning renewable energy projects. As part of the EU's REPowerEU program, the goal is to speed up the adoption of renewable energy sources to lessen reliance on Russian fossil fuels in the wake of Russia's invasion of Ukraine. All nations will create renewable energy "acceleration zones" where the permitting procedure for renewable energy projects would be fast. Deploying renewable energy will also be regarded as being in the "overriding public interest," which would restrict the justifications for legal challenges to new installations. Recently, two delegated acts[19] are adopted in accordance with the 2018 RED II, that provide clarity to the EU's regulations on renewable hydrogen (Figure 7). The first

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[16] Accelerate the rollout of renewable energy (europa.eu)

[17] Renewable Fuels of Non-Biological Origin: e.g., renewable hydrogen, synthetic ammonia, methanol from renewable hydrogen.

[18] Adopted from Interinstitutional negotiations | Ordinary Legislative Procedure | European Parliament (europa.eu)

[19] A delegated act is a non-legislative act adopted by the Commission to supplement or amend certain non-essential elements of a legislative act, allowing the Commission to react quickly and flexibly to regulatory requirements using its technical knowledge. Implementing and delegated acts - Consilium (europa.eu)

act focuses on Renewable Fuels of Non-Biological Origin (RFNBO) and establishes the criteria for products categorized as renewable hydrogen, which is crucial for achieving renewable energy targets in the transportation sector and address crucial aspects: renewability, additionality, temporal correlation, and geographical correlation. The second delegated act pertains to the methodology for calculating greenhouse gas (GHG) savings, proposing a detailed scheme for assessing the life-cycle emissions of renewable hydrogen and recycled carbon fuels. These calculations will ensure compliance with the GHG reduction threshold specified in the RED II). Both acts are entered into force after the public consultation period. [20]

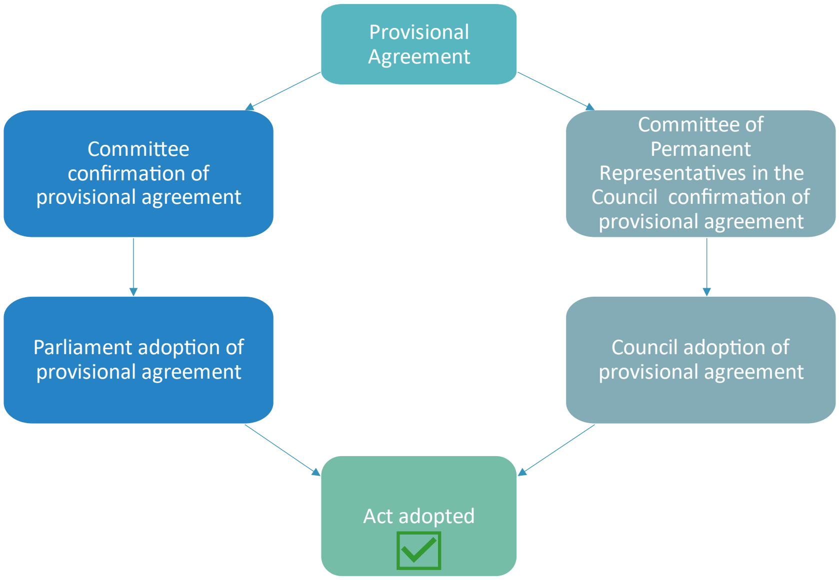

Figure 6: Steps in the negotiation process of the EU after the provisional agreement is reached.

RFNBOs, or **Renewable Fuels of Non-Biological Origin**, are a category of fuels that are derived from renewable sources other than biomass. They offer a sustainable alternative to conventional fossil fuels and have the potential to significantly reduce greenhouse gas emissions.

One **key characteristic** of RFNBOs is their ability to be used as an intermediate product in the production of conventional fuels. This means that they can be blended with or used in combination with fossil fuels to reduce their environmental impact. RFNBOs can serve as a bridge towards a cleaner energy future by gradually replacing fossil fuels.

RFNBOs are considered renewable because they are produced using energy from renewable sources such as solar, wind, and geothermal power. The production of

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[20] Renewable hydrogen production: new rules formally adopted (europa.eu)

RFNBOs involves using renewable electricity generated by sources like wind and solar power. In the case of hydrogen production, water molecules are split through electrolysis, separating hydrogen and oxygen. The resulting hydrogen can then be compressed or liquefied for storage and later used as a fuel.

Other RFNBOs, such as ammonia and synthetic hydrocarbons, require a carbon source for their production. Carbon dioxide (CO2) captured from various sources is combined with hydrogen to produce these fuels through different chemical processes. This recycling of CO2 helps reduce the overall carbon emissions and contributes to a circular economy.

RFNBOs have wide-ranging applications beyond the transport sector. In the industrial sector, they can be used as feedstock or energy sources in the production of chemicals, plastics, and other materials. Additionally, RFNBOs can be used for industrial heating and power generation, replacing fossil fuels in these processes.

Moreover, RFNBOs offer an attractive solution for energy storage. Hydrogen, in particular, can store excess renewable energy generated from sources like wind and solar power. This stored energy can then be released when needed, providing a reliable and sustainable energy storage option.

Guarantees of Origin:

Guarantees of Origin (GOs) are closely related to Renewable Energy Directive (RED) II (Art 19). To indicate to end customers how much energy comes from renewable sources, transparent and non-discriminatory standards are needed. GOs function as tracking mechanisms, enabling the verification of the origin of energy, while green certificates serve as documentation to demonstrate eligibility for support schemes. [21]

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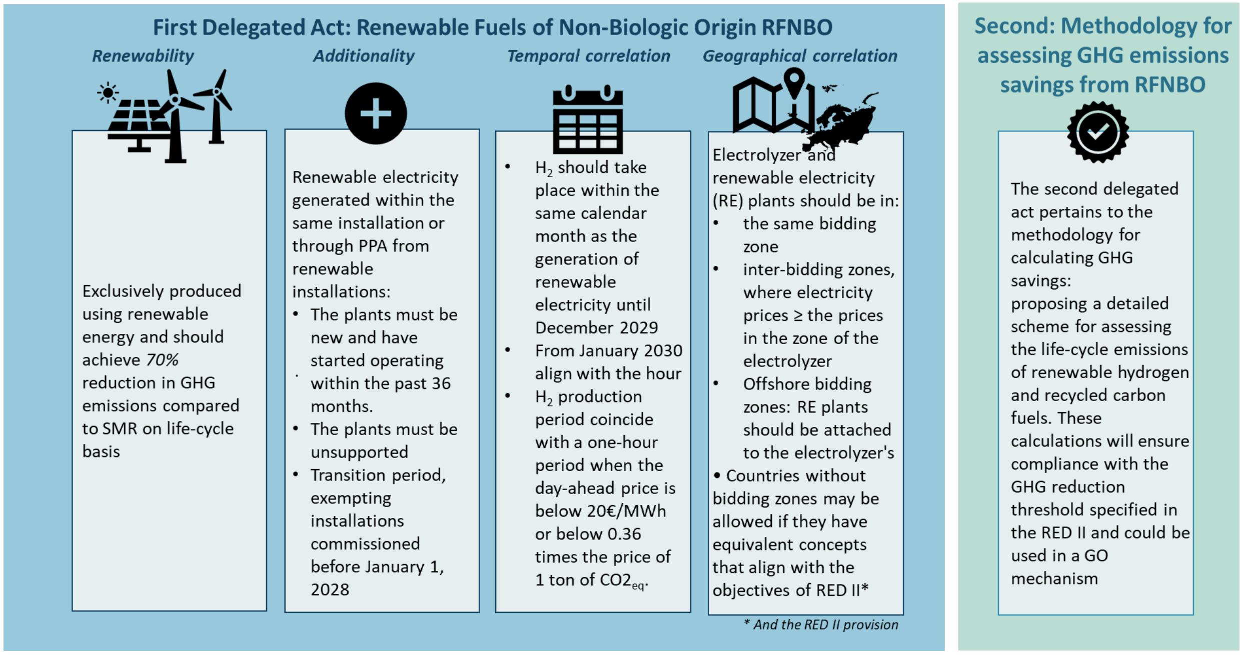
[21] International Electricity Market Glossary



First Delegated Act: Renewable Fuels of Non-Biologic Origin RFNBO

Renewability

Exclusively produced using renewable energy and should achieve *70%* reduction in GHG emissions compared to SMR on life-cycle basis

Additionality

Renewable electricity generated within the same installation or through PPA from renewable installations:

- The plants must be new and have started operating within the past 36 months.
- The plants must be unsupported
- Transition period, exempting installations commissioned before January 1, 2028

Temporal correlation

- H_2 should take place within the same calendar month as the generation of renewable electricity until December 2029
- From January 2030 align with the hour
- H_2 production period coincide with a one-hour period when the day-ahead price is below 20€/MWh or below 0.36 times the price of 1 ton of $CO2_{eq}$.

Geographical correlation

Electrolyzer and renewable electricity (RE) plants should be in:

- the same bidding zone
- inter-bidding zones, where electricity prices ≥ the prices in the zone of the electrolyzer
- Offshore bidding zones: RE plants should be attached to the electrolyzer's

• Countries without bidding zones may be allowed if they have equivalent concepts that align with the objectives of RED II*

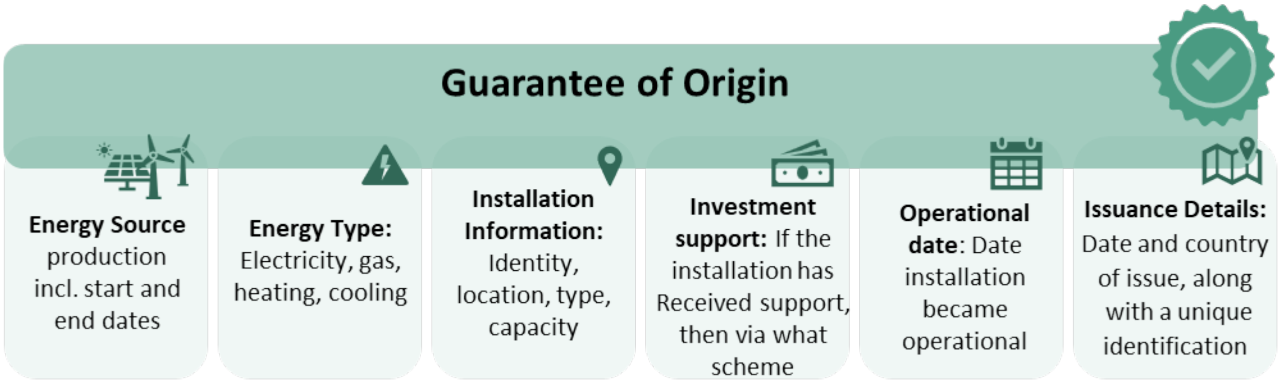
** And the RED II provision*

Second: Methodology for assessing GHG emissions savings from RFNBO

The second delegated act pertains to the methodology for calculating GHG savings: proposing a detailed scheme for assessing the life-cycle emissions of renewable hydrogen and recycled carbon fuels. These calculations will ensure compliance with the GHG reduction threshold specified in the RED II and could be used in a GO mechanism

Figure 7: Visual representation of the two Renewable Energy Directive Delegated Acts[22]

According to *the consumer Rights Directive 2011/83/EU* [23] energy suppliers are required to provide end-users pre-contractual information. RED II defines GOs for renewable energy: these documents should entail the energy mix coming from the energy supplier, especially when green tariffs are in effect. These electronic documents are EU-tradable and recognized across the Member States. A guarantee of origin (standard size 1 MWh) shall include the following details:



Guarantee of Origin

Energy Source production incl. start and end dates

Energy Type: Electricity, gas, heating, cooling

Installation Information: Identity, location, type, capacity

Investment support: If the installation has Received support, then via what scheme

Operational date: Date installation became operational

Issuance Details: Date and country of issue, along with a unique identification

Figure 8: Visual representation of Guarantee of Origin (GO) Details

Governance system and enabling policies:

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[22] Detailed description is provided in Annexure 3

[23] Q&A EU's internal electricity market design revision (europa.eu)

There are several enabling policies and funding mechanisms in effect in the EU. Examples are for instance the NextGenerationEU (NGEU) and the Important Projects of Common European Interest (IPCEIs). Member states can use the recovery plan NGEU for several initiatives of hydrogen across the value chain. The framework IPCEI is there to support and foster strategic cross-border projects in key technological areas. It is aimed at promoting innovation, and the growth of European industries in sectors vital to the EU's long-term economic development. IPCEIs are typically focused on “cutting-edge” technology as for instance: "IPCEI Hy2Tech," in July 2022, which aimed to decarbonize industrial and transportation activities for end users. And with "IPCEI Hy2Use" in September 2022 hydrogen infrastructure and eco-friendly industrial hydrogen solutions are promoted. Another notable initiative is the Clean Hydrogen Alliance (launched July 2020) that brings together private and public sectors and encourages a sustainable hydrogen ecosystem in Europe. [24]

2.2.2 USA

National hydrogen strategy:

In 2017, the Department of Energy (DOE) initiated the H2@Scale[25] program with the aim of making large-scale hydrogen generation, transport, storage, and utilization accessible and dependable throughout the US energy system at an affordable cost. Despite the enactment of the Energy Policy Act of 2005 (EPACT), there has been minimal advancement as the level of hydrogen production remains the same as it was when the Act was introduced. From 2017 to 2020, the US Department of Energy (DOE) allocated around $150 million per year for hydrogen and fuel cells. The Ministry of Economy, Trade, and Industry (METI) of Japan on the other hand budgeted $560 million for support of hydrogen in 2019. The nation's commitment to clean energy has recently expanded during the Biden administration, and this includes greater investment in hydrogen and the realization of some of the goals of the DOE's comprehensive **Hydrogen Program Plan** (2020). [26]

Notably, President Biden signed the Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL) that contains a proposal for a Clean Hydrogen Production Standard (CHPS) to define low-carbon hydrogen production in the US. It provides substantial government funding for research and development of hydrogen infrastructure, with the goal of demonstrating clean hydrogen production for various sectors by 2040. It also allocates $8 billion to create at least four clean

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[24] European Clean Hydrogen Alliance (europa.eu)

[25] U.S. Department of Energy Efficiency and Renewable Energy, Hydrogen and Fuel Cell Technologies Office. 2020. “H2@Scale”, https://www.energy.gov/eere/fuelcells/h2-scale

[26] Summary of Japan's Hydrogen Strategy (env.go.jp)

hydrogen hubs, one of which must show clean hydrogen generation using renewable energy.[27]

The US government may have a greater chance of achieving its hydrogen investment goals because of the recent adoption of the Inflation Reduction Act (IRA), which went into effect on August 16, 2022. According to the IRA *qualified clean* hydrogen is defined as hydrogen produced by a process that results in a lifecycle greenhouse gas emissions rate of no more than 2 kilograms of CO2e per kilogram of hydrogen.[28] And with the adopted act, several tax credits are aimed at promoting clean hydrogen:

1. Tax credits for producing electricity from renewable resources: The bill extends the tax credit for producing electricity from various renewable sources such as wind, biomass, geothermal, solar, landfill gas, qualified hydropower, and marine and hydrokinetic resources.
2. Tax credits for investment in energy properties: The bill extends the tax credit for investment in certain energy properties, including solar, fuel cells, waste energy recovery, combined heat and power, small wind property, and microturbine property.
3. Tax credits for clean fuels: The bill extends the income tax credit for biodiesel and renewable diesel, biodiesel excise tax credit, alternative fuels tax credit, and second-generation biofuel producer tax credit. It also introduces a new tax credit for the sale or mixture of sustainable aviation fuel.
4. Tax credits for clean hydrogen production: The bill creates a new tax credit to produce qualified clean hydrogen, defined as hydrogen with a low lifecycle greenhouse gas emissions rate. This tax credit is applicable over a specified 10-year period.
5. Tax credits for clean vehicles: The bill modifies and extends the tax credit for qualifying plug-in electric vehicles and introduces a new tax credit for previously owned qualified clean plug-in and fuel cell vehicles. It also establishes a tax credit for qualified commercial clean vehicles.

In Figure 9 a small timeline of the above-mentioned regulations is shown.

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[27] Infrastructure Investment and Jobs Act Accelerating Deployment of Hydrogen

[28] H.R.5376 - 117th Congress (2021-2022): Inflation Reduction Act of 2022 | Congress.gov | Library of Congress

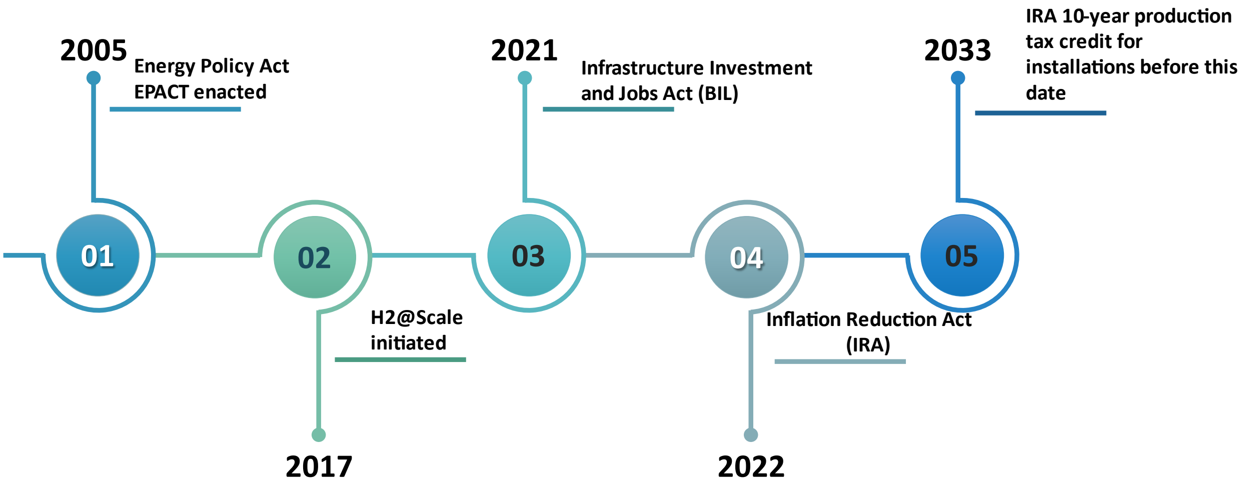

Figure 9: Timeline for green hydrogen related regulations in the US

Policy Priorities:

The DOE has outlined the following actions (Figure 10) for clean hydrogen[29] in their September 2022 draft[30].

Prioritize strategic and impactful applications of *clean hydrogen*: The objective is to employ clean hydrogen in sectors where alternative deep decarbonization solutions are limited, thus maximizing its value. Target markets include the industrial sector, heavy-duty transportation, and long-duration energy storage for a cleaner grid. Additionally, there is potential for exporting clean hydrogen or hydrogen carriers, which would enhance energy security for our allies. Long-term opportunities will be explored to harness these benefits.

Decrease the cost of clean hydrogen: The launch of the Hydrogen Energy Earth shot (Hydrogen Shot) initiative in 2021 will accelerate innovation and scalability, fostering private sector investments and driving advancements across the entire hydrogen supply chain. The aim is to significantly reduce the cost of clean hydrogen. This effort will also address critical vulnerabilities in materials and supply chains while emphasizing efficient, durable, and recyclable design.

Emphasize the development of regional networks: This entails establishing regional hubs for clean hydrogen, enabling large-scale production and utilization of clean hydrogen in proximity. By creating critical mass infrastructure and facilitating market growth, these networks will drive scaling opportunities. Moreover, they will leverage location-specific prospects to promote equity, inclusion, and sustainability Immediate priorities include generating near-term impact, creating job opportunities (including well-paying union jobs), and catalyzing domestic manufacturing and private sector investments.

Figure 10: Policy priorities identified by US DOE

Guarantees of Origin:

The above-mentioned BIL requires the DOE to develop to establish an initial standard that defines the carbon intensity of clean hydrogen, which will serve as a benchmark

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[29] Hydrogen that is produced with a carbon intensity equal to or less than 2 kilograms of CO_2eq emitted per kilogram of hydrogen at the production site

[30] DOE National Clean Hydrogen Strategy and Roadmap (energy.gov)

for certain programs outlined in the BIL. To assure a comprehensive strategy, the DOE, and the Environmental Protection Agency (EPA) will collaborate while gathering input from industry and various stakeholders. The main provisions of the standard include:

- Support to produce clean hydrogen from a variety of low-carbon energy sources: The standard will include the production of pure hydrogen from specific sources of low-carbon energy. These sources include fossil fuels with CCUS and hydrogen-carrying fuels such as ethanol and methanol, biomass, and nuclear energy.
- Define clean hydrogen: The standard lowers the earlier stated definition to "*clean hydrogen as hydrogen that is produced with a carbon intensity equal to or less than 2 kilograms of carbon dioxide-equivalent emitted per kilogram of hydrogen at the production site. This definition establishes the desired level of carbon emissions associated with clean hydrogen.*" [31]
- Consideration of technological and economic feasibility: The standard will consider the feasibility of the technologies and the economic viability of implementing them. This ensures that the defined carbon intensity targets are realistic and attainable within the industry.

Furthermore, the DOE is mandated to review and update the initial standard within five years of its establishment to accommodate any advancements in technology or changes in the clean hydrogen landscape. This ensures that the standard remains relevant and aligned with the evolving state of clean hydrogen production. The DOE will use several tools, among which: the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model that will allow for precise characterization of the decarbonization potential of these. The GREET model will be critical in assessing emissions connected with the production, distribution, and final use of pure hydrogen across the whole value chain. [32]

The roadmap of the DOE's Clean Hydrogen Strategy notes the importance of standardized, global lifecycle analysis methodologies. Over 20 nations involved in the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) highlighted the necessity as one of their top priorities. Harmonizing lifecycle analysis approaches is crucial, according to IPHE, a global government cooperation established in 2003 to advance hydrogen and fuel cell technology. The IPHE Hydrogen Production Analysis (H2PA) task group is actively involving the US. H2PA focuses on creating methodologies that may be used to analyze the lifecycle of producing hydrogen. The H2PA is still working on adding more pathways to this guidance and taking emissions

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[31] *DOE National Clean Hydrogen Strategy and Roadmap (energy.gov)

[32] GREET: The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model | Department of Energy

from hydrogen distribution into account. Although IPHE's recommendations are not legally enforceable, they are a useful tool for member nations in creating uniform accounting frameworks. This guarantees consistency and dependability in the evaluation of emissions throughout the hydrogen value chain, including potential collateral effects.

Next to on-road applications, there are opportunities for hydrogen and its carriers emerging in the maritime sector. Hydrogen and hydrogen carriers like ammonia and methanol are potential replacements for conventional bunker fuel since the International Maritime Organization (IMO) has established stricter limits on the amount of sulfur in ship fuel.[33] In order to develop and demonstrate hydrogen and fuel cell technologies for maritime applications, the DOE and the Maritime Administration (MARAD) have been working together on important advancements, including for instance the world's first pier-side hydrogen fuel cell.[34] These programs are intended to de-risk innovations and to facilitate market acceptance, as well as stimulate private sector investments. In addition, various initiatives have been launched in partnership with international organizations such IMO to solve safety issues, and aid in developing global harmonized norms and standards.

Governance System and enabling policies:

The USA government has a strategy for promoting the use of hydrogen as a fuel or feedstock[35], which involves a combination of policies and initiatives at both the Federal and State levels. These policies include financial incentives to encourage investment in hydrogen technology, as well as government-funded research and development to advance the state of the technology. Additionally, regulatory policies are being updated to ensure that hydrogen can be safely and efficiently integrated into the energy system. With hydrogen being classed as “an alternative fuel” according to the federal government, it allows for eligibility for several tax credits (e.g., the Alternative Fuel Excise Tax Credit), subsidies, and grants, which could potentially lead to a more widespread use.

As mentioned earlier *clean hydrogen* production in the US typically involves utilizing low-carbon or carbon-free energy sources, such as renewable energy or fossil fuels coupled with CCS. Examples are the earlier mentioned tax credits of the IRA. Another example is the Hydrogen Shot program, a prominent U.S. Department of Energy initiative that aims to reduce the cost of renewable hydrogen. This flagship initiative is designed to work in conjunction with other efforts, such as the rapid deployment

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[33] https://www.maritime-executive.com/article/imo-answers-questionson-the-2020-sox-regulation

[34] Maritime Fuel Cell Generator Project (energy.gov)

[35] ACC Welcomes the Hydrogen for Industry Act (americanchemistry.com)

and scaling up of hydrogen through the establishment of hydrogen hub, the provision of loan guarantees, and the implementation of various mechanisms.

2.2.3 Japan

National hydrogen strategy:

The Government of Japan recently announced its plans to update its hydrogen strategy in May 2023, aiming to increase hydrogen supply from 2 Mt to 12 Mt by 2040.[36] The revised strategy will align with new targets and focus on expanding domestic electrolyser manufacturing to capture 10% of the global market share by 2030. Prime Minister Fumio Kishida has called for approximately ¥15 trillion ($112.8 billion) in investments over the next 15 years to promote hydrogen and renewable energy utilization. Japan has already made progress with the establishment of a strategic roadmap and the Japan Hydrogen Association. The shift towards domestic electrolyser production aligns with the recommendations of the Renewable Energy Institute's report, emphasizing the need for clean hydrogen production to achieve Japan's net-zero emissions target by 2050.

A recent study from the Japanese Renewable Energy Institute titled "*Re-examining Japan's Hydrogen Strategy*" highlights the shortcomings of Japan's current approach to hydrogen and emphasizes the need for a transition to renewable energy.[37] The study points out the lack of a comprehensive strategy for achieving a decarbonized society, unlike the EU's active development of a hydrogen strategy aligned with carbon neutrality objectives. Although Japan is constructing a large-scale hydrogen supply chain, it lacks a clear energy strategy for decarbonization and the identification of key sectors where hydrogen can have the greatest impact.

The report describes the 2017 hydrogen initiative as "*misguided*", due to its support for grey hydrogen production and the allocation of a significant portion of the hydrogen budget to "*bad idea applications*" such as fuel cell vehicles, refueling stations, and residential power systems that accounted for 70% of the funding. And that these factors have contributed to the delay in Japan's hydrogen development. In contrast, Europe and the US have made more progress in domestic green hydrogen production, which is crucial for addressing decarbonization and energy security challenges. This delay is attributable to Japan's preference for grey and blue hydrogen and its reliance on hydrogen imports. According to the report, Japan has taken some initiatives since the 2014 initial Strategic Roadmap for Hydrogen and Fuel Cells. However, three major difficulties must be addressed:

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[36] April 5, Reiwa 4 Ministerial Meeting on Renewable Energy and Hydrogen | Prime Minister's Day | Prime Minister's Office website (kantei.go.jp)

[37] Re-examining Japan's Hydrogen Strategy: Moving Beyond the "Hydrogen Society" Fantasy (renewable-ei.org)

- Selection of low-priority applications: Japan's strategy has focused on applications with low priority, failing to identify and prioritize sectors where hydrogen can have the most significant impact.
- Promotion of grey and blue hydrogen: Japan has earlier placed emphasis on grey and blue hydrogen, which are derived from fossil fuels and have limited emissions reduction potential.
- Significant lag in domestic green hydrogen production: Japan has experienced a significant delay in the domestic production of green hydrogen, which hampers its ability to keep up with other countries in this crucial area.

These issues highlight the need for Japan to reassess its hydrogen strategy and prioritize the development of green hydrogen to catch up with global leaders in decarbonization efforts. The development of hydrogen supply chains, including maritime transport, is a significant area of focus for the Japanese government. Several projects are underway to establish hydrogen infrastructure and explore different carriers as e.g., liquefied hydrogen and ammonia. Japan also plans to establish manufacturing technology for renewable hydrogen production by 2030. To maintain flexibility, Japan invests in various hydrogen carriers and keeps its options open, considering their different advantages and long-term viability. This approach allows the country to adapt to emerging technologies and market developments.[38]

Policy Priorities:

Hydrogen and ammonia are positioned as key drivers for decarbonizing the Japanese energy system. The government's policy initiatives focus on several key areas[39]:

- Developing the Hydrogen Supply Chain: Japan is actively working on building a robust hydrogen supply chain, including storage infrastructure. This involves efforts to enhance hydrogen production, transportation, and distribution networks to meet the growing demand.
- Expanding Domestic Demand: The government aims to stimulate domestic demand for hydrogen and ammonia. This includes promoting their usage in various sectors, such as transportation and power generation, to accelerate the transition towards a low-carbon economy.
- Cost Reduction Targets: Japan aims to substantially reduce the delivered cost of hydrogen, targeting a cost of JPY30/Nm3 by 2030. This cost reduction is crucial to make hydrogen more economically viable and competitive with traditional energy sources.
- Decarbonizing Thermal Power Generation: Hydrogen and ammonia will be utilized to decarbonize thermal power generation. The government has set

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[38] Japan's Hydrogen Industrial Strategy (csis.org)

[39] focus-on-hydrogen-in-japan.pdf (cliffordchance.com)

targets, including a goal of achieving 20% ammonia co-firing in coal power plants and 30% hydrogen co-firing in gas power plants by 2030. These measures will significantly reduce carbon emissions from the power sector.

- Power Mix Integration: Japan plans for hydrogen and ammonia to comprise 1% of the country's overall power mix by 2030. This integration will diversify the energy sources and contribute to the overall decarbonization of the electricity generation sector.
- Public-Private Collaboration and Research: Japan has established substantial ongoing public-private co-investment in research and development (R&D) and pilot projects, particularly in the field of hydrogen transportation technologies. This collaborative approach supports innovation and technological advancements in the hydrogen sector.
- Power-to-Gas Solutions: Japan envisions "power to gas" as a solution to address renewable power intermittency and achieve efficient domestic hydrogen production. This approach involves converting surplus renewable energy into hydrogen through electrolysis, storing it, and utilizing it during periods of high demand.
- Regulatory Frameworks: To facilitate the wider adoption of hydrogen and ammonia, regulatory frameworks will need revision and support. Updated regulations will provide a favorable environment for the safe and efficient use of hydrogen and ammonia across various sectors.

Guarantees of Origin:

Japan currently lacks a specific regulatory framework dedicated to hydrogen and ammonia. Instead, existing regulations pertaining to dangerous gases apply at different stages of the supply chain. These regulations were originally designed to produce fertilizers and for other industrial purposes. The High-Pressure Gas Safety Act (HPGSA) addresses the explosiveness and combustibility of hydrogen and imposes regulations on its production and storage. Ammonia is also subject to regulations under the HPGSA. Approval from the prefectural governor is necessary for ammonia production or storage if the business operator and facilities meet certain requirements. However, this existing regulation does not directly address activities related to the more widespread use of green hydrogen and. The Japanese government is currently exploring options for amending current regulations or implementing a new regulatory framework. This is to ensure the safe and efficient deployment of hydrogen and ammonia as key components of Japan's energy strategy.[40,41] To facilitate the widespread adoption of green hydrogen, the government is exploring

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[40] focus-on-hydrogen-in-japan.pdf (cliffordchance.com)

[41] Hydrogen law and regulation in Japan | CMS Expert Guides

the establishment of a trading scheme that enables the exchange of the environmental value associated with hydrogen. Options under consideration include leveraging existing systems such as the "J-credit Scheme" used for certifying greenhouse gas emissions reductions and absorption, as well as the "Act on the Rational Use of Energy". The "Non-fossil Fuel Energy Value Trading Market" is also considered a promising avenue for promoting the trading of green hydrogen's environmental attributes.

2.2.4 Concluding Remarks

Table 3 offers a concise overview of the three discussed regions. As can be seen from Table 3, all three countries have already published their Hydrogen Strategies, outlining notable production targets for hydrogen by 2030. These targets demonstrate substantial progress compared to the current minimal production of green hydrogen. However, they still fall significantly short of the scale of deployment required by 2050.

Table 3: Overview of green hydrogen regulations in EU, USA, and Japan.

Region	Hydrogen targets	Policy priorities	Hydrogen instruments
EU	**Hydrogen strategy:** 2024: • Minimal 6 GW of renewable hydrogen electrolysers. • 1 million tonnes of renewable hydrogen produced 2030: • 40 GW of renewable hydrogen electrolysers. • Production of 10 million tonnes of renewable hydrogen. • Imports hydrogen relying on 40 GW electrolysers	• Focus on aligning the climate and energy legislative framework with the goals of achieving climate neutrality by 2050 and reducing GHG emissions by at least 55% by 2030. • Most recent renewable energy target to 42.5% by 2030, with additional targets for renewable hydrogen use in various sectors. The agreement also includes provisions for expediting permitting processes and simplifying legal objections to accelerate renewable energy deployment.	European Clean Hydrogen Alliance (project of IPCEI) Within the IPCEI framework state aid is permitted if selected projects meet the following conditions: • Support the strategic EU objectives • Include several EU countries • Include private funding from the beneficiaries • Generate favorable spillover effects throughout the EU • Display a high commitment to research and innovation
US	**Hydrogen program plan** • USD 2/kg for hydrogen production • USD 1/kg hydrogen for industrial and stationary power generating applications • USD 300/kW electrolyser capital expenses, 80,000 hours durability and 65% system efficiency	• Focus on strategic applications of clean hydrogen, reducing its cost, and developing regional networks for large-scale production and utilization. • The DOE's Hydrogen Shot initiative aims to accelerate innovation and scalability, driving advancements across the entire hydrogen supply chain and addressing critical vulnerabilities in materials and supply chains.	• Focus on coordinating R&D projects to make hydrogen more adaptable to different uses and industries • The crucial US 45Qtax credit for carbon capture and storage (CCS) provides a credit of at least USD 85 per ton of CO2 captured and stored. [42]

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[42] Section 45Q Credit for Carbon Oxide Sequestration – Policies - IEA

Region	Hydrogen targets	Policy priorities	Hydrogen instruments
Japan	**Basic Hydrogen Strategy**[43] 2030: • Increase annual hydrogen supply to 300,000 tonnes, and reduce the cost of hydrogen to USD 3/kg 2050: • Reduce the cost to USD 2/kg	• Focus on developing a robust hydrogen supply chain, stimulating domestic demand, reducing the cost of hydrogen, decarbonizing thermal power generation, integrating hydrogen and ammonia into the power mix, promoting public-private collaboration and research, implementing power-to-gas solutions, and establishing supportive regulatory frameworks. • Development of bases in collaboration with Australia, the Middle East, and Asia, and swiftly advance the development of a leading system that is ahead of Asia in integrating regulations and support. • These priorities aim to accelerate the adoption of hydrogen and ammonia across various sectors and contribute to the overall decarbonization of Japan's energy system.	• Advancing Hydrogen and Fuel-Cell Technologies • Funding provided for research, development, and demonstration purposes • Allocation of a budgetary support of JPY 95.5 billion for hydrogen in the year 2021

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[43] Revision in June, with new target of an annual supply of 12 million tonnes of Hydrogen by 2040 Japan aims to boost hydrogen supply to 12 million T by 2040 | Reuters

As mentioned earlier Guarantees of Origin play a crucial role in demonstrating the origin of hydrogen by the quantity of renewable energy in an energy supplier's mix. Regarding GOs, the EU especially has stringent legal conditions. The RED II defines GOs and their criteria, enabling transparent tracking and trading of renewable energy across EU member states. To further ensure the credibility of renewable hydrogen[44], the European Commission has adopted the delegated acts that define criteria for renewable hydrogen, including requirements for renewability, additionality, temporal correlation, and geographical correlation. In the US, the guarantees of origin are an important aspect of the National Hydrogen Strategy, with the DOE mandated to develop a standard for the carbon intensity of clean hydrogen[45]. This standard will define clean hydrogen and consider the feasibility of technologies and economic viability. The DOE will collaborate with stakeholders and utilize tools like the GREET model to accurately assess the decarbonization potential and evaluate emissions throughout the value chain. Regarding guarantees of origin, Japan currently lacks a specific regulatory framework for hydrogen and ammonia. The government is exploring options to amend existing regulations or introduce a new framework to support their safe and efficient deployment. Additionally, the establishment of a trading scheme for green hydrogen's environmental attributes is being considered, leveraging existing systems such as the J-credit Scheme and the Non-fossil Fuel Energy Value Trading Market.

2.3 Green Hydrogen Standardization

2.3.1 International Standards

In the EU, harmonized European standards are issued by bodies such as the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC), upon the European Commission’s request. Comparable hierarchical frameworks can be identified in other nations such as the American Society of Mechanical Engineers (ASME) in the United States that is able to add additional industrial codes, standards, and guidelines.

European standards promote cross-border trade, lower costs for suppliers and buyers, guarantee safety and compatibility, and assist companies in seamlessly integrating into the value chain. The European Standardization System strictly adheres to the principles defined by the World Trade Organization (WTO) and involves experts from various sectors and societal stakeholders to produce market-driven deliverables that consider the public interest and priorities of society. CEN and

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[44] Renewable hydrogen can be obtained via electrolysis using renewable electricity to split water into hydrogen and oxygen and is referred to as ‘renewable fuels of non-biological origin’ (RFNBO) - Hydrogen (europa.eu)

[45] Clean hydrogen is defined as hydrogen produced with a carbon intensity equal to or less than 2 kilograms of carbon dioxide-equivalent produced at the site of production per kilogram of hydrogen produced. Alternative Fuels Data Centre: Regional Clean Hydrogen Hubs (energy.gov)

CENELEC are two distinct private international non-profit organizations that usually channel proposals for European Standards, with work assigned to a Technical Committees. National mirror committees then decide on contributions, and external stakeholders also participate. During the drafting stage consensus must be reached [46], followed by a public enquiry, votes and comments, and formal voting. Once published, European Standards become national standards and must be implemented by CEN and CENELEC members, guaranteeing the same measures across all member countries.

Major hydrogen incidents progressing the evolution of safety standards:

Accidents in the hydrogen value chain can have severe consequences, including property damage, injuries, and even fatalities. While hydrogen is a promising energy source, it requires strict safety measures to prevent accidents.

EU

- **The Hindenburg Disaster[47]:** One of the most well-known accidents involving hydrogen occurred on May 6, 1937, when the German airship Hindenburg caught fire while attempting to dock in New Jersey, United States. The accident resulted in the death of 36 people and highlighted the flammability risks associated with hydrogen.

US

- **Equipment Failure[48]:** A report by DoE's National Energy Technology Laboratory (NETL), highlights equipment failure to be the most commonly identified probable cause of accidents in the hydrogen industry. This includes failures in pressure vessels, piping, valve systems, compressed gas containers, electrical equipment, and measurement sensors. Out of the 347 incidents reported to the H2 Tools website on a voluntary basis, 25.9% contributed to equipment failure and 13.3% contributed to other technology-related causes such as design flaws, material incompatibility, or inadequate equipment.
- **Hydrogen Explosion at Power Plant in Ohio[49]:** In 2007, a routine gaseous hydrogen delivery resulted in a fatal explosion. This incident occurred due to a rupture disk failure on an onsite storage tank, leading to hydrogen leakage and accumulation, followed by ignition, and resulting in fatalities and injuries.
- **Hydrogen explosion and fire incident in Santa Clara, California[50]:** In 2019, an accident resulted by a leak during the fueling of a hydrogen tanker truck at the Air Products and Chemicals, Inc. facility. The leak led to a subsequent explosion during the shutdown process. Firefighters responded to the explosion, which damaged the emergency shutoff panel and valve near the

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[46] European Standards - CEN-CENELEC (cencenelec.eu)

[47] Accidentology Involving Hydrogen, Ministry of Ecology, Energy, Sustainable Development and Town & Country Planning, 2009

[48] https://www.hydrogeninsight.com/transport/equipment-failure-is-the-biggest-cause-of-hydrogen-related-accidents-us-national-lab/2-1-1505699

[49] https://wha-international.com/case-study-power-plant-hydrogen-explosion/

[50] https://h2tools.org/sites/default/files/2021-06/AP_Santa_Clara_Incident_Review_Report_Rev1.pdf

tanker. Although no injuries were reported, the incident led to business evacuations in the immediate area and shelter-in-place order for nearby residents.

Japan

- **Destruction of the Kadena Air Base Hydrogen Filing Station[51]:** In 2014, a hydrogen filling station at the Kadena Air Base in Okinawa, Japan, experienced a major accident. The explosion and subsequent fire destroyed the hydrogen facility, causing significant damage and disrupting operations.
- **Fukushima Daiichi Nuclear Power Station Accident[52]:** In 2011, a severe earthquake measuring 9.0 on the Richter scale and subsequent series of seven tsunamis on the site of the Fukushima Daiichi Nuclear Plant led to the nuclear accident. This resulted in severe damage to the infrastructure and equipment. As a result of inadequate core colling, hydrogen was generated from the damaged fuel in the reactors and accumulated in the reactor buildings – and ignited, producing explosion in the reactor building. The presence of these gases posed significant challenges during the management of the nuclear accident.

South Korea:

- **Hydrogen gas leak in chemical plant[53]:** Additionally, another incident occurred in South Korea in 2019, where a hydrogen gas leak and subsequent fire at a chemical plant caused workers to suffer burns, emphasizing the need for robust safety protocols.

The progression of hydrogen safety standards has been influenced by key incidents in the EU, US, and Japan. Some of these incidents include **hydrogen leakage and accidents at fueling stations**, as well as the **generation of flammable gases** resulting from the nuclear accidents. These incidents have led to research and development efforts aimed at improving safety measures, such as the **development of catalytic recombiner devices inside storage containers, performance tests of catalysts for safe conversion of hydrogen, the analysis of accidents involving hydrogen fueling stations,** and more. Additionally, efforts have been made to **characterize hydrogen transport accidents and to study the effectiveness of hydrogen leakage detection for fuel cell vehicles**. These incidents have prompted further research and testing, as well as the formulation of roadmaps and safety standards, to promote the safe use and handling of hydrogen. Meanwhile, an analysis of accidents involving hydrogen fueling stations in both Japan and the USA has highlighted the **importance of proper management of hydrogen gas for safety.**

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[51] Sakamoto J, et al., Leakage-type-based analysis of accidents involving hydrogen fueling stations inJapan and USA, International Journal of Hydrogen Energy (2016)

[52] https://www.nrc.gov/docs/ML1134/ML11347A454.pdf

[53] Hydrogen hurdles: a deadly blast hampers South Korea's big fuel cell car bet, Reuters, 2019

Specific safety standards were established in the EU in response to hydrogen incidents through the **Clean Hydrogen Joint Undertaking's Hydrogen Incidents and Accidents Database (HIAD 2.0)**[54]**.** The revamp of this database is aimed at enhancing the quality and number of events contained in the database to derive lessons learned and recommendations.

Specific Initiatives:

EU: In the EU, the evolution of hydrogen safety standards can be seen through advancements in regulations and guidelines. The EU has been actively working towards ensuring the safety of hydrogen-related activities. Some notable examples include:

- **Hydrogen Refueling Station Safety:** The EU has developed safety standards and regulations for hydrogen refueling stations to ensure the safe supply of hydrogen for fuel cell vehicles. These standards include guidelines on proper handling, storage, and dispensing of hydrogen at refueling stations.
- **Product Safety Standards:** The EU has established product safety standards for hydrogen-powered devices and equipment. These standards cover a wide range of products, including fuel cells, hydrogen storage systems, and hydrogen-powered appliances. Compliance with these standards ensures that the products meet the necessary safety requirements.
- **Risk Assessment and Management:** The EU has implemented risk assessment and management protocols for hydrogen-related activities. These protocols help identify potential risks associated with hydrogen use and provide guidelines for their mitigation. They also emphasize the need for proper training, maintenance practices, and emergency response plans.
- An example of the evolution of hydrogen safety standards in the EU is the establishment of the **Hydrogen Safety Panel by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU).** This panel provides advice on safety issues related to hydrogen and fuel cells, contributing to the continuous improvement of safety measures in the EU.

US: In the US, hydrogen safety standards have also evolved over time, driven by the increasing adoption of hydrogen technologies. The US has implemented regulations and guidelines to ensure the safe handling, storage, and use of hydrogen. Some key examples include:

- **National Fire Protection Association (NFPA) Codes and Standards:** The NFPA develops and maintains codes and standards that address the safe use

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[54] https://www.sciencedirect.com/science/article/pii/S0360319922012976

of hydrogen in various applications. NFPA 2, "Hydrogen Technologies Code," provides requirements for the safe production, storage, and use of hydrogen across different sectors.

- **Transportation Safety Regulations:** The US Department of Transportation (DOT) has established safety regulations for the transportation of hydrogen in cylinders, tanks, and pipelines. These regulations include guidelines on packaging, labeling, and handling of hydrogen during transportation.
- **Occupational Safety and Health Administration (OSHA) Guidelines:** OSHA provides guidelines and standards to ensure the safety of workers involved in hydrogen-related activities. These guidelines cover areas such as hazard communication, personal protective equipment, and emergency response planning.
- An example of the evolution of hydrogen safety standards in the US is the development of the **Hydrogen Safety Best Practices Manual by the US Department of Energy (DOE).** This manual provides comprehensive guidance on the safe handling, storage, and use of hydrogen in various applications, promoting consistent safety practices across the industry.

Japan: In Japan, the focus on hydrogen safety has been significant due to the country's strong commitment to hydrogen as an energy source. Japan has implemented various safety measures and standards to ensure the safe transportation, handling, and use of hydrogen. Examples include:

- **Hydrogen Safety Guidelines:** Japan has developed comprehensive guidelines for the safe use and handling of hydrogen. These guidelines cover topics such as hydrogen storage, transportation, and refueling station safety. They provide detailed instructions for risk assessment, ventilation, and emergency response.
- **Hydrogen Safety Promotion Measures:** The Japanese government has implemented hydrogen safety promotion measures to ensure the safe development and deployment of hydrogen technologies. These measures include the establishment of safety evaluation criteria and the promotion of safety education and training.
- **International Collaboration:** Japan actively participates in international collaborations on hydrogen safety, such as the International Energy Agency (IEA) Hydrogen Implementing Agreement. These collaborations facilitate the sharing of best practices and the development of harmonized safety standards.
- An example of the importance placed on hydrogen safety in Japan is the active involvement of organizations such as **the Japan Hydrogen Association**

and the Japan Society of Safety Engineering (JSSE), which work towards the continuous improvement of hydrogen safety standards in the country.

Importance of Sfety Standards:

- **Risk identification and management:** Safety standards help identify and manage potential risks, reducing accidents due to equipment failure, poor maintenance, or mishandling.
- **Regulation and compliance:** Safety standards regulate the industry, protecting workers, the public, and the environment. Compliance ensures adherence to safety measures.
- **Emergency preparedness:** Safety standards provide guidance on emergency response, minimizing the impact of accidents.
- **Training and awareness:** Safety standards enhance awareness among workers, ensuring everyone understands their role in maintaining safety.
- **Continuous improvement:** Safety standards promote continuous improvement, updating recommendations based on new knowledge and incident investigations.

Where Safety Standards can help:

- Hydrogen system siting and personnel exposure distances
- Hydrogen delivery to near-consumer use points
- Noise mitigation of hydrogen venting and system operation
- Updated first responder guidelines for hydrogen delivery vehicles and FCEVs
- Material suitability for hydrogen service

Next to CEN and CENELEC, global standardization organizations exist, such as International Standardization Organization (ISO) and International Electrotechnical Commission (IEC), which brings together experts from approximately 170 countries to collaboratively develop voluntary, consensus-based international standards that promote innovation and offer solutions to global challenges.

ISO and IEC have agreements with CEN and CENELEC to facilitate promotion of EU standards and their advantages to international trade and markets harmonization. These initiatives aim to align European standards with international counterparts and avoid duplication of work and structures. CEN and CENELEC support the prioritization of ISO and IEC standards, ensuring a fair and consistent global playing field.

In terms of hydrogen standards, the International Organization for Standardization (ISO) has already published 18 of them, while 22 more are now under development.[55] For a timeline of the evolution of ISO standards, please see Annexure 5. The ISO and the IEC both contribute significantly to the creation of safety regulations for green hydrogen technology. Two Technical Committees (TC) are entirely focused on fuel cell and hydrogen technology:

- *The ISO/TC 197: Hydrogen technologies develop standards for the production, storage, transport, measurement, and use of hydrogen.* This technical committee is focused on the safety concerns associated with hydrogen.
- *The IEC/TC 105: Fuel cell technologies develop standards for any type of fuel cells and their applications for power and heat, transport, electrolysis (as reverse fuel cells), flow batteries.* This TC is more focused on electrical safety.

Additionally, there are other ISO Technical Committees that are relevant to green hydrogen safety even though they are not exclusively dedicated to hydrogen. Since hydrogen is a flammable gas, standards describing these applications and products are also relevant:

- *ISO/TC 58: Gas cylinders, Standardization of gas cylinders and other pressure receptacles, their fittings and requirements relating to their manufacture and use.*[56]
- *ISO/TC 220: Cryogenic vessels, Standardization in the field of insulated vessels (vacuum or non-vacuum) for the storage and the transport of refrigerated liquefied gases of class 2 of the UNECE ADR.*[57]

Because of the widespread usage of hydrogen as an energy source in a variety of industries, its standardized framework and uses are comprehensive and complicated. An overview of the relevant TC/Working groups on hydrogen is described in the Annexure. Furthermore, to create more structure in the technical standards relevant to green hydrogen, throughout this report these will be organized around hydrogen supply chain segments according to applications shown in Figure 3.

Hydrogen production:

As mentioned earlier, electrolysis is an important step in the production of green hydrogen. The creation of green hydrogen might be said to begin with the electrolysis process. However, renewable power must be provided into this electrolyser. And to promote the integration into today's energy markets, the development of hydrogen-integrated energy systems should be stimulated by governments.[58] Next to electrical

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[55] ISO/TC 197 - Hydrogen technologies

[56] ISO/TC 58 - Gas cylinders

[57] ISO/TC 220 - Cryogenic vessels

[58] Hydrogen electrolyser technologies and their modelling for sustainable energy production: A comprehensive review and suggestions - ScienceDirect

grid connectivity, also PtX technologies, and gas quality considerations, and material compatibility standards are needed to ensure safety of the green hydrogen production. These safety standards should be developed through research activities and subsequently fed to international standards, as these were not published yet at the date of this report.

When power sources are intermittent and/or deliver current densities that are significantly lower than these ideal levels for extended periods of time, traditional electrolysers may struggle to operate effectively and safely.[59] Integration into the energy system can introduce additional safety considerations and challenges: For instance, in some electrolysers, the gas permeability of the separation membrane rises at low power levels, causing a phenomenon known as "cross-over." As a result, the hydrogen level of the oxygen stream rises, and vice versa. The standard *ISO 22734:2019*, titled *"Hydrogen generators using water electrolysis—Industrial, commercial, and residential applications*," serves as the reference safety document and provides standards for safety and specifies how all the materials and components will be tested. *ISO 22734* is currently being updated to ensure safer functioning when used with variable power sources in response to these difficulties. The standard will be supplemented by a technical report, *ISO TR 22734-2*, which will include assessment guidelines for supplying electrical grid services. The standard covers alkaline electrolysis and solid polymeric materials like PEM and anion exchange membranes (AEM). *IEC 62282-8-201:2023* on the covers solid oxide electrolysers. Another standard covering these is in *UL LLC 22644*[60]*.*

Hydrogen storage:

Large-scale storage of hydrogen will play a fundamental role in the potential hydrogen economy. [61] One of ISOs technical committees *ISO/TC 197* has been working on "*Standardization in the field of systems and devices for the storage of hydrogen"* And especially WG-15 is focused on cylinders and tubes for stationary storage.[62] There are several standards under development e.g.

- *ISO 19884-2 "Gaseous hydrogen—Cylinders and tubes for stationary storage*, *Part 2: Material test data of class A materials (steels and aluminum alloys) compatible to hydrogen service",*[63] *which will be updated to: ISO/AWI TR 19984-2*[64]

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[59] s12209-021-00310-x.pdf

[60] https://www.shopulstandards.com/ProductDetail.aspx?productId=UL2264A_2_O_20211202

[61] Large-scale storage of hydrogen (sciencedirectassets.com)

[62] ISO/TC 197 - Hydrogen technologies

[63] ISO/AWI TR 19884-2 - Gaseous Hydrogen - Cylinders and tubes for stationary storage — Part 2: Material test data of class A materials (steels and aluminum alloys) compatible to hydrogen service

[64] https://www.iso.org/standard/86285.html

- *ISO 19884-3"Gaseous hydrogen—Cylinders and tubes for stationary storage*, *Part 3: Pressure cycle test data to demonstrate shallow pressure cycle estimation methods*" is in the drafting process and is designed to address the specific operational conditions associated with hydrogen storage, including shallow pressure cycles. [65] This *will be updated to: ISO/AWI TR 19984-3.*

Due to the phenomenon known as hydrogen embrittlement [66], which degrades the mechanical properties of steel over time, it's necessary that increased safety standards are in place. An example of ensuring the safety of gas storage are periodic inspections. Although traditional visual inspection is still widely utilized, sophisticated non-destructive procedures like acoustic emission testing (AT) have evolved. Although not specific to hydrogen only, an example can be found in document:

- *ISO/TS 19016:2019*, titled "*Gas cylinders—Cylinders and tubes of composite construction—Modal acoustic emission (MAE) testing for periodic inspection and testing.*" This document details the use of MAE testing during periodic inspection and testing of hoop wrapped and fully wrapped composite transportable gas cylinders and tubes, with aluminum-alloy, steel, or non-metallic liners or liner less construction, intended for compressed and liquefied gases under pressure. [67]

Hydrogen transport: road-vehicles:
Previously, the Ministry of New and Renewable Energy (MNRE) of India authored a report on international green hydrogen standards compared to Indian standards. Based on their results and our cross-reference the following published, in progress and technical standards in revision were found, see Figure 11.

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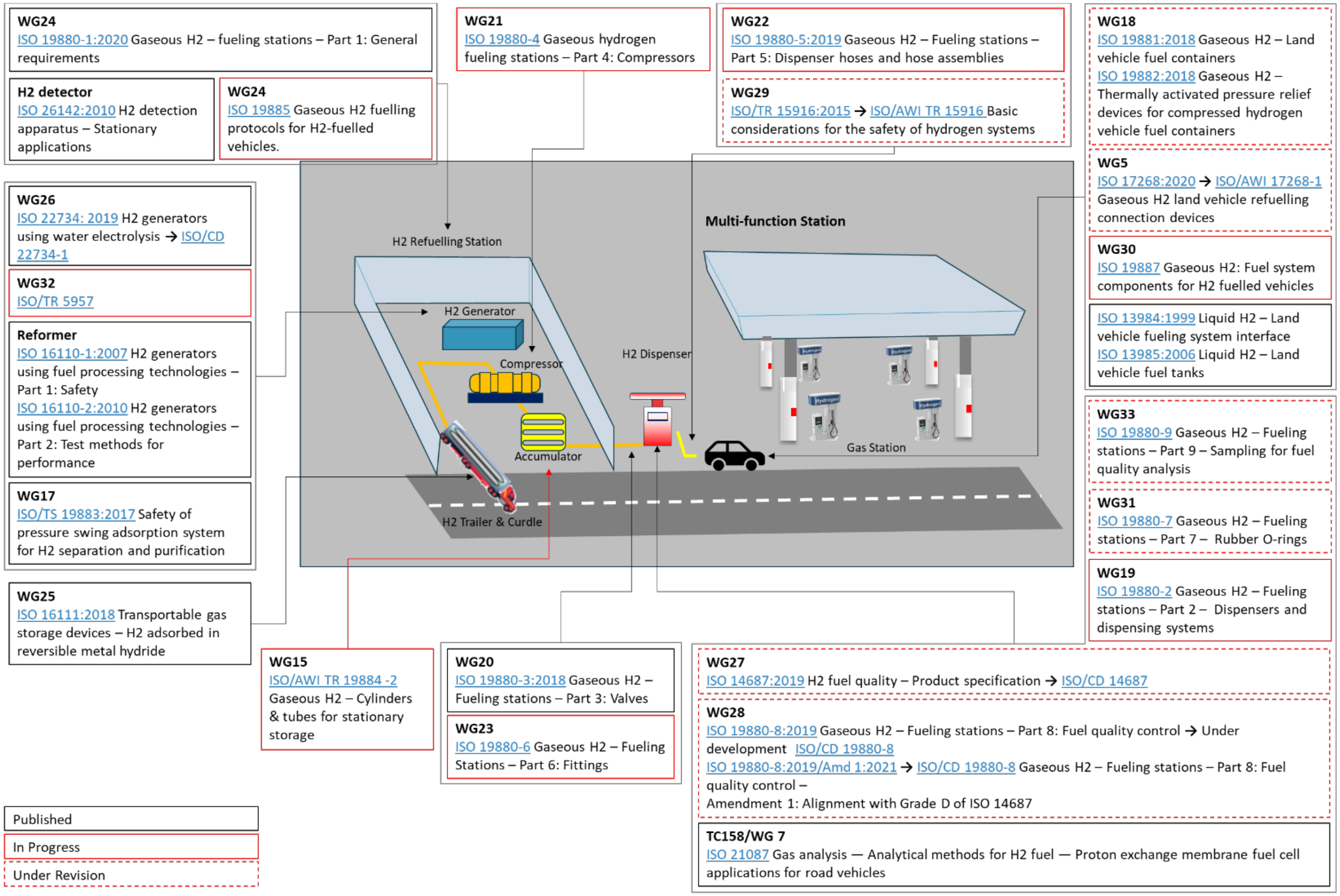
[65] ISO/AWI TR 19884-3 - Gaseous Hydrogen - Cylinders and tubes for stationary storage — Part 3: Pressure cycle test data to demonstrate shallow pressure cycle estimation methods

[66] Hydrogen Embrittlement - an overview | ScienceDirect Topics

[67] ISO/TS 19016:2019 - Gas cylinders — Cylinders and tubes of composite construction — Modal acoustic emission (MAE) testing for periodic inspection and testing



WG24
ISO 19880-1:2020 Gaseous H2 – fueling stations – Part 1: General requirements

H2 detector
ISO 26142:2010 H2 detection apparatus – Stationary applications

WG24
ISO 19885 Gaseous H2 fuelling protocols for H2-fuelled vehicles.

WG21
ISO 19880-4 Gaseous hydrogen fueling stations – Part 4: Compressors

WG22
ISO 19880-5:2019 Gaseous H2 – Fueling stations – Part 5: Dispenser hoses and hose assemblies

WG29
ISO/TR 15916:2015 → ISO/AWI TR 15916 Basic considerations for the safety of hydrogen systems

WG18
ISO 19881:2018 Gaseous H2 – Land vehicle fuel containers
ISO 19882:2018 Gaseous H2 – Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers

WG5
ISO 17268:2020 → ISO/AWI 17268-1 Gaseous H2 land vehicle refuelling connection devices

WG30
ISO 19887 Gaseous H2: Fuel system components for H2 fuelled vehicles

ISO 13984:1999 Liquid H2 – Land vehicle fueling system interface
ISO 13985:2006 Liquid H2 – Land vehicle fuel tanks

WG26
ISO 22734: 2019 H2 generators using water electrolysis → ISO/CD 22734-1

WG32
ISO/TR 5957

Reformer
ISO 16110-1:2007 H2 generators using fuel processing technologies – Part 1: Safety
ISO 16110-2:2010 H2 generators using fuel processing technologies – Part 2: Test methods for performance

WG17
ISO/TS 19883:2017 Safety of pressure swing adsorption system for H2 separation and purification

WG25
ISO 16111:2018 Transportable gas storage devices – H2 adsorbed in reversible metal hydride

WG15
ISO/AWI TR 19884 -2
Gaseous H2 – Cylinders & tubes for stationary storage

WG20
ISO 19880-3:2018 Gaseous H2 – Fueling stations – Part 3: Valves

WG23
ISO 19880-6 Gaseous H2 – Fueling Stations – Part 6: Fittings

WG33
ISO 19880-9 Gaseous H2 – Fueling stations – Part 9 – Sampling for fuel quality analysis

WG31
ISO 19880-7 Gaseous H2 – Fueling stations – Part 7 – Rubber O-rings

WG19
ISO 19880-2 Gaseous H2 – Fueling stations – Part 2 – Dispensers and dispensing systems

WG27
ISO 14687:2019 H2 fuel quality – Product specification → ISO/CD 14687

WG28
ISO 19880-8:2019 Gaseous H2 – Fueling stations – Part 8: Fuel quality control → Under development ISO/CD 19880-8
ISO 19880-8:2019/Amd 1:2021 → ISO/CD 19880-8 Gaseous H2 – Fueling stations – Part 8: Fuel quality control –
Amendment 1: Alignment with Grade D of ISO 14687

TC158/WG 7
ISO 21087 Gas analysis — Analytical methods for H2 fuel — Proton exchange membrane fuel cell applications for road vehicles

Published
In Progress
Under Revision

Figure 11: Adopted figure from MNRE Presentation, descriptions of current standards added and verified by the consultants[68]

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[68] Hydrogen standards Gap analysis, SIAM, Hydrogen Sub Group III (MNRE), 2023 SIAM PPT_20230424_GH2_gapanalysis.pdf (dropbox.com)

Aviation:
In the aviation sector, there are ongoing standardization projects related to the use of hydrogen. Two notable standards developments are:

- *SAE AIR7765; EUROCAE/SAE "Hydrogen Fuel Cells Aircraft Fuel Cell Safety Guidelines" (Standard by SAE International, 02/05/2020) Which* provides technical guidelines for the safe integration of PEM fuel cells into the aircraft and covers aspects such as hydrogen storage in liquid and compressed forms, fuel distribution, and electrical systems.
- *SAE AIR6464*[69] *which is a* standard that defines technical guidelines for the safe integration of PEM.
- *AS6858 "Installation of Fuel Cell Systems in Large Civil Aircraft" (2023-04-21)* Which is a SAE/EUROCAE collaboration and specifies the technical requirements for the safe integration of hydrogen-fueled PEM and Fuel Cell Systems into a large civil aircraft.

Maritime:
As a United Nations (UN) agency, the International Maritime Organization (IMO) plays a crucial role in ensuring the safety, security, and environmental protection of the shipping industry. IMO is responsible for developing a global regulatory framework that is implemented and enforced worldwide and issues codes that carry the same legal weight as UN Regulations and are binding on member states.

One significant area of focus for the IMO is the transportation of dangerous goods by sea. The IMO has developed the *Code on International Maritime Dangerous Goods* (IMDG Code) to regulate and promote the safe handling and transportation of dangerous goods. This code aligns with the objectives of the *ADR* (*Agreement Concerning the International Carriage of Dangerous Goods by Road*).

In recent years, there has been an increasing emphasis on reducing pollution and emissions in the shipping industry. As a result, alternative fuel options are explored that can enable low- to zero emissions. Recognizing the need to support the development of lower-emission technologies in maritime transportation, the IMO introduced the *Code on International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels*, known as the *IGF Code.*[70] This code sets out mandatory requirements for ships powered by low-flashpoint fuels, providing guidelines to ensure safety in the use of these fuels. It aims to ensure an equivalent level of safety and reliability as traditional technologies and covers not only propulsion machinery, but also support roles during the stages of design, building, and operation. *Another standard is*

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[69] *https://www.sae.org/standards/content/air6464/*

[70] International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF Code) (imo.org)

the IGC code/MSC.420 which is a code for marine transport of liquified gases.[71] The Alternative Fuels workstream of the Global Industry Alliance to Support Low Carbon Shipping (Low Carbon GIA) with input from IMO and ICS have conducted a regulatory mapping exercise and have revealed the following efforts in developing safety standards for methanol, ammonia, and hydrogen as fuels [72]:

- *ISO/AWI 6583* "Specification of methanol as a fuel for marine applications" is under development, with currently, IMPCA Methanol reference specification and ASTM D1152 standard used when specifying methanol quality.
- *ISO 14687:2019 "Hydrogen fuel quality – Product specification"* which will be updated to *ISO/CD 14687* [73]
- *For Ammonia no marine standard available yet*

For alternative power generating systems, such as propulsion and auxiliary power systems, classification societies have also created their own guidelines and standards. For instance, DNV has added fuel cells, battery storage, and gas storage and new operational reliability standards for e.g., gas fueled ammonia.[74]

The creation of specialized port infrastructure is also required by the development of hydrogen-powered ships. The various aspects of hydrogen bunkering at ports are covered by the pertinent components of the regulatory framework for stationary installations specified in this chapter. The development of detailed rules and specifications for hydrogen bunkering, including liquid bunkering, is still ongoing. For the purposes of translating the criteria to hydrogen bunkering, existing standards for liquefied natural gas (LNG) bunkering, such as *ISO 20519:2017* and *ISO 16904:2016*, may be used as a base.

In maritime vessels, carriers should adhere to the International Convention for the Safety of Life at Sea (SOLAS), which outlines the minimum specifications for the design, fittings, and operation of ships, when transporting liquid hydrogen in bulk on board marine vessels. Additionally, liquid hydrogen carriers must adhere to the IGC Code, approved by *IMO Resolution MSC.5(48) 2016*, which outlines specifications for the building and operation of gas carriers. The IGC Code covers the transportation of liquid hydrogen if the ship is "*engaged in the carriage of liquefied gases having a vapor pressure exceeding 0.28 MPa absolute at a temperature of 37.8 °C and other products when carried in bulk, regardless of ship size, including those of less than 500 gross tonnages.*" [75]

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[71] https://www.sae.org/standards/content/air6464/

[72] Alternative marine fuels: Regulatory mapping: GreenVoyage2050 (imo.org)

[73] https://www.iso.org/standard/82660.html

[74] DNV Rules for Ships - July 2022 edition

[75] Handbook_for_hydrogen-fuelled_vessels.pdf (iims.org.uk)

2.3.2 EU

A recent report on European Technical standards is published by the European Clean Hydrogen Alliance (ECHA) in March 2023.[76] In this "*Roadmap on hydrogen standardization*" a comprehensive analysis on ongoing hydrogen related standardization activities is described and an overview of the standardization gaps and priorities along the value chain is described.

In the report of ECHA, a list of approximately 400 standardization topics were gathered. The study mentions that other subjects will be identified over time, and the list reflects a snapshot of the parties' current understanding of standardization at the time it was developed. The relevant TCs have been established in the EU and are currently hard at work creating and upgrading the standards required for producing hydrogen. The main objective is to develop clean alternative hydrogen production techniques that meet specific emission limits. While electrolysis is a well-known pathway, there may be other low-carbon production methods available depending on the completion of the regulatory framework. To ensure the advancement and technological leadership of European engineering technologies, harmonized standards aligned with industry best practices will be essential for scaling up production.

Another important step will be the standardization of gas infrastructure, which involves two main components: *functional* standardization, which covers design, construction, operation, and maintenance; and *equipment* standardization, which addresses specific components such as valves, meters, pressure regulators, safety devices, etc. It is important to adapt these European and worldwide standards to allow for the repurposing and development of current infrastructure for hydrogen. *CEN/TS 17977* covers the use of hydrogen in repurposed natural gas systems. According to DNV, repurposing natural gas pipelines is expected to cost only 10-35% compared to new construction costs, which could lead to a global repurposing of half of all natural gas pipelines towards hydrogen, and even to 80% in specific regions.[77] Overall, current natural gas infrastructure functional requirements should be revised to adapt to hydrogen. In practical terms, the newly constructed infrastructure for natural gas must be designed to accommodate hydrogen and e-methane in the future, also known as "hydrogen-ready." To this end specific specifications for adaptation measures, such as material choice, sealings, and safety considerations. Furthermore, evaluation standards that consider safety, operating, and maintenance issues must be developed to guarantee that the infrastructure is adequate for

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[76] https://ec.europa.eu/docsroom/documents/53721

[77] Repurposing onshore pipelines for hydrogen: Guiding operators through the re-evaluation process - DNV

hydrogen. *EN 16726* focuses on gas quality for hydrogen, has been updated to include hydrogen concentrations. Considering the parallels and differences between hydrogen and methane (natural gas), it is essential to evaluate the impact of hydrogen on gas infrastructure and make necessary adaptations.

For bulk hydrogen underground storage, the standard *EN 1918:2016*, titled "*Gas infrastructure—Underground gas storage,*" and its subsections offer practical advice for storage. Part 1:5 covers consecutively, storage in salt caverns, in rock caverns, in aquifers and functional recommendations for surface facilities. In all circumstances, safety management is required, with each storage option having requirements such as maximum pressures.

According to the European Clean Hydrogen Alliance report, the following elements require special consideration for hydrogen:[78]

- Safety measures for detecting hydrogen and preventing explosions
- The impact of hydrogen on different materials, depending on the nature of the materials [79]
- Technical system compatibility
- Gas quality, including repurposed grids, various production technologies and harmonization of standards between all parties (producers, pipeline operators, end-users)
- Hydrogen's energy density
- (Underground) Storage
- Hydrogen infrastructure from terminals to grid, standards for hydrogen and its carriers throughout the terminal to electrical grid supply chain must be developed. Additionally, a consistent and unified approach is required to assess the greenhouse gas (GHG) emissions associated with hydrogen systems across the entire value chain.

For a faster development of hydrogen infrastructure standards, it will be of upmost importance to update the legal framework of the EU on Gas Applications Regulations, the GAR. Which primary objective is to ensure that appliances and fittings meet the necessary gas safety requirements to gain access to the European Union market. Furthermore, GAR addresses the energy efficiency aspects of these products, particularly in cases where there is no dedicated EU eco-design legislation applicable.[80]

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[78] DocsRoom - European Commission (europa.eu)

[79] Kein Folientitel (hysafe.info)

[80] Gas Appliances Regulation (europa.eu)

For hydrogen standards in the industry, there is no one-size-fits-all solution and individualized assessment of different use cases of hydrogen should be assessed. Some examples that need to be considered are:

- Heating values and Wobbe Index variations of different hydrogen/natural gas mixtures must be considered.
- Technological modifications, such as specialized sensors or material specifications are also necessary to update the existing European Standards for the use of pure hydrogen and mixtures of hydrogen.
- Sensing technologies used to measure and detect hydrogen's chemical and physical properties (such as quality, quantity, temperature, pressure, and so on) must be reliable and comparable.
- Calibration with metrological references is required for effective validation in documentary standards and to ensure traceability. To this end standard test conditions must be defined and validated to ensure consistent and certification testing procedures, as e.g., done by TÜV SUD. [81]

Hydrogen in transport

The mobility sector includes (heavy-duty and off-) Road vehicles, railroads, maritime vessels, and aviation. One-fifth of the EU's greenhouse gas emissions are attributed to road mobility. Heavy vehicles will be required to lower emissions by 45% by 2030 and 90% by 2040 under the proposed guidelines. [82] At time of writing CEN/TC 268 published the following standards for road vehicles:

- *EN 17127:2020 - "Outdoor hydrogen refueling points dispensing gaseous hydrogen and incorporating filling protocols"*
- *EN ISO 17268:2020 - "Gaseous hydrogen land vehicle refueling connection devices (ISO 17268:2020)"*
- *EN 17124:2022 - "Hydrogen fuel - Product specification and quality assurance - Proton exchange membrane (PEM) fuel cell applications for road vehicles"*

And the following is being developed for heavy-duty vehicles: [56]

- *A standard containing the technical specifications as well as uniform solution for hydrogen refueling points dispensing compressed (gaseous) hydrogen for heavy-duty vehicles.*

For the maritime section, as mentioned earlier there is no specific standard for the use of onboard compressed hydrogen as fuel for ships yet. However, for a more

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[81] Hydrogen Component Testing | TÜV SÜD (tuvsud.com)

[82] Hydrogen Europe

detailed hydrogen examination, the current DNV standards for compressed natural gas (CNG) might serve as a starting point.[83] *EN 1252-1:1998* on storage tank materials, *EN 1797:2001* on gas/material compatibility, and *EN 13648 part 1, 2, and 3* on safety equipment for protection against high pressure are a few European standards connected to hydrogen storage.

The EU is expected to import a large amount of green hydrogen in the future. As described in Chapter 2, hydrogen can be bound to molecules like green ammonia, methanol, and others that are more readily transported in liquid form to help in transportation. It is critical to establish standards for all viable hydrogen transportation carriers and to ensure that all relevant technologies are covered as these will be necessary to ensure the dependable operation of facilities and provide assurance along the whole value chain.

2.3.3 US

Codes and standards are important in ensuring the safe construction, operation, and maintenance of equipment, systems, and facilities. *Codes* in the US are typically adopted by local jurisdictions and hold the force of law. They often reference or incorporate standards that apply to the specific equipment used within these structures. The National Fire Protection Agency (NFPA) already has a specific hydrogen code in place: *NFPA 2 Hydrogen Technologies Code*, for most hydrogen needs. For buildings, outdoor storage, and several additional areas like dispensing, electrolysers, fueling stations etc. hydrogen-specific gas requirements are described. Complementing *NFPA 2*, *NFPA 55* describes Compressed Gases and Cryogenic Fluids Code.

Although hydrogen has long been used in industrial settings, it has only recently become popular in consumer contexts as a fuel for cars and stationary power plants. As a result, the US is still developing standards for hydrogen and fuel cell technology.[84]

Industry stakeholders, manufacturers, governmental bodies, and safety experts collaborate with codes and standards development organizations to prepare, evaluate, and establish technically sound guidelines for hydrogen and fuel cell systems. The regulation of compressed gas, including hydrogen technologies, in the US involves various organizations such as the Compressed Gas Association (CGA), the American Society of Mechanical Engineers (ASME), and the Society of Automotive Engineers

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[83] Handbook_for_hydrogen-fuelled_vessels.pdf (iims.org.uk)

[84] http://www.fuelcellstandards.com.

(SAE). There are various US standards dedicated to hydrogen or with hydrogen-specific portions. Some examples are:

- *The Boiler and Pressure Vessel Code (Hydrogen section)*
- *ASME Code for Pressure Piping (Hydrogen section)*
- *The ASME B31.12-2019 on Hydrogen Piping and Pipelines*
- *Article KD-10 of the ASME BPVC VIII.3-2019, high-pressure gaseous hydrogen transport and storage.*
- *ANSI/CSA CHMC1-2014 offers test procedures for assessing material compatibility in compressed hydrogen applications—Metals,* provides a mechanism for designers to compare performance while still requiring adherence to other standards.
- *ANSI/CSA CHMC2-2019 test techniques for evaluating material compatibility in compressed hydrogen applications—Polymers* provides uniform testing methods. These methods assess hydrogen permeability, static and cyclic hydrogen exposure, and material stability, wear, and aging.

2.3.4 Japan

There are two primary parts to the Japanese standardizing process:

- *The Japanese Industrial Standards Committee (JISC)* is an organization affiliated with the Ministry of Economy, Trade, and Industry (METI) of Japan and tasked with investigating and debating industrial standards.
- *Japanese Standards Association (JSA)* is the entity in charge of creating Japanese industry standards (JIS) and supports management systems and standardization.

Japan is aiming to establish global standards for water electrolysis equipment, for liquid hydrogen and methylcyclohexane (MCH) supply chains, as well as safety standards for ammonia and hydrogen-fired power plants. These efforts are led by METI, which aims to provide clear guidelines and ensure the safety and reliability of hydrogen technologies. The government is also focusing on funding and supporting hydrogen-related projects through the green innovation fund.

JISC participates in international standard activities of ISO and IEC, representing Japan as an active since 1952.[85] JISC joined the IEC in 1953 and contributes to the development of pertinent policies. JISC submits a significant amount of new international standards to ISO/IEC each year and the secretariat for various ISO/IEC technical committees and subcommittees. Japan has made attempts to actively participate in ISO, IEC, and UNECE GTR13, with a focus on safety, as a reflection of its commitment to building a global *"hydrogen society."* JISC and CEN inked an MoU

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[85] 1111-JSP2013.indd (standardsuniversity.org)

in June 2008 to formalize their collaborative cooperation. Furthermore, in the standardization field between Japan and the United States, the NIST-METI-ANSI Dialog is held annually with participation of relevant organizations to exchange a wide range of information pertaining to standards policies.

Actions for improved national regulations/standards coordination and harmonization are included in the 2019 update of the hydrogen roadmap, along with a comparison to the frameworks in the US and the EU. An interim report on the Hydrogen Safety Strategy has also been made public by Japan's METI.[86] With a long-term goal of creating a safety regulation system covering the entire hydrogen supply chain by 2050, this approach attempts to produce comprehensive rules for hydrogen safety over the next five to ten years. The study group on the formulation of the hydrogen safety strategy held discussions on which the report is based. This is crucial, according to Japan, because hydrogen is far more combustible than natural gas, which raises serious safety concerns. Currently, there is no uniform global framework for hydrogen safety, and the current regulations do not cover some dangers, like those associated with mixing hydrogen with methane gas or using existing gas pipes to carry hydrogen. To guarantee secure production, transportation, and use of hydrogen, more investigation and standards are required. This may entail carrying out risk assessments of the current infrastructure, assessing the integrity of pipeline materials, and applying best practices for leakage prevention, detection, and mitigation in hydrogen transportation systems. It may also entail enhancing reporting requirements for hydrogen blending.

Hydrogen in transport:

The JIS C 88xx series of Japanese standards, which includes the *JIS C 8831 standard on Safety Evaluation Test for Stationary Polymer Electrolyte Fuel Cell Stack*, focuses on proton exchange membrane (PEM) fuel cells. The JIS C 62282 series on stationary Fuel Cell Power Systems, which is in line with the IEC series of the same name, is one example of a JIS standard that has been adjusted to conform to the global framework. The following are two early hydrogen-specific standards that were notable and helped with the introduction of FCEVs. Both of the following were initially released by the Japanese Automobile Research Institute (JARI) in 2004 and eventually turned into laws:

- *JARI S 001 Technical Standard for Compressed Hydrogen Fuel Devices Containers.*
- *JARI S 002 Technical Standard for Compressed-Hydrogen Fuel Device Components (Valve and PRD).*

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[86] Interim Report for the Hydrogen Safety Strategy Released (meti.go.jp)

These documents were based on relevant compressed natural gas (CNG) specifications and initial editions were limited to a container's maximum working pressure of 35 MPa. Additionally, the Japanese Petroleum Energy Centre (JPEC) developed the *JPEC-S 003* standard for hydrogen fueling protocols. While it shares similarities with the *SAE J2601* standard, the *JPEC-S 003* standard includes the refilling of buses with a total storage capacity of up to 25 kg, a milestone achieved by SAE only recently.

Ongoing technical standards improvement is the relaxation of pressure limitations for hydrogen stations. Originally, stations were not permitted to exceed a pressure of 70 MPa. However, they have been permitted to run up to 82 MPa since 2016 generating higher filling efficiencies. JPECs *JPEC-TD 0004*, outlining the parameters for self-service filling at hydrogen stations, is another recent innovation.

2.3.5 Concluding Remarks

The utilization of electrolysis to produce green hydrogen is a well-established technique and water-electrolysis hydrogen generators have been in commercial settings for more than a century, with established technical standards. Nevertheless, the recent development lies in the scale-up of this hydrogen production: the implementation of very-large-scale systems that aim to convert renewable electricity and water into the valuable commodity of hydrogen. A comprehensive review of international standards, EU, US, and Japanese standards for industrial and commercial applications related to hydrogen has been undertaken, following a value chain approach due to the extensive number of standards involved. Within the review process various aspects of hydrogen utilization and safety are covered. Prioritization is necessary to focus on areas that require intensive attention and action for standardization processes or content development. As is depicted from the identified list of standards, some areas of the value chain are more covered (e.g., hydrogen fuel cells) than others that still require standardization topics to be initiated or allocated to the appropriate technical committees.

A non-exhaustive overview of the technical standards on green hydrogen across the hydrogen value chain can be seen in Figure 12.

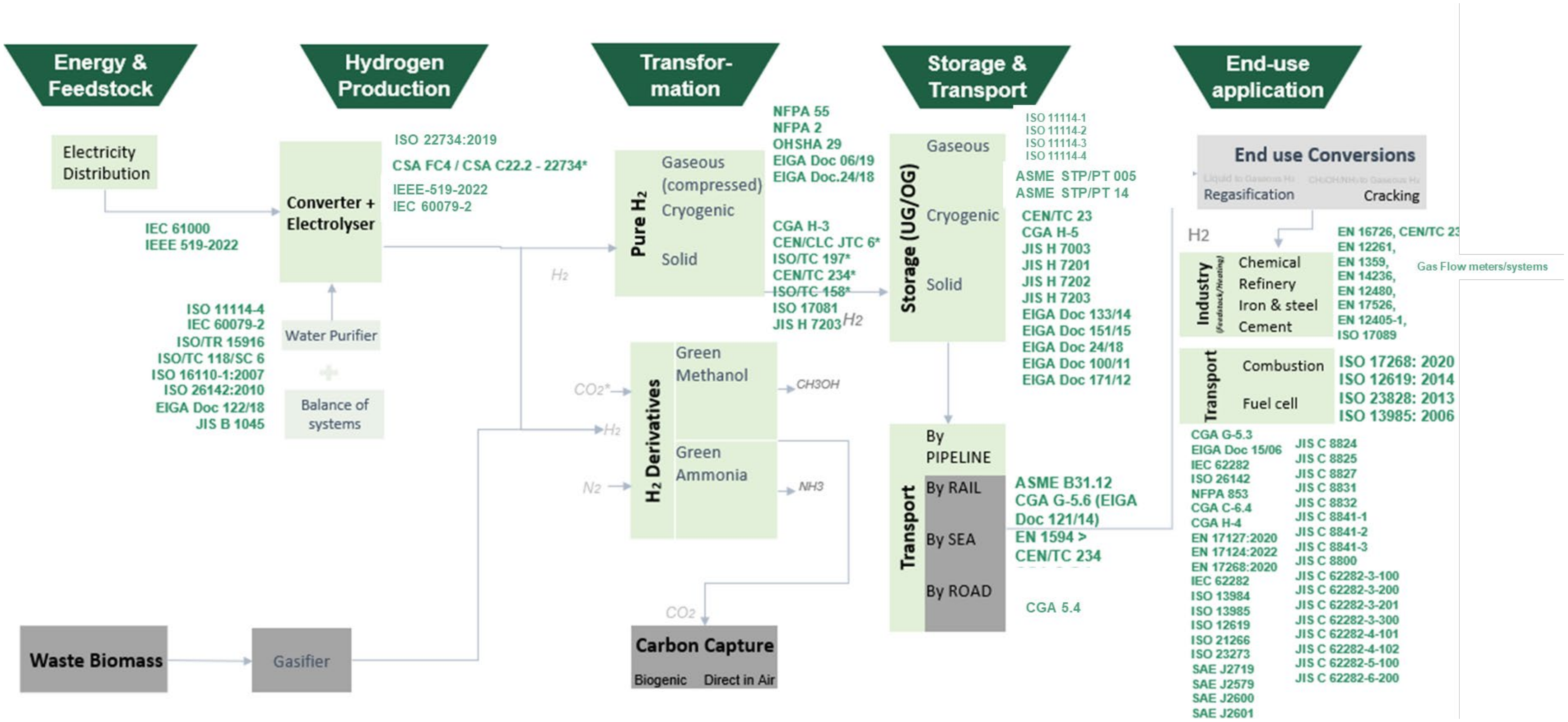

Figure 12: A proportion of the international technical standards assessed in this study relevant to the hydrogen value chain[87]

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[87] Consultant Analysis

In the hydrogen production part of the value chain, the focus is on international standards pertaining to hydrogen generation using water electrolysers and fuel processing technologies. It also addresses the safety aspects of pressure swing absorption systems for hydrogen separation and purification.

1. **Electrolyser Standards:** Technical standards are required to define both the performance criteria and efficiency metrics for large scale electrolysers used in green hydrogen production. These should cover among others: hydrogen production rate, reliability, energy consumption, durability, and integration into the electrical grid to ensure consistent and optimal performance of the whole electrolysis systems.
2. **Safety Regulations:** Hydrogen production presents all kinds of safety challenges. Specific standards are required to address e.g., the operation, design, and installation of electrolysers including guidelines for electrical safety, explosion prevention, leak detection, and emergency shutdown procedures.
3. **Electrical Standards:** Standards are needed to ensure both the compatibility and safety of all electrical components, e.g. electrical connections, voltage requirements, load factor, grounding, protection systems, and electromagnetic compatibility to ensure reliable and safe operation of electrolysers.
4. **Water Quality and Treatment:** The quality of water used in electrolysis can impact the performance of the systems. Technical standards on the water quality requirements, including further guidelines for water treatment, impurity levels, pH range, and conductivity, to ensure the optimal operation and lifespan of electrolysis systems are needed.
5. **System Integration and Interoperability:** Need of standards to enable the integration and interoperability of electrolysers with other parts of the hydrogen production systems, such as electrical interfaces, communication protocols, control systems, and data exchange formats to facilitate the seamless integration of electrolysis systems into larger hydrogen infrastructure.
6. The **different carriers of hydrogen** are described in the hydrogen transformation part of the value chain. The development and implementation of technical standards for green hydrogen carriers are essential to ensure safe and efficient transport of hydrogen. Here are some key areas where technical standards gaps exist for green hydrogen carriers:
7. **Material Compatibility:** Green hydrogen is typically transported as a gas or a cryogenic liquid. Technical standards are needed to define the material compatibility requirements for storage tanks, pipelines, valves, and other equipment used in hydrogen carriers. These standards should address issues such as hydrogen embrittlement, permeation, and leakage prevention.

8. **Safety Regulations:** Green hydrogen carriers need to comply with stringent safety regulations to mitigate the risks associated with hydrogen transportation. Technical standards are required for the design, construction, and operation of carriers, including guidelines for structural integrity, leak detection systems, emergency shutdown procedures, and fire suppression measures.
9. **Hydrogen Purity and Quality:** Technical standards are needed to ensure the purity and quality of hydrogen during transportation. These standards should define acceptable levels of impurities and moisture content, as well as establish protocols for sampling, testing, and certification of hydrogen quality to maintain its integrity and prevent degradation during transport.
10. **Loading and Unloading Procedures:** Standardized procedures for loading and unloading hydrogen from carriers are necessary to ensure efficiency, safety, and compatibility with various infrastructure systems. Aspects as pressure and flow control, connection interfaces, and containment measures during transfer operations must be covered.
11. **Certification and Inspection:** To ensure that green hydrogen carriers meet the necessary safety and performance requirements these standards should outline the criteria and protocols for vessel inspections, periodic testing, and certification procedures to verify compliance with regulatory and industry standards.

In this value chain part especially, more work is needed. In the Annex Excel all covered standards are shown. Highlighted in the column *status* are under '*to be identified'* the standardization topics that could not be allocated to existing projects or committees, the so-called gaps. While there are existing standards for gas distribution networks and pipelines, there is a need for additional standards specifically tailored to hydrogen.

12. These standards should address the **properties of hydrogen**, such as its high diffusivity and potential for embrittlement of storage, and provide guidance on materials selection, construction practices, and maintenance requirements.
13. **Metrological and Technical Requirements:** Standards are required for metrological and technical requirements related to hydrogen distribution. This includes standards for accurate measurement of hydrogen flow rates, pressure, and composition, as well as guidelines for calibration and verification of measurement devices used in hydrogen distribution networks.
14. **Gas Measurement:** Specific standards for gas measurement in hydrogen distribution networks need to be developed. These should cover accurate measurement techniques: flow- and pressure measurements, gas quality monitoring.

15. **Pressure Systems/Regulations:** There is a need for dedicated standards and regulations for pressure systems specific to hydrogen. These standards should define requirements for the design, manufacturing, and inspection of hydrogen pressure vessels, pipelines, and related equipment.

In the end-user part of the value chain, international standards related to hydrogen refueling stations are widely covered. And quite some standards for hydrogen land vehicle refueling connection devices, refueling protocols for vehicles, fuel quality control, certification and on-site hydrogen storage and associated devices are described. For industrial applications the following gaps are identified:

16. **Labelling of renewable or low carbon ammonia**
17. **Ammonia** **production metrology** for GHG emissions determination.
18. **Specific Requirements for Hydrogen-Fired Gas Appliances:** Standards for hydrogen-methane appliances are necessary to ensure their safe and efficient operation. These standards should cover design requirements, performance criteria, safety features, and installation guidelines for appliances that utilize hydrogen as a fuel, such as hydrogen boilers, heaters, and fuel cells.

Within the international standards on mobility and safety in hydrogen applications verification of existing gas installations, essential safety requirements for electrical equipment and gas equipment, fuel cell technologies, safety specifications, performance, test methods, and installations are reviewed. There are already quite some technical standards on the refueling infrastructure and storage and handling of green hydrogen. The gaps of technical standards for green hydrogen, ammonia, and methanol, in both the transport and maritime sector are found in:

19. **Fuel Specifications:** For green hydrogen, ammonia, and methanol, specific standards for purity, composition, impurities, and energy content are needed to ensure compatibility and optimal engine performance.
20. **Storage and Bunkering:** Ammonia and methanol have different properties and requirements compared to traditional fuels. Technical standards are required for the safe storage, transportation, and handling of these, including guidelines for infrastructure design, materials compatibility, and safety protocols and protocols for bunkering procedures to ensure compatibility with different vessel types.
21. **Engine Performance and Efficiency:** Combustion engines may require modifications or specific designs to fully utilize the potential of green hydrogen, ammonia, and methanol. Standards are needed to define engine performance criteria, efficiency metrics, emission limits, and combustion characteristics to optimize the use of these alternative fuels.

22. **Emission Control:** Green hydrogen, ammonia, and methanol have the potential to reduce carbon emissions compared to fossil fuels. However, comprehensive standards for emission control (NO_x, N_2O) when using e.g., green ammonia need to be developed to ensure compliance with environmental regulations, including the establishment of limits for greenhouse gas emissions and other pollutants.
23. **Refueling Infrastructure:** Standards for refueling infrastructure, such as hydrogen dispensing stations, ammonia storage facilities, and methanol distribution networks, need to be established to ensure interoperability, safety, and reliability across different regions and jurisdictions. Especially for the maritime sector, this involves aligning regulations, guidelines, and safety standards across different countries and regions to ensure seamless operations, bunkering, and fuel supply chains globally.

2.4 Green Hydrogen Certifications

Certification is a crucial element of any trade as it serves as a tool and mechanism to demonstrate compliance with specific requirements. According to the definition in (IRENA, Creating a Global Hydrogen Market, 2023) [88] certificates for hydrogen and its derivatives should:

> *"Incorporate information on compliance with standards and regulatory requirements while enabling verification through sustainability criteria's such as carbon footprint and renewable energy content."*

To this end, reliable mechanisms for evaluating and certifying certify the sustainability standards of both locally produced and imported hydrogen and its carriers is crucial. Since hydrogen and its carriers can be combined from different sources, accurate information about the nature of that derivative is needed through a mass balance or guarantees or origin system by which the chain of custody is evaluated. In the upcoming paragraphs, we will delve into various examples of certification schemes, such as ISCC, CertifHy, and TÜV Süd. It is important to acknowledge that several other schemes are currently being developed. Our objective in the following sections is to explore these schemes and identify any potential gaps that could impact the advancement of the global hydrogen market. Furthermore, it is important to distinguish the different certification schemes:

1. **Regulatory certification, following EU RED II Delegated Act requirements:**

- **Chain of custody option:** ONLY mass balance allowed.

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[88] Creating a global hydrogen market: Certification to enable trade (azureedge.net)

- **Schemes:** ISCC EU and CertifHy are currently the officially applied schemes, with RSB, REDcert, Green Hydrogen Organization, TÜVs potentially following suit. Importantly, as of now, no scheme has received official recognition.

2. **Market-based (or voluntary) certification:**

- **Chain of custody option:** Free choice between Mass balance or book & claim (guarantees of origin).
- **Schemes:** ISCC PLUS, CertifHy, RSB, REDCert, TÜVs, and others operate in this category. It's important to note that recognition is not required for this category as it is not directly related to RED II regulations."

2.4.1 International[89]

2.4.1.1ISCC

The international sustainability and carbon certification system (ISCC) has a broader scope than just green hydrogen as the mechanisms aims are to safeguard the forests, preserve lands with significant carbon stocks, support biodiversity conservation, and encourage the efficient use of waste.[90] Furthermore, ISCC strongly believes in establishing sustainable supply chains and therefore wants to prioritize the identification and reduction of GHG emissions. In the ISCC name, various schemes related to different sectors exists with the following important for hydrogen:

- **ISCC-EU** *To reduce GHG Emissions in the Transport and Energy Sector.* This RFNBO scheme will formally serve to comply with RED II Art. 27 and 28. Technically, this scheme could be defined under paragraph 2.3.2 EU because of its connections to RED II.
- **ISCC-PLUS** *For the bioeconomy and circular economy for food, feed, chemicals, plastics, packaging, textiles, and renewable feedstock derived from a process using renewable energy sources.* This standard will include hydrogen and its derivatives.

Besides the sustainability criteria, both schemes have additional criteria's such as water usage and social impact in their Annexures.

While ISCC[91] does have additional sustainability requirements for farms/plantations/forest sourcing areas, it's crucial to note that these criteria primarily pertain to biomass sourcing and may not directly apply to hydrogen production. There is speculation that these criteria could become relevant for hydrogen production in the future. However, as of now, ISCC EU will primarily

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[89] ISCC, CertifHy, and TÜV SÜD CMS 70 are examples form the international context. There are few more schemes which are existing and under development.

[90] ISCC System – Solutions for sustainable and deforestation free supply chains (iscc-system.org)

[91] ISCC Voluntary Add-ons – ISCC System (iscc-system.org); ISCC EU 202-1 Agricultural Biomass: ISCC Principle 1 (iscc-system.org), ISCC EU 202-2 Agricultural Biomass: ISCC Principles 2-6 (iscc-system.org)

consider the requirements outlined in the EU RED II Delegated Act. It's essential to stay informed about any updates or developments in ISCC's sustainability criteria, particularly as they pertain to hydrogen production:

1. Protection of land with high biodiversity value or high carbon stock
2. Environmentally responsible production to protect soil, water, and air
3. Safe working conditions
4. Compliance with human, labour, and land rights
5. Compliance with laws and international treaties
6. Good management practices and continuous improvement

From: ISCC

Point 3 and 4 are further described in the Annexure from the ISCC-PLUS: [92]

- Social development
  - Self-Declaration on Good Social practice regarding Human rights (ILO core labor standards, respect for a living wage, respect for social environment, commitment of fair contract arrangements)
  - Other forms of social benefits are offered by the employer to the workers and their families/communities
- Employment conditions
  - No forced labor
  - No child labors
  - No discrimination
  - Respect of gender equity
  - Regular employment available when possible
  - Workers treated with dignity and respect
  - Workers provided with fair legal contracts
  - Living wage is at least legal/industry minimum standards
  - There is a person responsible for Worker's Health Safety and good social practice
  - Records on all Workers and employees are available
  - Working times and overtime are documented

From: ISCC-PLUS

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[92] ISCC PLUS (iscc-system.org)

2.4.2 EU

2.4.2.1 CertifHy

CertifHy is initiated by question of European Commission and is funded by the Clean Hydrogen Partnership. It actively supports and advocates for the sustainable production of hydrogen across different sectors, including energy, transport, chemical conversion, heating, and power generation. To establish a comprehensive EU-wide system of Guarantees of Origin (GOs), CertifHy certificates are intended to be stored in a centralized European database called the Registry. This Registry manages the entire life cycle of CertifHy certificates for each account holder. Both renewable and non-renewable hydrogen are given a tradeable value under the CertifHy Certificates program. Controlling the information and preserving the quality of the certificates is of the utmost importance in ensuring the scheme's dependability, accuracy, and verifiability. As shown in the Figure 13, various actors, including Certification and Issuing Bodies, carry out the necessary controls.

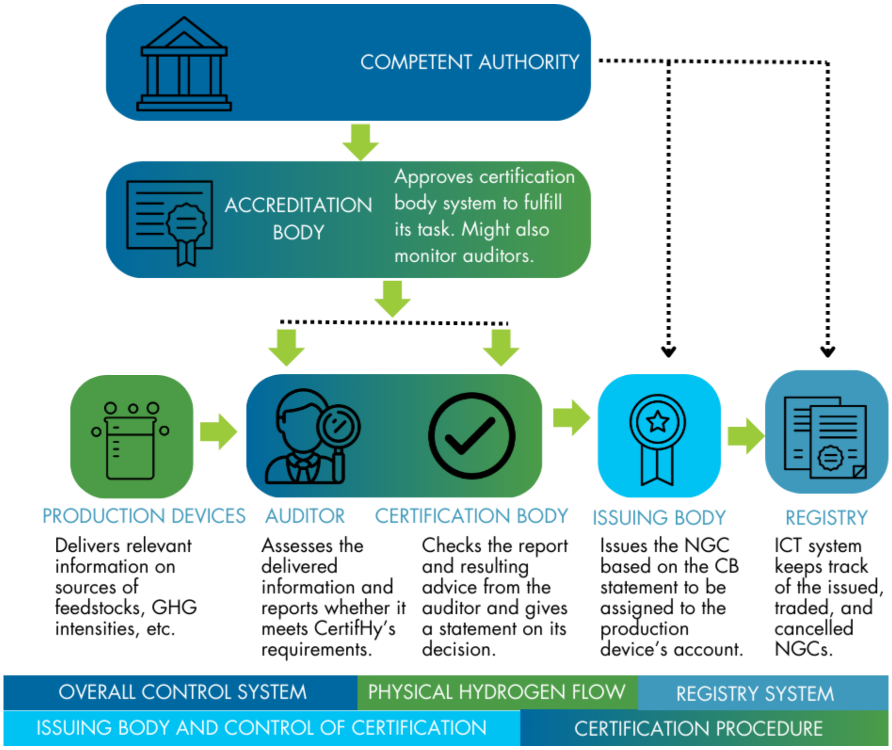

Figure 13: Steps of EU certification scheme, such as CertifHy. [93]

To establish a robust scheme, Auditors play a crucial role in ensuring that producers and their production devices comply with the requirements of CertifHy. These

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[93] Source: STEPS OF CERTIFICATION - CERTIFHY

Auditors are part of a Certification body that holds the necessary accreditation to carry out this task. The Accreditation body is overseeing the quality assurance system of the Certification Body, it ensures that the Certification body has the necessary technical competence to carry out their responsible tasks. Any accreditation body in Europe – a member of the International Accreditation Forum – is allowed to accredit certification bodies. The Issuing body, which functions directly under the Competent authority, oversees issuing CertifHy Certificates. The Account Holder manages hydrogen CertifHy Certificate transfers, trades, and cancellations inside the CertifHy registry. The issuing body has the right to examine these activities.

Figure 14[94] gives an overview of the renewable labels of CertifHy. For the green hydrogen label, wind/solar/hydro electricity production processes are counted as zero GHG emissions, while biomass-based production could come with a GHG emission as defined in RED II. As stated in the figure, the carbon intensity limit is fixed at 60% below the GHG emissions from a steam methane reformer, being the current best available technology. Given the fact that the two Delegated Acts specified in RED II Art. 27 (renewability of RFNBOs) and Art. 28 (Methodology for GHG calculations) are adopted quite recently, these criteria have only recently received official approval. Consequently, the RFNBO scheme is still awaiting full recognition, as it can only begin the official recognition process after this initial period. It is worth noting that the CertifHy scheme is currently not officially recognized by the EC and operates based on market principles rather than regulatory mandates.

CERTIFHY™ GREEN HYDROGEN

Originating from renewable sources (defined in art 2 of the Renewable Energy Directive II) and having a greenhouse gas balance below a defined threshold, which is min. 60% below the production of hydrogen through steam reforming of natural gas (benchmark process with a current GHG footprint of 91 gCO2eq/MJ). This GHG intensity will be regularly re-assessed, as the emission reduction % targets are due to increase over time.

Renewable Fuels of Non-biologic origin (RFNBO)

- Green ammonia
- Green methanol

- CertifHy™ Voluntary Scheme **is pending** recognition by the European Commission as EU Voluntary Scheme for RFNBO

Figure 14: CertifHy Green Hydrogen and pending RFNBO label.

2.4.2.2 TÜV SÜD CMS 70

The TÜV SÜD CMS 70 GreenHydrogen Basic Standard and the TÜV SÜD CMS 70 Green Hydrogen+ Standard are two other voluntary schemes that were developed in lack of EU regulatory mechanisms. In the long term, the GreenHydrogen Basic

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[94] Source: HOME - CERTIFHY

Standard could comply with H2-GO in RED II Art. 19, whereas the GreenHydrogen+ could compare the common GO Schemes with additional features as:

- Stricter guidelines for using certified hydrogen solely for heating reasons
- Electricity from new renewable energy plants
- Avoidance of grid bottlenecks in the supply

2.4.3 US

In the US, the equivalent of GOs is referred to as renewable energy certificates or credits. These certificates function as market-based instruments representing ownership of the environmental, social, and other non-energy attributes associated with renewable electricity generation.

2.4.3.1 Clean Hydrogen Production Standard

The US DOE proposed a clean hydrogen production standard to define low-carbon hydrogen production in the US. This standard sets forth a specific target of 2 $kgCO_2eq/kgH_2$ for life cycle emissions, to be considered low-carbon hydrogen, measured well-to-gate.[95] Although this standard is not mandatory, it can potentially be for various government subsidies or grants, such as the Hydrogen Production Tax Credit under the Inflation Reduction Act. The definition of *clean hydrogen*, as outlined in the BIL/Infrastructure Investment and Jobs Act, states that hydrogen produced must possess a carbon intensity that is equal to or less than 2 $kgCO_2eq/kgH_2$ at the production site.[96] Currently, the specifics and application of the proposed standard (CHPS) and its alignment with the definition set forth in the BIL Act are passed.

2.4.3.2 Low Carbon Fuel Standard[97]

The Low Carbon Fuel Standard is implemented by the California Air Resources Board in 2011, where it is actively promoting low-carbon fuel alternatives. It serves as an incentive mechanism for fuel suppliers, encompassing hydrogen, biodiesel, and electricity, which meet the criteria of being low carbon. For entities involved in hydrogen production for fuel purposes (fuel cells or as feedstock for other fuels) the standard offers the opportunity to earn credits. These credits can subsequently be traded within the California Credit Market. The carbon intensities of hydrogen are determined by the production pathway employed and has specific values for each pathway.

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[95] Clean Hydrogen Production Standard | Department of Energy

[96] The Infrastructure Bill is Accelerating the Deployment of Hydrogen (natlawreview.com)

[97] Low Carbon Fuel Standard | California Air Resources Board

2.4.4 Japan

At the time of writing, Japan is not creating a guarantees of origin scheme for green hydrogen yet. It does monitor global advances on green hydrogen and contributes to the work being done by international organizations and standards.

2.4.4.1 Aichi Prefecture Low-Carbon Hydrogen Certification

The current certification scheme in Japan is the which is a collaborative initiative between the Aichi Prefecture Government, the cities of Chita and Toyota and industries in the areas. Under Aichi, the Aichi Prefecture Government takes responsibility for certifying all produced hydrogen, while industry partners oversee the supply, transportation, and utilization of low-carbon hydrogen. One notable aspect of the initiative involves the use of biogas derived from sewage sludge, which is transported through existing gas pipelines. The city gas is converted into hydrogen and used in fuel cell forklifts near the Toyota site. Moreover, to supplement the production of bio-hydrogen, on-site solar panels are employed to generate green hydrogen through electrolysers. This additional source of hydrogen contributes to the overall low-carbon hydrogen supply. However, one must consider that the certification coverage is limited to the Aichi Prefecture only, emphasizing the commitment to foster a low-carbon hydrogen economy within this specific region.

2.4.5 Concluding Remarks

The important regulatory mechanisms, and certain certification schemes investigated in this study are summarized in Table 6 and Table 7 respectively. The regulatory certification mechanisms will establish protocols for tracking emissions reductions, particularly in the case of imported hydrogen. This can be accomplished through collaborations or by referencing voluntary programs. Furthermore, they will specify whether the proposed methodology will be customized to suit different end-use sectors. And they will outline the procedures for end users to exhibit compliance with emissions reduction standards, typically defined in legislation as a percentage reduction from a baseline value, and to gain acknowledgment for their adoption of low-carbon fuels.

Table 4: Overview of different regulatory mechanisms relevant to hydrogen certification

Country	Mechanism	Status of regulatory mechanism	Boundary and scope (sectors)	Emission threshold [gCO_{2eq}/MJ]	Power supply requirements for electrolysis	H2 production pathway
EU	**European Commission** Renewable Energy Directive	Active	Transport, Energy: Upstream production to point of use	28.2	GO (Guarantee of Origin) and delegated act criteria	Electrolysis

	II (RED II)				additionality, solar wind, or hydro	
	European Commission EU Taxonomy	Active	Boundary not specified	28.2	GO required, grid, nuclear solar wind, or hydro	Electrolysis, Fossil SMR/ATR with CCS, Biogas SMR
US	**US Department of Energy** H2Hubs draft	Active	Transport, Energy: Point of production	37.04	No GO/additionality specified	Electrolysis, Fossil SMR/ATR with CCS, Biogas SMR
	California Air Resources Board Low Carbon Fuel Standard (California only)	Active	Transport: Upstream (methane) to point of use	No threshold (Certificate issued based on reduction from annual target)	GO required, grid, solar wind, or hydro	Electrolysis, Fossil SMR/ATR with CCS, Biogas SMR

Table 5: Overview of different certification schemes for hydrogen certification

Country/Region | Organization & Title	Label	Chain of Custody model	Emission threshold [gCO_{2eq}/MJ]	Power Supply requirements	Qualification Criteria
European Union CertifHy	Green H_2	Book & Claim	36.4	GO + additionality, solar wind, or hydro	GHG emissions, Electricity supply
	Low-carbon H_2	Book & Claim	36.4	GO required, grid, nuclear	GHG emissions
	Green RFNBO	Book & Claim	36.4	GO + additionality, solar wind or hydro	GHG emissions, Electricity supply
International Sustainability and Carbon Certification (ISCC) **ISCC PLUS**	Green H2	Mass Balance	28.2	GO + additionality, solar wind, or hydro	GHG emissions, Electricity supply, Land use change, water use,

Country/Region | Organization & Title	Label	Chain of Custody model	Emission threshold [gCO_{2eq}/MJ]	Power Supply requirements	Qualification Criteria
					safe working conditions
TÜV Süd CMS70	Green H2 +	Book & Claim	24	GO + additionality, solar wind or hydro	GHG emissions, Electricity supply
	Green H2	Mass Balance	28.2	GO + additionality, solar wind or hydro	GHG emissions, Electricity supply
Japan Aichi Prefecture	Low-carbon H2	Book & Claim	No threshold	GO + additionality, solar wind, or hydro	GHG emissions, Electricity supply
International Green Hydrogen Organization	Green H2, in preparation	Not specified	8.3	GO required, solar wind, or hydro	GHG emissions, Electricity supply, Land use change, water use, safe working conditions

The reason for the inadequacy of existing certification schemes studied lies in the fact that they only validate the existing standards and requirements, which are not globally aligned. Consequently, these certification systems may be suitable and adequate, yet for their national or regional scope only. Our objective in the following sections is to explore these schemes and identify any potential gaps that could impact the advancement of the global hydrogen market. The most critical areas of concern can be divided into three key areas:

- **A single methodology for green hydrogen in a modular approach:** A modular certification framework needs to be adapted that applies distinct sustainability criteria and thresholds to distinct stages of the hydrogen supply chain. Furthermore, a unified methodology to calculate the emissions intensity of all hydrogen production pathways is needed, such as the methodology of IPHE.[98] This methodology should leverage existing schemes where possible and effectively address key sources of emissions. Some of the current shortcomings include:

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[98] Introduction to the IPHE Methodology - PtX Hub (ptx-hub.org)

    - Carbon Intensity Targets: The meaning of "green hydrogen" varies widely between nations. Others have too low carbon intensity thresholds. It is crucial that nations set challenging and clear carbon intensity targets that are in line with long-term climate objectives. In addition, different contexts have varied needs and processes for renewable energy.
    - LCA Assessments: Lifecycle methodologies are commonly used to quantify emissions and oversee crucial inputs. It is essential for LCAs to encompass the entire hydrogen value chain, from production to storage, transportation, and end-use. They should consider all climate and air pollutants, including hydrogen emissions, using the latest data and location-specific measurements, as will be done in e.g., ISCC.
    - The holders of the green hydrogen schemes must consider and establish the transportation and distribution supply chain inclusion in production standards. As first trade agreements will be directly conducted between hydrogen producers and end users this is a critical point. To enable e.g., the decarbonization of steel an end-user framework for a book-and-claim CoC (Chain of Custody) system must be established. This framework should incorporate processes to accurately monitor and allocate emission benefits of the scheme while avoiding any erroneous double counting. However, the current scaling limitations are evident due to the lack of specific efforts in addressing transportation and blending-related considerations in international trade. Furthermore, the tracking models for hydrogen and their integration with end-user schemes have not been defined yet.
- **Align Accounting Methods and Policy Requirements:** Consistency must be ensured between accounting methods and policy requirements concerning additionality, temporal considerations, and geographical criteria for hydrogen produced using grid electricity. And a process to facilitate mutual recognition between different certification schemes for hydrogen and its derivatives is needed which will enhance consistency and enable smooth cross-border trade. Harmonized systems of quality infrastructure need to be established to ensure fairness and accountability in hydrogen certification by national standards bodies. For example, in the EU, there will be rigorous criteria for domestic renewable energy (RE) that will also apply to other imported goods. The existing certification schemes' criteria do not currently conform to the evolving regulatory frameworks. For the EU certification schemes under RED II and its Delegated Acts, this process is still ongoing.
- **Consider Hydrogen derivatives:** Develop internationally recognized methodologies to manage the blending of traded hydrogen, as well as its blends with natural gas and biomethane. This will enable the connection of production criteria with market requirements. Continuity and certification requirements for hydrogen derivatives that are likely to be traded are needed such as ammonia, to ensure a comprehensive approach.

CHAPTER 3 Assessment of Green Hydrogen in India

This chapter highlights the As-Is landscape of hydrogen market in India, including supply and demand. It gives an overview of different techniques used for production of hydrogen in India and amount consumed by different industries. It also maps out the relevant stakeholders involved in various stages of the hydrogen value chain such as regulatory bodies, executionary bodies, R&D bodies, key industry players, and any others involved. A detailed mapping of their roles and responsibilities has been presented. Further, as a part of the As-Is landscape, all available regulations, standards, and certifications are studied in detail in this chapter to identify the gaps in the existing hydrogen ecosystem. Further recommendations are provided to enable the green hydrogen ecosystem in India.

Various ongoing developments have highlighted that India has the potential to act as a key player in the global green hydrogen export market, enhancing energy security and fostering economic growth.[99]

Paris Agreement Commitment	•India's vision of becoming a global leader in clean energy transition align perfectly with the development and utilization of green hydrogen
TERI	•Green hydrogen has the potential to meet 14% of India's total energy demand by 2050, thereby reducing carbon dioxide emissions by up to 20%.
IEA	• India has the capacity to become one of the world's largest producers and consumers of green hydrogen, which in turn can lead to the creation of millions of jobs and attract significant investments.
Projects & Pilots	•Various pilots and projects in the pipeline across the stages of the value chain which are at different stages of implementation.

In conclusion, green hydrogen represents a transformative opportunity for India. By embracing this clean energy source, India can address its energy needs sustainably, reduce GHG emissions, and contribute to global climate change mitigation efforts. With the support of the NGHM, India can become a prominent player in the green hydrogen market, attracting investments, boosting energy security, and propelling itself towards a cleaner and more prosperous future.

3.1 Hydrogen As-Is Market Landscape

In 2020, the hydrogen demand in India amounted to five million tons (Mt).[100] Within this demand, nearly 99 percent is being utilized in two primary sectors: petroleum refining and the production of ammonia for fertilizers. Hydrogen plays a crucial role

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[99] Report on The Potential Role of Hydrogen in India – 'Harnessing the Hype'.pdf (teriin.org); Refer Annexure 6 for list of projects.

[100] National Green Hydrogen Mission, MNRE, 2023

in the production of ammonia (NH3), which is used to manufacture urea and other fertilizers. In the petroleum refining sector, hydrogen is primarily used for hydrocracking (70 – 75%), converting heavier feedstocks into more valuable products, as well as for desulphurization, reducing the sulfur content of fuels. By substituting Grey Hydrogen with Green Hydrogen in both these sectors, it is possible to reduce the carbon footprint and decrease reliance on imported fossil fuels.

However, the production of hydrogen heavily relies on fossil fuels, with natural gas contributing 75% (5.25 Mt), followed by coal gasification process. Additionally, industrial processes generate 10% (0.7 Mt) of hydrogen as a by-product, such as in chlor-alkali production. Figure 15 provides the quantum of hydrogen produced and consumed by India in the year 2020 by various methods and industries, respectively.

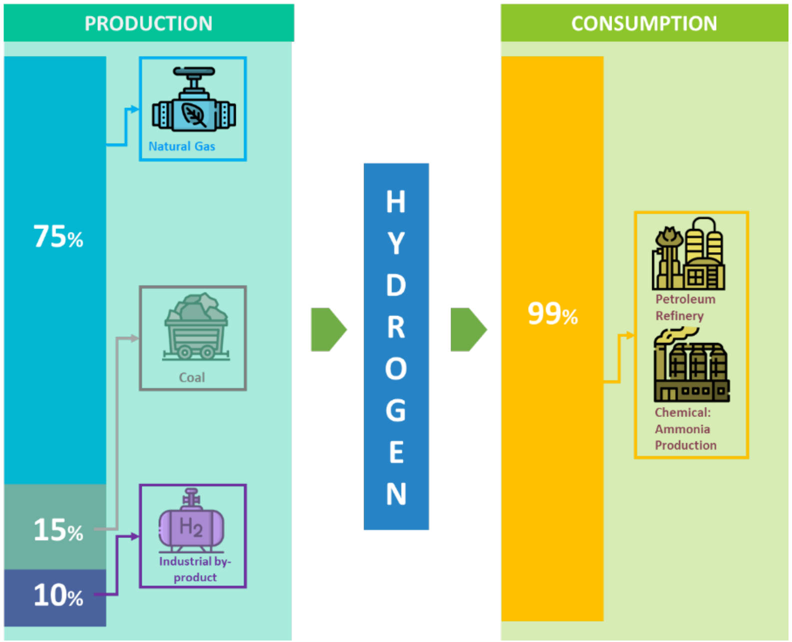

Figure 15: Hydrogen production and consumption in India[101]

With the increasing global focus on decarbonization, transitioning from carbon-intensive hydrogen production methods to green hydrogen is crucial. The current reliance on natural gas and coal for hydrogen production in India contributes to GHG emissions. By adopting green hydrogen, India can significantly reduce carbon emissions, support a cleaner energy landscape, and meet the hydrogen demand of various heavy industries. This shift will provide environmentally friendly feedstock for chemical reactions, reduce emissions in metallurgical processes, and offer cleaner

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[101] IEA

heat sources and sustainable fuel options, thus paving the way for a greener and more sustainable future.

3.2 Stakeholder Mapping

Stakeholder mapping of the green hydrogen value chain involves identifying and analyzing the various actors and organizations that play a significant role in the development, regulation, and standardization of green hydrogen-related activities. This mapping exercise helps to understand the dynamics and relationships among different stakeholders and enables effective coordination and collaboration within the green hydrogen sector. This study has been prepared in consultation with BIS, ARAI, CII, FICCI, SIAM, and private players.

3.2.1 Regulatory Bodies

One crucial group of stakeholders in the green hydrogen value chain are regulatory bodies. These entities, often governmental or intergovernmental, establish and enforce regulations and policies related to green hydrogen production, transformation, storage and transportation, and end-use applications. They ensure safety, environmental compliance, and promote the integration of green hydrogen technologies into existing energy systems while driving the adoption and deployment of green hydrogen as a clean and renewable energy source in India. Their roles include policy development, standards implementation, licensing and permits, safety management, environmental impact assessment, market oversight, research and development support, international collaboration, and stakeholder engagement. Their key roles and responsibilities are as follows:

- **Policy Development and Regulation:** Formulate policies, regulations, and guidelines for green hydrogen production, transportation, storage, and use.
- **International Collaboration:** Participate in international forums and align regulatory frameworks with global best practices for green hydrogen.
- **Stakeholder Engagement:** Engage with industry stakeholders to understand their needs, address concerns, and promote a sustainable green hydrogen industry.

3.2.2 Standardization Bodies

Standardization bodies are another vital set of stakeholders in the green hydrogen value chain. They work towards developing and maintaining technical standards and specifications for green hydrogen-related technologies, infrastructure, and applications. These standards ensure interoperability, safety, and quality across the green hydrogen value chain. Standardization bodies can facilitate harmonization and consistency, enabling the widespread adoption of green hydrogen technologies and fostering market confidence. Their key roles and responsibilities are as follows:

- **Standards and Certification:** Develop quality, safety, and environmental standards for green hydrogen production and establish certification processes.

- **Licensing and Permits:** Oversee the licensing and permitting process for green hydrogen projects, ensuring compliance with safety and environmental requirements.
- **Safety and Risk Management:** Establish safety regulations and guidelines for the handling, storage, and transportation of green hydrogen.

3.2.3 Other Key Players

In addition to regulatory bodies and standardization bodies, there are various other key players involved in the green hydrogen value chain. R&D institutions play a crucial role in advancing green hydrogen technologies, conducting scientific studies, and exploring innovative applications. These institutions contribute to the knowledge base, drive technological advancements, and provide expertise to support the growth of the green hydrogen sector.

Other stakeholders may include industry associations, trade unions, energy companies, equipment manufacturers, project developers, financial institutions, and end-users. Industry associations represent the collective interests of stakeholders, promoting collaboration, knowledge sharing, and advocating for favorable policies. Energy companies and equipment manufacturers are involved in the production, distribution, and deployment of green hydrogen technologies and infrastructure. Project developers and financial institutions facilitate investment and implementation of hydrogen projects, ensuring their viability and commercialization. Finally, end-users play a vital role in driving the demand and adoption of hydrogen technologies and applications. Their key roles and responsibilities are as follows:

- **Research and Development Support:** Support research and development initiatives in the green hydrogen sector and foster collaboration with research institutions.
- **Environmental Impact Assessment:** Assess the environmental impact of green hydrogen projects and ensure compliance with environmental regulations.
- **Market Oversight and Competition:** Monitor and regulate market activities related to green hydrogen, ensuring fair competition and consumer protection.
- **Financing for projects, PPP**

Effective stakeholder mapping in the green hydrogen value chain involves understanding the roles, interests, and influence of each stakeholder group. It helps identify potential synergies, barriers, and opportunities for collaboration, ensuring a coordinated and inclusive approach to the development and deployment of green hydrogen technologies. By engaging and involving diverse stakeholders, a robust and sustainable green hydrogen ecosystem can be fostered, enabling the transition to a clean energy future. Annexure 7 highlights the stakeholder’s roles and responsibilities in the Green Hydrogen Value chain.

3.3 Green Hydrogen Regulations

With the launch of National Green Hydrogen Mission 2023, Government of India has target to make India Global Export hub for Hydrogen. Green Hydrogen Policy was notified by Ministry of Power (MoP) in Feb 2022, focused on production by manufacturers, distribution licenses, grid connectivity to renewable energy plant, statutory clearances in a time bound manner, manufacturing near ports, and land for storage etc. Ministry of New and Renewable Energy (MNRE) is the nodal ministry for overall coordination and implementation of National Green Hydrogen Mission 2023. This section provides the details of the existing legislations in India which may directly/ indirectly influence the green hydrogen value chain.[102]

The Legislations are studied into several categories. These categories are Power and Gas sector, Industry, Environment, Land & Water, Transportation and Others. Refer Annexure 8 for details on the regulations.

Table 6: Existing regulation and bodies related with green Hydrogen

Legislation Category	Importance for Green Hydrogen Standards	Relevant Legislation in India	Areas for Additional Legislation	Related/Relevant Bodies as mentioned in the Act
Power Sector Legislation	RE integration, integration into power grid, renewable purchase obligations, power purchase agreements, open access	Electricity Act, 2003	Specific provisions for GH2 in Electricity Act	• Ministry of Power, Government of India • Central Electricity Authority - CEA (Sec. 70) • Central Electricity Regulatory Commission - CERC (Sec. 76), State Electricity Regulatory Commission - SERC (Sec. 82), Joint Commission - JC (Sec. 83), • Central Transmission Utility or a State Transmission Utility - CTU or STU (Sec. 54), • The Appellate Tribunal (Sec. 110) of Electricity Act, 2003
Gas Sector Legislation	Integration into gas infrastructure, blending	Petroleum and Natural Gas Regulatory Board (PNGRB) Act	Extension of PNGRB Act to include GH2 provisions	• Petroleum and Natural Gas Regulatory Board (PNGRB) • The Appellate Tribunal is same as per Electricity Act 2003 Section 110 (Sec. 30 of PNGRB Act)
Industry Legislation	Emissions control, waste management	Pollution Control Acts (central and state level)	Regulations specific to GH2 production	• Central Pollution Control Board (CPCB) at the central level; State Pollution Control

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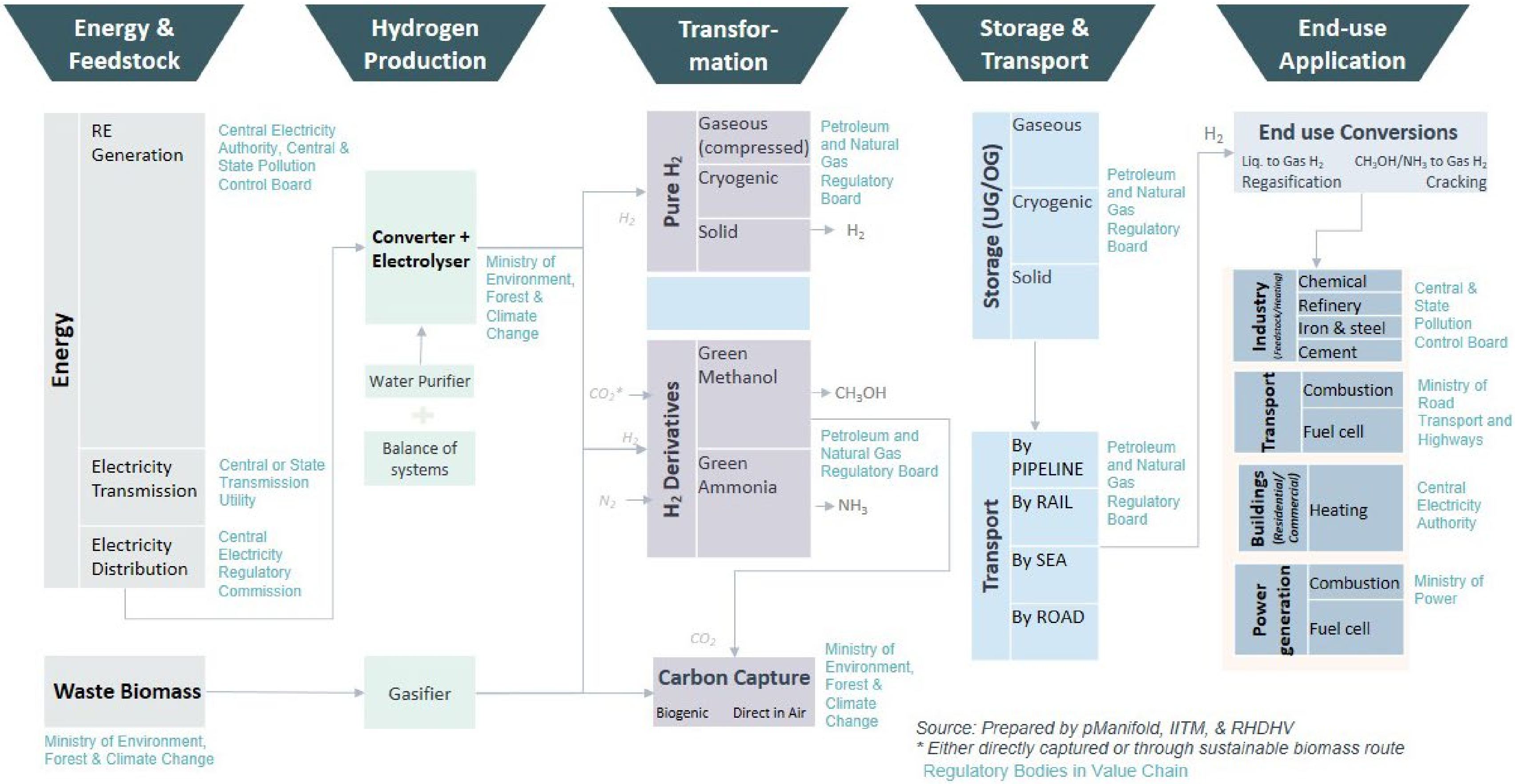
[102] Consultant Analysis

Legislation Category	Importance for Green Hydrogen Standards	Relevant Legislation in India	Areas for Additional Legislation	Related/Relevant Bodies as mentioned in the Act
				Boards (SPCBs) at the state level
Environmental Legislation	Environmental impact assessments, pollution control measures, conservation of natural resources	Environment Protection Act, 1986	Strengthening of environmental regulations for GH2	• Ministry of Environment, Forest, and Climate Change (MOEFCC), Government of India
Land and Water Legislation	Land acquisition, water pollution control	Land Acquisition Act, 2013	Specific regulations for land and water use in GH2 projects	• Ministry of Rural Development, Government of India • National Monitoring Committee for rehabilitation and resettlement (Sec. 48), Land Acquisition, Rehabilitation and Resettlement Authority (Sec. 52) of Land Acquisition Act, 2013
Transport Legislation	Vehicle standards, safety, green tax, and incentives	Central Motor Vehicles Rules (CMVR), 1989	Inclusion of regulations for H2-fueled vehicles	• Ministry of Road Transport and Highways (MoRTH) • Regional Transport Authorities
Other Relevant Legislation	Research and development funding, standards development, certification authorities	National Hydrogen Energy Mission (NHEM), Bureau of Indian Standards (BIS)	Strengthening of NHEM, development of specific H2 standards	• Ministry of New and Renewable Energy

In today's context, several additions are required in each of these acts. The Electricity Act, 2003 can have specific provision for green hydrogen, PNGRB Act can be extended to include provision of green Hydrogen. As per environmental act, regulations need to be strengthened for the mission implementation. Specific amendments may be made for land and water-related regulations. Under transport, hydrogen fueled vehicles may be included. These could help in strengthening the National Hydrogen Energy Mission for development of hydrogen specific standards to be pushed forward.



Source: Prepared by pManifold, IITM, & RHDHV

** Either directly captured or through sustainable biomass route*

Regulatory Bodies in Value Chain

Figure 16: Regulatory Bodies in the Hydrogen Value Chain

3.4 Green Hydrogen State Policies

India's National Green Hydrogen Mission aims to make India a leading producer and supplier of Green Hydrogen in the world. As part of this mission, various Indian states have recognized the potential of green hydrogen and have aligned their needs with the national objectives. These states are actively working towards developing their own green hydrogen projects and creating a hydrogen economy.

Table 7: Green Hydrogen State Policies in India

State/ UT	Policy Status	Targets	Measures	Priority sectors identified
Andhra Pradesh[103]	Notified	1. Production capacity of 0.5 million tons per annum (MTPA) of GH2 and 2 MTPA of GNH3 over the next five years 2. Support the development of eco-system for GH2/GNH3 production 3. Attract investments, provide employment, and improve the economy of the State 4. Create 12,000 jobs per MTPA production of GH2 in the State 5. Promote setting up of GH2 and GNH3 and its related equipment manufacturing facilities in the State 6. Make Andhra Pradesh the preferred destination for production and export of GH2/GNH3	1. Developers who produce GH2/GNH3 using RE, or waste biomass will come under the purview of this policy. They will have to pay facilitation charges to the nodal agency, which is the New and Renewable Energy Development Corporation of Andhra Pradesh (NREDCAP) 2. The policy provides various incentives, including 100% reimbursement of net State Goods and Services Tax (SGST) on the sale of GH2 and GNH3 for five years, a waiver on electricity duty for RE used in production, reimbursement of intrastate transmission charges, reimbursement of cross-subsidy surcharge, priority grid connectivity, and exemption from land-use conversion charges and stamp duty payment. The policy also encourages government land allocation and eligibility for industrial incentives for GH2 and GNH3 production units	Nitrogenous Fertilizers & Refinery Sector
Gujarat[104]	Notified (Land Policy)	1. The land leased out for the production of green hydrogen cannot be sublease (sub-lease) to others 2. Tripartite agreement must be signed between the Collector, GPCL and the establishment of solar, wind, wind-solar hybrid plants for the production of green hydrogen	1. Duration of the lease period will be 40 years, government land for setting up solar, wind, wind-solar hybrid energy plants. 2. Applicant should have experience in generating minimum 500 MW renewable power 3. Applicant shall have a minimum net worth of Rs 1200 crore per lakh metric tonnes per annum for the proposed capacity of renewable energy plant for the production of green hydrogen 4. The annual rent of the land allotted by the government is Rs 15,000 per hectare (an increase of 15 percent in fares will have to be calculated every three years)	GH2 Projects

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[103] ANDHRA PRADESH GREEN HYDROGEN & GREEN AMMONIA POLICY - 2023

[104] Gujarat Policy-2023 for leasing the government fallow land for green hydrogen production using non-conventional energy sources, May 2023

State/ UT	Policy Status	Targets	Measures	Priority sectors identified
			5. Existing rules, regulations, instructions of the Department of Energy and Petrochemicals will have to be followed	
Karnataka[105]	Notified RE Policy	1. Storage and transportation of GH2/GNH3 is targeted as maximum demand for H2 will have to be shipped 2. Ensure availability of water, ports, large-scale RE projects, domestically manufactured electrolysers, and pumped storage	1. Support to H2 and fuel cells on case-to-case basis to evaluate the feasibility 2. Support new initiatives/pilot projects H2 and fuel cells	GH2, GNH3, Pumped storage, Fuel cells
Madhya Pradesh[106]	Notified RE Policy	1. Promoting production of "GH2" using electrolysis process or any other commercial process that uses RE power 2. Promotion of Electrolyzer manufacturing units using RE power for manufacturing of Electrolyzer 3. Electrolyzer manufacturing units using non-RE power for manufacturing of Electrolyzer	Both are applicable for Production of "Green Hydrogen" using electrolysis and Electrolyzer manufacturing units using RE power 1. For Investment size < Rs. 50 Cr. – general incentives as per respective policy of Industry/MSME Department 2. For Investment size => Rs. 50 Cr. – special incentives earmarked for RE Equipment manufacturing sector under Industrial Promotion Policy	GH2 Production using Electrolysis and Electrolyzer manufacturing units using RE power
Odisha[107]	Notified RE Policy	1. Come with a separate Policy for development of an ecosystem for GH2/GNH3 in the State 2. Additional incentives for production of GH2/GNH3 under the Industrial Policy Resolution until the State comes up with a separate Policy 3. Undertake study on GH2,	1. 100% exemption from payment of Electricity Duty for a period of 20 years 2. Reimbursement of Power Tariff of INR 3/unit consumed and purchased from GRIDCO for a period of 20 years 3. Cross subsidy surcharge & additional surcharges and state transmission charges will be exempted/	GH2, GNH3 to meet demands of Petrochemical/ Fertilizer/ Steel industry, Long haul transport, City gas

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[105] Karnataka Renewable Energy Policy 2022-2027

[106] Madhya Pradesh Renewable Energy Policy – 2022

[107] Odisha Renewable Energy Policy, 2022

State/ UT	Policy Status	Targets	Measures	Priority sectors identified
		determine the techno-economic viability for energy storage and for mobility and industrial applications 4. Prepare a roadmap for commercial usage	reimbursed for a period of 20 years 4. 30% Capital subsidy for new industries	distribution as well as export
Rajasthan[108]	Notified	1. Produce 2000 kilo Tonnes per Annum (KTPA) of GH2 by 2030 2. Commission at least one GH2 valley to cater to the demand from fertiliser plants and refineries within Rajasthan and in other States 3. Develop at least one Giga factory for electrolyser manufacturing. The state should also aim to export these domestically manufactured electrolysers across the globe 4. Cater to at least 20% of GH2 exports from India either as fuel, chemicals derived from GH2 or technology products like electrolysers 5. A minimum share of consumption will be met through GH2 by designated consumers in the State as per mandate prescribed in NGHM which shall be extended in phased manner 5. Blend of at least 10% GH2 (on a volume basis) in natural gas pipelines for gas produced within Rajasthan by 2030.	1. The Nodal Agency for this Policy is Rajasthan Renewable Energy Corporation Limited (RRECL) 2. Generators allowed to obtain RE through Open Access from existing/new RE Projects as per relevant RERC Regulations and State Policies 3. Develop a GH2 Valley/Cluster at suitable location 4. Incentives/facilities are made available on individual GH2 Plant capacity of maximum 20 KTPA 5. Benefits applicable for 10 years from the date of commissioning of the projects a. 100% waiver of Intra-state transmission and wheeling charges, b. waives on additional surcharge and cross subsidy charges, c. Limiting benefits to the GH2 quantum	H2 generation and its derivatives, GH2 Parks, Green tourism, GH2 Fuel cells for applications in Transportation, Distributed applications of GH2 in Residential, Commercial, Industrial, and Mobility Sectors

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[108] Rajasthan Green Hydrogen Policy, 2023

State/ UT	Policy Status	Targets	Measures	Priority sectors identified
Uttar Pradesh[109]	Draft	1. GH2 cost reduction to 2.0 USD/Kg in the policy period and to further decline it to 1 USD/Kg in long-term 2. 20% GH2 blending in total H2 consumption of the state by 2028 for existing fertiliser and refinery units, and upto 100% by 2035 3. State centre of excellence (CoE) to lead R&D, and techno-economic innovation activities 4. Rank 1 in the ease of doing business index based on the Business Reform Action Plan (BRAP) recommended by DIPP	1. Incentives provided in 'Industrial Investment and Employment Promotion Policy 2017' and exemptions provided under 'Scheme for Promoting Establishments of Private Industrial Parks 2017'shall apply to new GH2/GNH3 investments and expansion of existing fertiliser units 2. Single window clearance platform "Nivesh Mitra' and Grievance redressal of 15 days for projects 3. Incentives under 'Make in UP' shall apply to production of GH2/GNH3 or based productions 4. Focus on Long-term infrastructure and manufacturing capacity expansion 5. GH2 Ecosystem Fund through green cess to support small infrastructure projects 6. Development of H2 ready pipelines to transport GH2/GNH3 to feasible distances 7. Adequate water supply and electricity transmission infrastructure 8. Adequate land provision at concessional rates with necessary regulatory support in case of availability of government land 9. GH2 Innovation Awards for winning start-ups to seek funding from state 10. Sustainable and economic solutions for transport and storage feasibility 11. Technology demonstration and proof of concept pilots in emerging use cases such as heavy-duty transport, energy storage, etc. 12. Geological survey to identify potential natural H2 storage sites 13. Land & Water resource incentives: 100% exemption from land tax, land use conversion charges, stamp duty, and 50% from industrial	Nitrogenous (N-) Fertilizers and Refinery

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[109] Uttar Pradesh Green Hydrogen Policy

State/ UT	Policy Status	Targets	Measures	Priority sectors identified
			water consumption charges if water is used to produce GH2; Infrastructure incentives; Operational incentives; Additional subsidy for every tonne of green urea in the state beyond 10% blending share in total, Employee benefits	

It is worth noting that currently Karnataka, Odisha, and Madhya Pradesh have arrangements for green hydrogen sector included as part of their notified RE policies, and hence, are considered for the study. Even though most of them have provisions for both supply and demand side, there is a need to address the banking and carbon credit mechanism in detail in these policies. Secondly, the coverage for the whole value chain is limited in the policies for e.g., storage and fuel cells related aspects. Also, the benefits for R&D and support for product development should be specifically addressed in the policies.

3.5 Green Hydrogen Standardization

As identified by the National Green Hydrogen Mission, the formulation of hydrogen codes & standards is pivotal for India's green hydrogen economy. Hydrogen standards provide guidelines and safety requirements for handling various stages of hydrogen value chain i.e., Production, transformation, storage & transport, and end-use application. These standards ensure consistency and reliability in the field of construction, design, testing and performance across various components in the value chain.

In the area of hydrogen production, there are 12 standards focusing on safety and reliability objectives[110], with one standard dedicated to sustainability. Additionally, there are 10 standards for performance objectives and six standards for design objectives. In the hydrogen transformation stage, the objectives are more limited, with one standard for safety and four standards for gas quality. For hydrogen storage and transportation, there are eight safety objectives, nine performance objectives, and 10 design objectives. Regarding end-use applications, each objective is covered by two standards, except for sustainability which currently has no specific standard.

While BIS remains the apex agency for notification of standards in form of adoption of international standards or creation of indigenous standards across the value chain, ARAI is concerned with standards and testing facilities in the transport/off-road applications of hydrogen. Similarly, OISD has its standards for the dispensing stations and safety in handling hydrogen and PESO is responsible for the storage related aspects. Additionally, the Bureau of Energy Efficiency (BEE) has been designated as the nodal authority for accrediting agencies involved in monitoring, verification, and certification of Green Hydrogen production projects.

Figure 17 illustrates the existing Indian standards related to the different stages of the hydrogen value chain, including production, storage and transport, and end-use applications.

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[110] Refer Annexure 10 for detailed view on categorization of objectives.

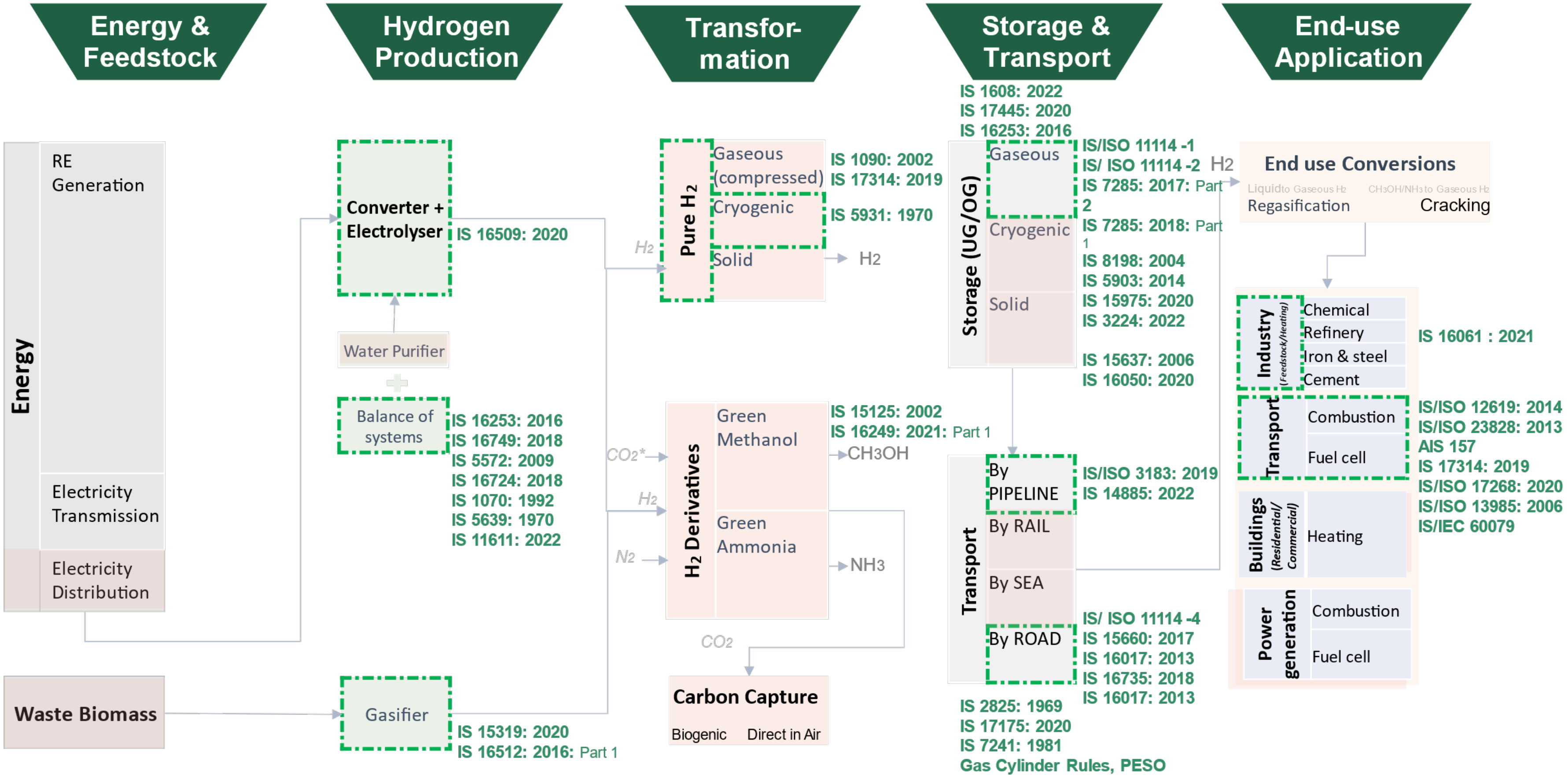

Figure 17: A proportion of the Indian technical standards assessed in this study relevant to the hydrogen value chain[111]

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[111] Consultant Analysis

3.6 Green Hydrogen Certification

Green hydrogen certification involves the verification and documentation of environmental attributes such as production methods, carbon intensity, and greenhouse gas emissions. Whereas standardization plays a pivotal role in the certification of green hydrogen by providing a comprehensive framework and a set of criteria that ensure the environmental integrity and sustainability of hydrogen production processes. These standards delineate the necessary greenhouse gas emission reduction thresholds, which hydrogen production must meet or exceed in order to be labeled as green.

Adherence to a specific standard not only facilitates the certification process itself but also enhances transparency in the market. When hydrogen is certified as green under a recognized standard, it assures end-users and investors of its environmental credentials. This assurance is paramount in distinguishing green hydrogen in a market where claims of sustainability require substantiation to prevent greenwashing and to build trust. Moreover, the principles that underpin the Green Hydrogen Standard, such as consultation, transparency, and independent verification, ensure that the certification process is both rigorous and fair. The incorporation of elements like concerns and appeals mechanisms and the ongoing development of the standard mean that certification remains dynamic and responsive to evolving technological and environmental considerations.

Ultimately, these standards provide a valuable tool for companies seeking to differentiate their product in a competitive market. By certifying their hydrogen as renewable or low-carbon, companies are able to market their product effectively, knowing that it meets the stringent criteria outlined by the standards. This certified status can secure them a notable advantage, enabling them to participate in markets that are increasingly demanding environmentally responsible energy solutions.

As stated earlier, India's NGHM aims to make the country a global leader in the production, use, and export of green hydrogen, a clean and renewable energy source. However, the absence of a green hydrogen certification framework in India poses a challenge in ensuring the origin and quality of green hydrogen and facilitating its trade in national and international markets.

Green hydrogen certification could account for carbon footprints based on the mode of distribution, such as comparing hydrogen delivered in trucks to that distributed through pipelines. India can also collaborate with projects like CertifHy, which aim to develop a harmonized and reliable green hydrogen certification scheme for Europe. These countries/regions have developed or are developing green hydrogen certification schemes, each with its own scope, criteria, methodology, and governance. However, they do follow a similar approach of defining green hydrogen categories based on their production pathways and carbon intensity, establishing thresholds and requirements for green hydrogen eligibility, and implementing a tracking system to trace green hydrogen along the value chain as shown in section 2.4.5.

A recent effort by MNRE has set the standards for green hydrogen production in India.[112] To be classified as "green", hydrogen must meet the following criteria:

- **H2 Production:** Through RE, including, but not limited to electrolysis or conversion of biomass
- **Renewable Energy:** May be stored in ESS or banked with grid
- **Well-to-Gate Emission:** The well-to-gate non-biogenic GHG emission of green hydrogen should not exceed **2 kg of carbon dioxide (CO2) equivalent per kg of hydrogen.**
    - **Processes Included:**
        - Electrolysis process: water treatment, electrolysis, gas purification, drying, and compression
        - Biomass Conversion process: biomass processing, conversion of biomass to hydrogen, gas purification, drying, and compression
- **Average Emission Over 12 Months:** The emission threshold mentioned above should be taken as an average over a 12-month period.
- Detailed **methodology for measurement, reporting, monitoring, on-site verification, and monitoring and certification** of green hydrogen and its derivatives shall be specified by MNRE.
- The **Bureau of Energy Efficiency** shall be the **nodal authority for accreditation of agencies** for all the monitoring, verification, and certification for green hydrogen production projects.

3.7 Gap Assessment

The role of gap assessment is to revisit the existing Indian regulations and standards on hydrogen value chain and identify the gap so that an effective and safe green hydrogen regulation and standard can be implemented.

3.7.1 Regulations

The regulatory framework governing the green hydrogen landscape in India, while extensive, has specific gaps that need to be addressed to streamline the development and deployment of green hydrogen technologies. These gaps, if handled effectively, will shape an environment more conducive to the proliferation of the green hydrogen

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[112] *Green Hydrogen Definition, MNRE, 2023*

sector within the country. Here are some of the key existing issues in the overall regulatory space:

- **Aligning regulations with clear guidelines:** The current regulatory framework leaves room for more unambiguity regarding the general governance of the green hydrogen sector. Guidelines fulfilling essential elements, including the erection and operation of green hydrogen plants, regulatory compliance, approval acquisition, and incorporating renewable energy sources, are yet to be explicitly articulated. For example, in the policy of Madhya Pradesh, banking of green hydrogen is not specifically addressed which will serve as a big limitation during approvals/ execution given severe limitations in both RE absorption capacity and excess firming capacity.
- **Simplification of approval processes:** The existing regulatory system can be optimized by streamlining the approval process for green hydrogen projects. At present, acquiring necessary permissions from multiple governmental agencies might involve potential complexities and delays. For example, the registrations and approval for solar plants are provided by SECI and the respective State Nodal agency. Similarly, for wind power projects, the necessary approvals are provided by NREDCAP in Andhra Pradesh. Moreover, the developers need to obtain clearances from SPCB. Similarly, for hydrogen production plants, obtaining building plans, power and water connections, and clearances from the SPCB, export registrations to procure equipment from abroad, securing factory licenses, etc. are required. Based on the project, the no. of agencies involved can be higher.
- **Facilitation of inter-agency coordination:** Enhanced cooperation between different governmental agencies is critical for achieving successful implementation of green hydrogen projects. Presently, gaps and challenges in coordination could lead to operational inefficiencies and delays. For example, ARAI is concerned for the standards of the vehicle receptacle, PESO is concerned for the dispensing nozzle. It is important to have same profiles in both for the refueling system to work. Earlier experience in CNG vehicles suggest that there was lacking coordination in this part.
- **Clarification of renewable energy sourcing mechanisms:** Green hydrogen production is fundamentally contingent on renewable energy sources like solar and wind power. There is, however, a distinct lack of clarity regarding the specific mechanisms such as Utility Green Pricing Mechanism, RECs, Unbundled Energy Attribute Certificates, and On-Site RE infrastructure for sourcing renewable energy for green hydrogen plants.
- **Institution of robust quality standards:** For the widespread adoption of green hydrogen, enforcing quality and safety standards is essential. While there are standards for hydrogen production, an urgent need exists for enumerating robust quality standards specifically for green hydrogen.

Specifically, regarding the legislation in each sector, the power sector legislation, gas sector legislation, industry-specific legislations, environmental sector legislation, land and water-related legislation, and transport sector legislation all have distinct roles and potential gaps that need to be filled or adjusted for a cohesive and effective legislative environment for green hydrogen ecosystem as outlined in Annexure 8. The legislation in each of the above-mentioned sectors are evaluated under four categories as highlighted in Table 9.[113] For instance, some of the identified gaps include the absence of T4S[114] regulations, the lack of classified industrial sectors, lack of procedures for operating LNG terminals, etc.

3.7.2 Standards

The compilation of standards from the three regions was conducted based on the analysis of the value chain. In addition, existing Indian standards were mapped and compared to ensure equivalence. This process revealed two primary categories: existing Indian standards and missing Indian standards.

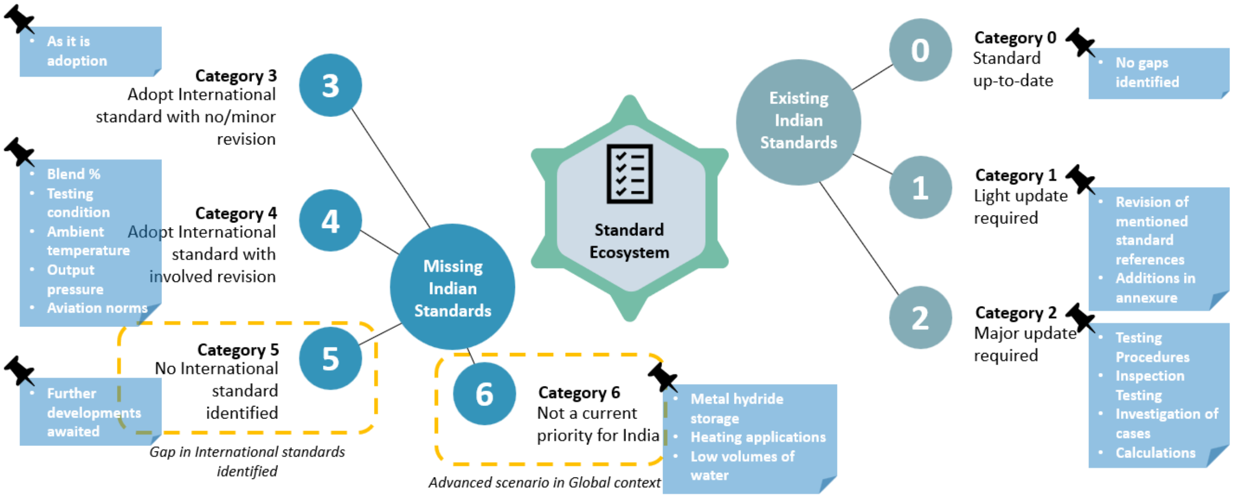

Figure 18: Actions required by India around green hydrogen standards

Upon careful assessment, it has been identified that the existing standards in India need to undergo revisions to encompass green hydrogen and its derivatives within their scope. Several key areas have been identified where modifications, additions, and adoption from international landscape are necessary to ensure comprehensive coverage and address the specific requirements of operating green hydrogen projects such as safety, efficiency, etc. As a result, further subcategories were established, as depicted in the accompanying figure. These standards are crucial for facilitating

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[113] Consultant Analysis

[114] T4S stands for Technical Standards and Specifications including Safety Standards. They are guidelines issued by the Petroleum and Natural Gas Regulatory Board (PNGRB), an organization in India responsible for regulating the oil and gas industry. The T4S regulations include rules and standards to be followed for the safety and technical requirements of gas installations. The existence of T4S regulations ensures that the installations adhere to certain quality and safety prerequisites, thus safeguarding both infrastructure and personnel involved in the industry. There have been various amendments to these regulations over the years to adhere to the evolving nature of the industry.

streamlined approval processes for all green hydrogen projects in the country and implementing NGHM at a large-scale.

- **Hydrogen Production:**
    a. Existing Standards: Current standards adopted do not cover SOECs, efficient resource and effluent management, and procedures for testing and inspection of components. Further, the safety considerations do not cover the safety requirements in production phase as well as operation of manufacturing facilities.
    b. Missing Standards: There is a need for standards pertaining to power performance measurements of hydrogen generator systems in low temperature water electrolysers, energy storage, compressed H2 systems, sustainability and origin, environmental impact, and Power-to-X processes. Additionally, the absence of standards addressing measurements, test procedures, and KPIs associated with electrolysers and standards for production of green hydrogen using alternative methods such as biomass pyrolysis was observed.
- **Hydrogen Transformation:**
    a. Existing Standards: Current standards do not encompass guidelines for installing, storage, and efficient use of components for handling cryogenic liquid. Further, the safe blending percentage should account for both the supply and demand side infrastructure. This could be determined by evaluating the infrastructure built in for delivery as well as the receiver's infrastructure.
    b. Missing Standards: There exists a lack of technical guidance for the conversion of hydrogen to liquid form or its derivatives, as well as a dearth of purity-related standards.
- **Hydrogen Storage and Transportation:**
    a. Existing Standards: Current storage and transport-related standards focus on cylinder-based systems. Notably, only one standard addresses the safety considerations for handling cryogenic liquids, which is an essential aspect in India's green hydrogen applications. Further, adequacy of Indian standards is not as stringent as NFPA or EIGA standards.
    b. Missing Standards: There is limited coverage for storage forms such as cryogenic, metal hydride or LOHC based systems. Further, for transportation, there are no standards that address pipeline-based systems. Only one standard addresses material compatibility issue.
- **Hydrogen End-use Applications:**
    a. Existing Standards: Current standards lack on necessary system integrity checks required in case of vehicle crash, details of breakaway

device in refueling infrastructure, safe blending percentage for various applications, and quality specification of hydrogen as a feedstock in industrial applications.

b. Missing Standards: Most of the standards are concentrated in the field of mobility applications. However, there is an evident gap in standards pertaining to maritime and aviation aspects of green hydrogen utilization. Currently, no standards govern the fuel cell installations for industrial vehicles, hydrogen-fueled ICEs, thermally activated pressure relief devices, operational parameters, and design specifications of equipment for safe use of hydrogen for combustion, lack of standards governing fueling stations.
c. Moreover, it has been noted that in India, the vehicle receptacle and dispensing nozzle are subject to separate standards. To ensure seamless interoperability, it is recommended to have a unified standard governing both components just like ISO 17268: 2020
d. In the Indian market, the standard for storing hydrogen is currently set at a pressure of 300 bars. This limitation poses a challenge for the industry, which is increasingly advocating for an elevation of this limit to 700 bars or more. Achieving this higher pressure is deemed critical for the economic viability of certain applications. The inability to realize a 700-bar pressure is perceived as a significant roadblock impeding progress in this sector.

These standards are divided into seven categories based on the efforts to update the standards. Table 8 below highlights the categorization system.

Table 8: Effort mapping for standard development

Standard Development Categorization System	
Category 0	Standards up to date
Category 1	Light update of existing Indian Standard
Category 2	Involved efforts for updating existing Indian Standard
Category 3	Adopt International Standards with no/minor revisions
Category 4	Adopt International Standards with involved revisions
Category 5	No International Standard identified
Category 6	Seems irrelevant/not related to (green) hydrogen

To do so, five crucial regulatory bodies would be involved in the process of bridging the identified gaps, including the Bureau of Indian Standards (BIS), the Petroleum and Explosives Safety Organization (PESO), the Automotive Research Association of India (ARAI), the Central Pollution Control Board (CPCB), and the Petroleum and Natural Gas Regulatory Board (PNGRB).

In addressing these revisions, BIS[115] plays a significant role across multiple stages. PESO is responsible for revisions related to safety aspects, particularly in storage and transportation. ARAI is involved in developing standards for end-use applications, particularly in the mobility sector. CPCB oversees environmental impact standards, while PNGRB focuses on adapting pipeline standards for hydrogen transportation.

3.7.3 Certifications

A certification framework for green hydrogen is essential for creating a transparent and credible hydrogen market that can attract investments and drive demand. It can also help end-users and governments to distinguish green hydrogen from grey hydrogen, which is derived from fossil fuels. The framework should include robust tracking systems that can trace the attributes of green hydrogen throughout the value chain, from production to consumption. Moreover, the framework should be aligned with international best practices, market developments, and national goals, such as those in the EU. Such a framework would help India facilitate the trading of hydrogen as a commodity on national and international markets. Gradually, help India realize its vision of becoming a major player in the global green hydrogen economy and contribute to climate change mitigation efforts.

India can learn from the experience of other countries and regions that have implemented certification systems for biofuels and other renewable energy sources. For example, India can draw inspiration from tracking certificates used for energy products like European biofuels. These certificates consider factors such as transport mode and distance traveled. Hydrogen, as a versatile and abundant element, can be produced and used in various ways, but not all hydrogen is equal. The color-based classification (such as the Green Hydrogen Policy (GHP) launched by the Power Ministry last year) defines green hydrogen as the one produced from renewable energy (RE) or biomass through water electrolysis. However, this method does not account for the greenhouse gas (GHG) emissions associated with the electricity supply for hydrogen production. Therefore, a certificate system should indicate the GHG content of each unit of hydrogen along the value chain, from production to transport. The carbon-based classification assigns a label to hydrogen depending on its GHG emissions.

Several countries and organizations have already proposed or implemented hydrogen certification and labelling schemes based on carbon intensity. India's NGHM aims to promote green hydrogen production and cross-border trade through a system of green certificates. The CertifHy project in Europe has developed a common framework for issuing guarantees of origin (GOs) based on carbon intensity

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[115] Refer Annexure 11 for the methodology of development of BIS Standards.

thresholds. NITI Aayog published a report in June last year that recommended a hydrogen labelling programme, including harmonized frameworks based on government-to-government and industrial partnerships for products embedded with hydrogen, such as green steel. NITI Aayog also proposed a digital tracking mechanism to verify the green credentials of hydrogen.[116]

In addition, the hydrogen value chain consists of production, transport, storage, and end-use. Each stage involves energy consumption and emission generation. Hence, setting the boundaries of a value chain for accounting and certifying hydrogen is crucial for developing a robust hydrogen market.

Further, according to the International Renewable Energy Agency (IRENA), there are four key regulatory foundations for hydrogen policymaking. Three of them are covered under NGHM, but the fourth one is about guarantees of origin, which is missing in the policy document.

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[116] Harnessing Green Hydrogen, Niti Aayog, 2022

CHAPTER 4 Recommended Actions for India

As hydrogen is set to become a globally traded commodity, it is crucial to establish a regulatory framework, consistent standards, and certification schemes (compliance requirements). Standardizing components, infrastructure, and practices across the hydrogen value chain is essential to guarantee safety, interoperability, and efficiency. Based on this, the following recommendations for different aspects of the hydrogen value chain are recommended:

- **Regulatory Framework:** Developing a well-defined regulatory framework that encourages compliance with established standards and ensures accountability across the entire hydrogen value chain. This should include monitoring mechanisms and enforcement procedures to maintain the integrity and safety of hydrogen operations.
- **Component Standards:** Developing standardized specifications for hydrogen production, storage, transportation, and utilization components. This will ensure compatibility and uniformity across different systems and technologies.
- **Infrastructure Standards:** Establishing guidelines for the design, construction, and operation of hydrogen infrastructure, including production plants, refueling stations, and distribution networks. These standards would encompass safety measures, quality control, and environmental considerations.
- **Safety Standards:** Creating comprehensive safety standards that cover all stages of the hydrogen value chain, including production, storage, transportation, and utilization. These standards should address potential hazards, emergency response protocols, and risk mitigation strategies.
- **Interoperability Standards:** Promoting interoperability among different hydrogen technologies, equipment, and systems to facilitate seamless integration and exchange of hydrogen resources. This includes standardizing communication protocols, data formats, and interfaces.
- **Certification Scheme:** Establishing a certification scheme is a valuable approach to showcase adherence to regulatory requirements and gain access to incentives established within national or regional legislative frameworks for hydrogen and its derivatives. Additionally, such a scheme can demonstrate compliance with voluntary reporting and disclosure obligations, particularly in terms of Corporate Social Responsibility (CSR) and Environmental, Social, and Governance (ESG) reporting. By implementing a certification scheme, stakeholders can confidently showcase their commitment to meeting relevant standards and showcase their environmental and social performance. This can further bolster trust and confidence in the hydrogen industry, as well as facilitate access to supportive policies and incentives.

Implementing these broad areas of recommendations will support the growth of the hydrogen sector, enable efficient global trade, and ensure a safe and sustainable hydrogen economy.

4.1 Regulations

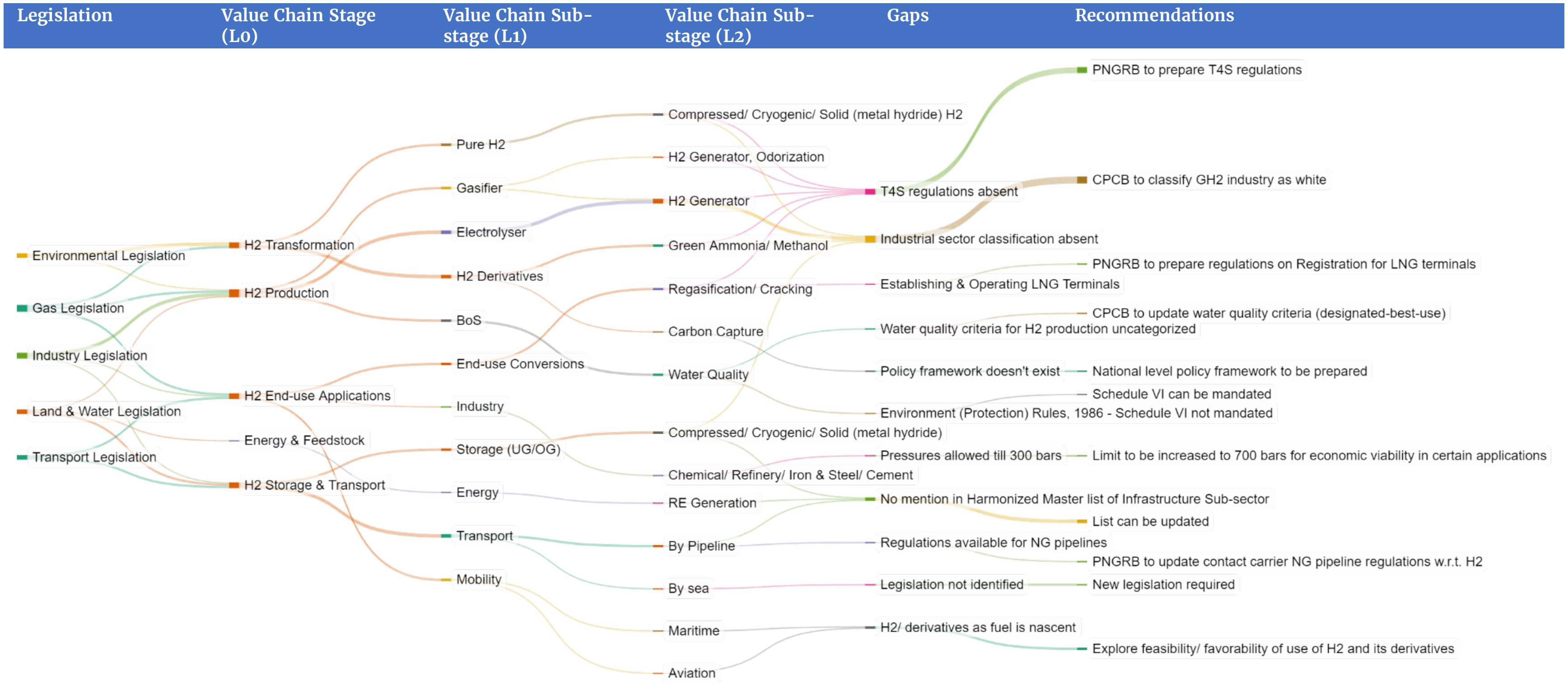

Figure 19: Gaps and recommendations for existing legislations across the hydrogen value chain[117]

The Sankey diagram as shown in Figure 19 demonstrates the gaps and challenges in the legislative framework of the hydrogen economy across various stages and sub-stages of the hydrogen value chain. It is imperative to recognize that legislative analysis is a continuous process, with ongoing efforts aimed at identifying and addressing gaps and enhancing the regulatory framework governing the hydrogen economy. Refer Annexure 8 for detailed list of gaps and recommendations in the regulatory landscape for green hydrogen.

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[117] Consultant Analysis

Stakeholder-specific Recommendations:

- **T4S Regulations:** The PNGRB should consider amending the current T4S regulations to incorporate green hydrogen and its derivatives, along with related sub-systems, such as refineries and gas processing plants utilizing green hydrogen. Additionally, the regulations should encompass industrial processes like regasification and cracking using green hydrogen derivatives. Alternatively, PNGRB may develop entirely new regulations to address the unique characteristics of green hydrogen.
- **LNG Terminal Regulations:** It is recommended that regulations be established for the establishment and operation of LNG terminals by PNGRB. These regulations would provide a framework for the safe and efficient handling of liquefied natural gas, thus facilitating the integration of green hydrogen infrastructure.
- **Contact Carrier Natural Gas Pipeline Regulations:** The contact carrier natural gas pipeline regulations should be updated specifically regarding green hydrogen by PNGRB. This update would ensure the incorporation of necessary provisions and guidelines for the transmission and distribution of green hydrogen through pipelines.
- **Green Hydrogen Facilities Classification:** The CPCB should classify green hydrogen production, storage, and transportation facilities under the white category of industry classifications. This classification would acknowledge the environmentally friendly nature of such facilities and promote their adoption.
- **Water Quality Criteria:** The CPCB should update the Water Quality Criteria (Designated-Best-Use) for the hydrogen production industry. This update would ensure that water quality standards applicable to hydrogen production are aligned with current environmental regulations. The inclusion of updated standards, as mandated by the Environmental (Protection) Rules, 1986 - Schedule VI, would further safeguard environmental considerations.
- **Standard Operating Procedure for Green Hydrogen Derivatives:** It is recommended that CPCB consider updating the standard operating procedure for the production and usage of green hydrogen derivatives. This update would provide clarity and guidance on the safe and sustainable utilization of these derivatives.
- **Harmonized Master list of Infrastructure Sub-sector:** The MoF should consider updating the Harmonized Master list of Infrastructure Sub-sector to incorporate the green hydrogen sector – renewable energy generation projects, green hydrogen production, storage, as well as pipeline transport facilities. By adding these elements to the list, MoF would ensure that these important components of the green hydrogen value chain receive the necessary recognition and support in terms of financing and regulatory frameworks.
- **Carbon Capture Systems:** The MoEF would play a crucial role in regulating the carbon capture and utilisation systems and sub-systems at a national level through a policy to ensure safe and efficient deployment of the technology.

- **Hydrogen Storage Pressures:** The PESO has a critical role in ensuring the safety and viability of hydrogen applications. To support the economic viability of hydrogen-related applications highlighted in the NGHM, PESO should consider approving operating pressures of hydrogen up to 700 bars and prepare necessary safety regulations and standard operating procedures for it. These approvals would provide the necessary flexibility for various hydrogen use cases while maintaining the highest safety standards.
- **Hydrogen and Derivatives in Maritime & Aviation Industry:** MoPNG should collaborate with MoPSW and MoCA to explore the feasibility of integrating green hydrogen and its derivatives in shipping and aviation sectors, respectively. By partnering with these relevant ministries, MoPNG can foster cross-sectoral collaborations and facilitate the adoption of green hydrogen technologies in these important industries.

Recommendations for the Overall Regulatory Space:

- **Aligning Regulations with Clear Guidelines:** Regulatory bodies should establish comprehensive guidelines for the commissioning and operation of green hydrogen plants. These guidelines should encompass aspects such as regulatory compliance, approval acquisition, and the integration of renewable energy sources. By providing clear guidance, uncertainties can be minimized, resulting in smoother project development and execution.
- **Simplification of Approval Processes:** To streamline administrative processes and expedite project execution, the establishment of a steering committee is recommended. This committee would serve as a single window for acquiring permissions, replacing the need for multiple approvals from various governmental agencies. This simplification would alleviate administrative challenges and enhance the efficiency of regulatory procedures.
- **Facilitating Inter-Agency Coordination:** Robust inter-agency connections should be established to foster better information exchange and collaboration amongst regulatory bodies. This coordinated effort would address any existing gaps and enhance the effectiveness of the regulatory process, ensuring a comprehensive approach to green hydrogen implementation.
- **Clarification of Renewable Energy Sourcing Mechanisms:** Clear guidelines and frameworks need to be formulated to secure renewable energy for green hydrogen production. Mechanisms such as power purchase agreements or renewable energy certificates should be considered to ensure a reliable and sustainable energy supply. These mechanisms would provide confidence to stakeholders and encourage investment in green hydrogen projects.
- **Institution of Robust Quality Standards:** To ensure the integrity and reliability of green hydrogen as an energy source, it is crucial to establish robust quality and safety standards. These standards should cover various aspects, including purity grades, storage, transportation, and usage. By implementing stringent

quality standards, the industry can ensure safe and consistent production and utilization of green hydrogen.

- **Enhanced Financial and Market Incentives:** To incentivize private sector engagement and expedite the development of the green hydrogen industry, enhancements should be made to financial and market incentives. This could involve providing financial benefits, such as tax breaks, grants, and subsidies. Additionally, market incentives like long-term power purchase agreements or guaranteed off-take arrangements can contribute to the financial viability and attractiveness of green hydrogen projects.

Nonetheless, it should be underscored that these recommendations are particularly pertinent for stakeholders involved in the green hydrogen sector and its surrounding regulatory environment. It's crucial that the execution of these broad recommendations is specifically adapted to individual contexts and sectors, all the while considering the progression and evolving dynamics of green hydrogen technologies and their affiliated industries.

4.2 Standards

Based on the analysis of existing Indian standards on green hydrogen value chain and the identification of missing standards, recommendations have been made to bridge the identified gaps. It is important to note that further analysis and validation may be necessary to determine the feasibility and applicability of implementing these recommendations in Indian green hydrogen standards. For a detailed overview of the identified gaps, recommendations, and specific standards to be referenced, please refer to the Annexure 12.

Hydrogen Production:
Following revisions and additions may be articulated to existing standards to enhance compliance and relevance to Indian standards:

- **IS 5572:2009** needs an update to incorporate a quantitative zoning classification, drawing from NFPA 497 to ensure suitability for Indian conditions.
- **IS 1070:1992** should be amended to include the specifications on sodium, chloride, and TOC as outlined in ASTM D1193-91.
- A comprehensive overhaul of **IS 16509:2020** is required to integrate solid oxide electrolysis at high temperatures, detail power input and capacity parameters, define operating temperature ranges, address corrosive environments, and include essential performance indicators, standardized testing, and installation procedures.

Additionally, there are gaps in Indian standards that necessitate attention. These standards are well established internationally and may be referenced:

- **IS 16749:2018** must include safety measures adapted from NFPA 2, tailored to the Indian environment and regulatory landscape.

- The **OISD piping standard** should expand to contain criteria for electrolyzer systems, taking cues from the ASME 31.12 hydrogen piping standard.
- A new standard focusing on **the separation, drying, and purification stages of hydrogen production** is prudent, with suitable international references.
- There should also be a **framework addressing the environmental footprint of hydrogen facilities**, likely modeled after NFPA 2.

Furthermore, a series of critical considerations require development, which are important topics even for the international standardization ecosystem:

- Specifications for **measurement, testing procedures, and key performance benchmarks** need to be established in the case of electrolysers.
- The **compatibility of plastic materials** with low-pressure hydrogen pipes and fittings warrants scrutiny and regulation.
- The inclusion of **diversified hydrogen production facilities**, such as those utilizing biomass pyrolysis, should be considered.
- Guidelines on effective **resource utilization and effluent management** are essential.
- Clear **definitions and classifications of hydrogen** based on production methodologies should be formulated.
- Finally, it is necessary to establish **protocols for environmental management, assess efficiency, and standardize emissions, along with the certification of hydrogen's origin.**

Streamlining the focus of the aforementioned topics and ensuring specificity will greatly improve the clarity and actionability of the standards.

Hydrogen Transformation:

To ensure the Indian standards are up to date and in line with current requirements, the following augmentations and modifications are suggested:

- **IS 16061: 2021** needs to be updated to include fuel quality requirements applicable to hydrogen when used as feedstock in industrial settings.
- **IS 1090: 2002** should be expanded to encompass the classification of compressed hydrogen gas for fuel uses, while incorporating methods such as gas chromatography for determining hydrogen purity within this standard.
- Though **IS 15125: 2002** is currently tailored to natural gas sampling, it should be adapted, with careful consideration, for hydrogen gas sampling.
- A detailed revision of **IS 16253: 2016** is recommended to incorporate a wider range of hydrogen sensor types, establish testing criteria for liquid hydrogen leak detection, and offer definitive guidelines for the installation of these sensors.

Regarding the gaps in Indian standards, the following points are raised for consideration from the international ecosystem:

- **IS 5931: 1970**, which currently deals with cryogenic liquids management, should be adjusted to integrate the NFPA 55 codes, with modifications to make

them more suitable for Indian conditions, for improved guidelines on installation, storage, use, and handling.
- There is a need for a new Indian standard that outlines **the gas quality traits, measures, and thresholds for hydrogen gases** classified under group H, with the inclusion of necessary alterations from EN 16726 to tailor it for the Indian context.

Moreover, it is imperative to address additional critical topics, including:

- The **purification processes** for hydrogen fuel gases,
- **Safety protocols** concerning **liquid hydrogen**,
- Standards for the **management of hydrogen and its derivatives at terminals** and within the hydrogen grid,
- The criteria for the **certification of low carbon and green hydrogen**.

Hydrogen Storage and Transport:

To elevate and align existing standards with Indian regulations, the following updates and expansions are proposed:

- The **chemical composition and heat treatment standards** for materials in gas cylinders and valves must be clearly defined, incorporating insights from international benchmarks such as ISO 17081:2014.
- It is essential to specify the **hydrogen permeation rates** on metal materials, utilizing established methodologies for measurement.
- Research into the **impact of hydrogen on the welded components** of cylinders and the susceptibility to stress corrosion cracking in varying environments should be a priority, drawing from the insights of CGA G 5.5 standards.
- Discussions around the **purity of hydrogen intended for use as feedstock in industrial processes** are necessary, ensuring they comply with recognized fuel quality standards.

Furthermore, addressing the lacunae in Indian standards relating to hydrogen storage and transport, the following considerations are outlined:

- Adopt and adapt critical international standards such as **ISO 11114-5, EN 17533, ISO 11623, and ASME STP/PT-0005** to evaluate materials compatibility for cylinders and valves, define standards for static hydrogen storage, and institute regular inspection protocols for composite cylinders.
- Develop **design guidelines for high-pressure composite hydrogen tanks**, considering the unique requirements of the Indian market.
- Extend existing **norms from LNG transport and storage** to cover the nuances of liquefied hydrogen.
- Institute **material handling guidelines** specific to metal hydrides.
- Safety and efficiency standards for **Maritime transport of hydrogen and its derivatives**
- Establish comprehensive building norms concentrating on the **safety aspect of hydrogen storage infrastructures**.

Hydrogen End-use Applications:

To ensure that Indian standards remain current and meet present-day requirements, the following augmentations are proposed:

- Discuss **fuel quality specifications** and **hydrogen consumption tests**.
- Include **protocols for implementing a breakaway device** during high-tension situations.
- Review and refer to standards ISO 9809-3 and ISO 9809-1 for calculating the **thickness of the cylindrical shell.**

Furthermore, there exist certain gaps within Indian standards that require attention. Internationally, these standards are well-established and could serve as points of reference:

- Emphasize the importance of **adopting or developing standards for fuel cells** to promote the commercial use of Fuel Cell Electric Vehicles (FCEVs).
- Cover **safety, performance, and environmental impact, as well as electromagnetic compatibility, fuel cell stack durability, hydrogen transport, fuel quality, and the design of fueling connectors**.
- Focus on the **safety of Liquid Organic Hydrogen Carriers (LOHC) and Liquid Inorganic Hydrogen Carriers (LIHC) for maritime transport.**
- Adopt international standards like **ISO 23273, JIS C 8824, JIS C 8825, and JIS C 8827**, while noting that TED 26 (BIS) is already focusing on the development of these component standards.
- Establish standards for **hydrogen dispensation at refueling stations**, which currently falls under the jurisdiction of OISD.

Additionally, other important topics to consider in the India green hydrogen standards include:

- Need for standards on LOHC and LIHC safety in maritime transport,
- Information and procedures for the periodic visual examination and inspection of natural gas and hydrogen fuel containers and their installations, and
- Standards for gas quality characteristics, electromagnetic compatibility, and fuel systems in various applications.
- Recommendations involve adopting relevant international standards such as **ASTM**, **ISO**, and **IEC**, while ensuring necessary adjustments and considering Indian context and regulatory frameworks.

4.3 Certifications

To establish a robust certification system for green hydrogen in India, the following recommendations may be followed:

- **Development of Standards:** The green hydrogen production standard set by MNRE should be further refined and expanded to cover all aspects of green hydrogen production, including its origin, quality, and emissions reduction potential. This will provide a clear framework for certification and ensure consistency in the industry.

Recommendations on India's Green Hydrogen Standard:

Definition Parameters for qualifying as "Green" H2	Identified Gaps & Comments
H2 Production: Through RE, including, but not limited to electrolysis or conversion of biomass	**It is a good idea to keep the processes open to cater to future technologies**
Renewable Energy: May be stored in ESS or banked with grid	**This would help in meeting the intermittencies of the RE sources**
Well-to-Gate Emission: The well-to-gate non-biogenic GHG emission of green hydrogen should not exceed **2 kg of carbon dioxide (CO2) equivalent per kg of hydrogen**. • **Processes Included**: • Electrolysis process: water treatment, electrolysis, gas purification, drying, and compression • Biomass Conversion process: biomass processing, conversion of biomass to hydrogen, gas purification, drying, and compression	• **This definition does comply with one of India's major objectives of PLI scheme.** It might become challenging when catering to the **Export Markets** as **Additionality, Temporal, and Geographical Correlation** are central considerations. These can be added in further revisions when actual on-ground export would off-take • Standard can be revised to include scope 2 emissions • Source of biomass needs clarification • Carbon capture would be important while considering biomass gasification process and can be added to the standard
Average Emission Over 12 Months: The emission threshold mentioned above should be taken as an average over a 12-month period.	**Reliable and effective method as it considers seasonal variations, allows for observation of long-term emission trends,** however, it might be challenging to **identify specific emission sources** or events that occur **within shorter timeframes**
Detailed methodology **for measurement, reporting, monitoring, on-site verification, and monitoring and certification** of green hydrogen and its derivatives shall be specified by MNRE.	Further details awaited.

Furthermore, the standard lacks specific guidelines or criteria for differentiating between electrolysis-based and biomass-based hydrogen production methods in terms of their environmental impact and sustainability. This lack of differentiation may lead to confusion and a lack of clarity regarding the definition and differentiation of green hydrogen. Thus, a clear set of guidelines or criteria for differentiating between both the production methods shall be set. A suggestive timeline for considering energy attributes and sustainability attributes under the certification scheme is highlighted in Figure 20.

- **Collaboration with Certification Agencies:** The government should collaborate with recognized certification agencies like TÜV SÜD, TUV NORD, DNV which offer Green Hydrogen certification services. These agencies have the expertise and experience to establish a reliable and internationally accepted certification process for green hydrogen. Their involvement will bring credibility and trust to the certification system.

- **Actively Participate in Shaping GH2 Definition:** It is crucial to align the certification system with international standards to facilitate global acceptance of Indian green hydrogen. India should actively participate in international discussions and collaborations on green hydrogen certification. By aligning the certification process with international standards, India can enhance its position in the global green hydrogen market.
- **Transparent Documentation and Reporting:** The certification process should include comprehensive documentation and reporting requirements. This includes maintaining records of hydrogen production methods, emission reduction measures, and compliance with environmental regulations. Transparent reporting will help build trust within the industry and provide stakeholders with the necessary information to make informed decisions.
- **Accreditation of Certification Bodies:** Establishing a proper accreditation process for certification bodies will ensure the competence and integrity of the certification process. Accreditation should be based on stringent criteria, including technical expertise, independence, impartiality, and adherence to international best practices. Accredited bodies can then carry out the certification process in a fair and reliable manner.
- **Periodic Audits and Monitoring:** Regular audits and monitoring should be conducted to ensure ongoing compliance with certification standards. Audits can verify the accuracy of reported data and assess the effectiveness of emission reduction measures. This will help maintain the integrity of the certification system and provide stakeholders with confidence in the green hydrogen produced in India.
- **Awareness and Education:** A comprehensive awareness and education campaign should be launched to promote the importance and benefits of green hydrogen certification. This campaign should target industry stakeholders, policymakers, and the public to raise awareness about the significance of certification for ensuring the quality and environmental sustainability of green hydrogen.

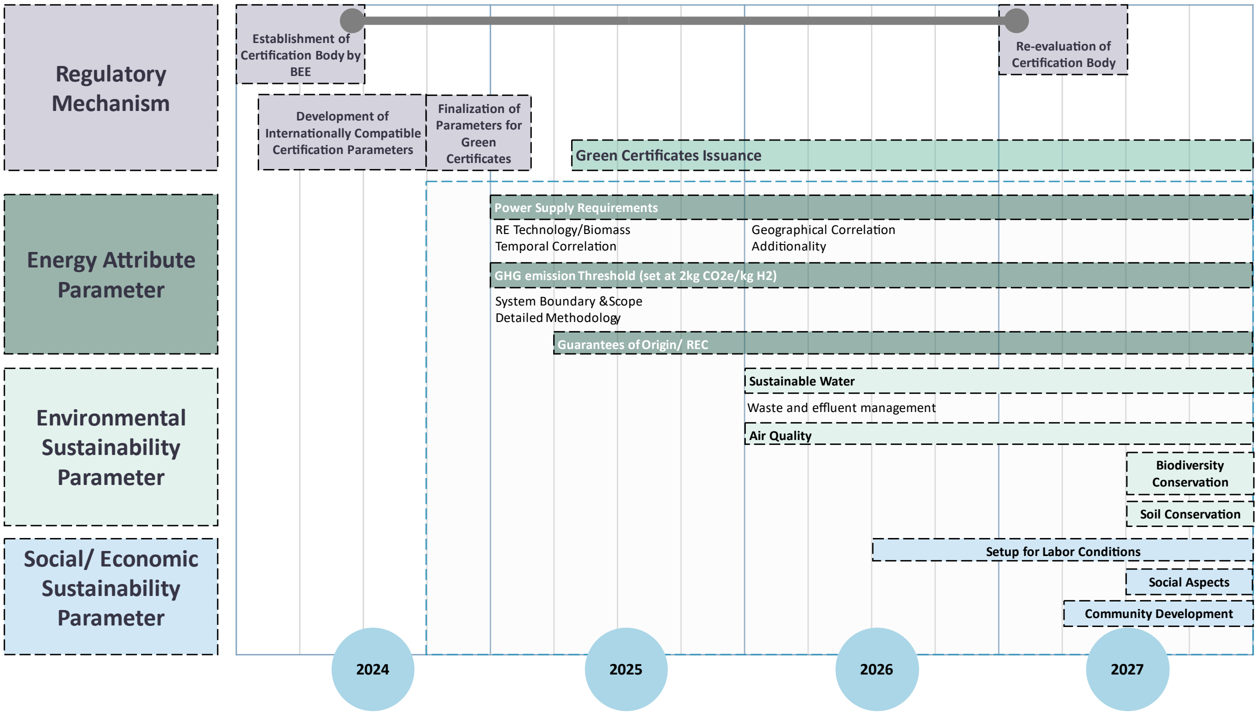

Figure 20: Tentative timeline for robust certification including energy and sustainability parameters

4.4 Concluding Remarks

Green hydrogen represents a significant opportunity for India to enhance energy security, foster economic growth, and contribute to global decarbonization efforts. By embracing green hydrogen, India can reduce carbon emissions, promote a cleaner energy landscape, while meeting the hydrogen demand of various industries. The support of regulatory bodies, standardization bodies, and other stakeholders is crucial here specifically for the development and deployment of green hydrogen technologies in India.

The production of hydrogen in India heavily relies on fossil fuels, primarily natural gas, and coal. However, with the increasing global focus on decarbonization, there is a need to transition from carbon-intensive hydrogen production methods to green hydrogen. Thus, the establishment of the National Green Hydrogen Mission is expected to support India's transition to a cleaner and more prosperous future by attracting investments and boosting energy security.

The analysis of existing regulations, standards, and certifications relevant to the green hydrogen ecosystem in India points out the gaps in the current regulatory framework, existing standards and provides recommendations for enabling a robust green hydrogen ecosystem. The importance of standardization and certification for ensuring safety, reliability, and trade of green hydrogen is emphasized.

Annexure

Annexure 1: Overview of Green Hydrogen and Derivatives[118]

Hydrogen: Hydrogen is a versatile energy carrier with applications in various heavy-industrial sectors and can offer long-term energy storage. The use of hydrogen as a fuel through electrochemical conversion in fuel cells releases only water, making it environment friendly. But, if combusted can release NOx, which is not environment friendly. However, hydrogen's unique energy properties present both opportunities and challenges. While it possesses a high gravimetric energy density compared to many hydrocarbon fuels, its volumetric energy density is relatively low, requiring pressurization or liquefaction for practical use. The source and production method of hydrogen greatly impact the environment, with cleaner sources yielding green hydrogen.

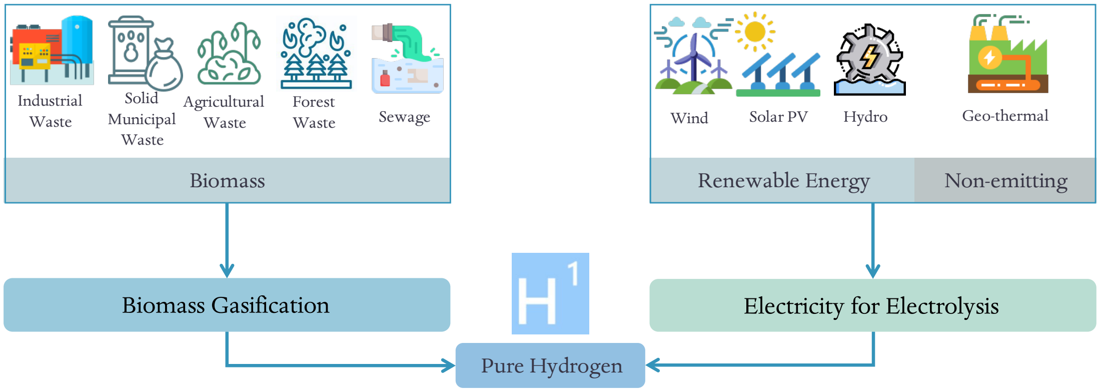

Figure 21: Production methods for green hydrogen

Traditionally, hydrogen has been produced through processes like steam methane reforming (SMR) and coal gasification, which are low cost but energy-intensive and contribute to significant CO_2 emissions. Producing hydrogen from unabated fossil fuels accounts for 6% of the global natural gas use and 2% of the coal consumption and is responsible for more than 900 $MtCO_2$ of annual CO_2 emissions.[119] However, new developments focus on alternative production technologies, such as electrolysis using renewable energy sources[120] or gasification of waste biomass[121] for green hydrogen production. Figure 21 highlights the different methods of production of hydrogen.

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[118] Here derivatives only consider green ammonia and green methanol

[119] Towards hydrogen definitions based on their emissions intensity, IEA

[120] Renewable energy sources include solar, wind, hydro and non-emitting source like geothermal energy.

[121] National Green Hydrogen Mission, MNRE, 2023

Handling hydrogen requires caution due to its small molecular size, and wide flammability range spanning from 4% to 74% in air.[122] Its low energy density by volume poses challenges for storage particularly. Hydrogen is susceptible to leaking through seals, gaskets, and even steel and can form explosive mixtures with air across a broad range of concentrations. Under the optimal combustion condition (a 29% hydrogen-to-air volume ratio), the energy required to initiate hydrogen combustion is much lower than that required for other common fuels (e.g., a small spark will ignite it), as illustrated in Figure 22.

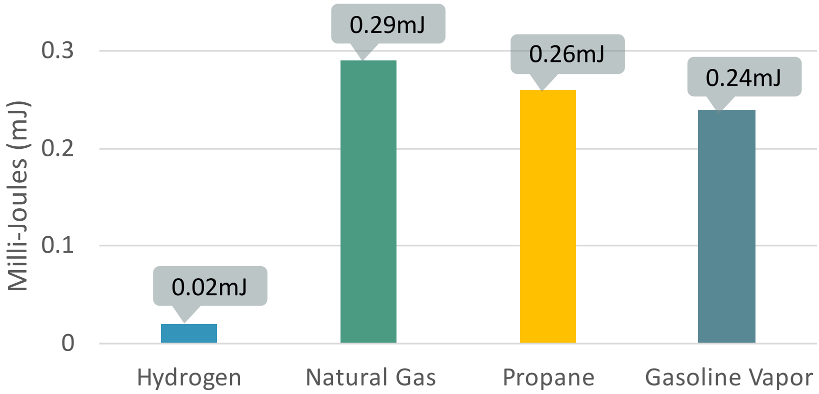

Figure 22: Minimum ignition energy of different fuels[123]

Liquid hydrogen presents different potential hazards and requires additional safety measures. Liquefying hydrogen necessitates cooling to cryogenic temperatures (around -253 deg C), close to absolute zero, or significant compression (e.g., 35Mpa at -253 deg C) for enabling useful quantities to be stored. When stored in liquid form, hydrogen is maintained under pressure at approximately -253 deg C, a temperature that can induce cryogenic burns and lung damage. Consequently, it comes as no surprise that sustaining such a low temperature during storage and transportation inevitably leads to high energy consumption and thermodynamic losses. Thus, alternative options like, ammonia, methanol, and other liquid organic hydrogen carriers (LOHC) are promising alternatives to liquid hydrogen and have attracted the most attention.

Ammonia: Ammonia, a colorless gas with a strong pungent odor is highly soluble in water and has diverse applications. Compared to conventional fuels like gasoline, ammonia has a lower energy density of approximately 11.5 MJ/L, which means a larger volume of ammonia is needed to store the same amount of energy. It has a relatively high ignition point of around 630 deg C, making accidental ignition less likely compared to other flammable gases. When burned, ammonia produces water

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[122] Explosive lessons in Hydrogen Safety

[123] https://h2tools.org/hydrogen-compared-other-fuels

and nitrogen gas as by-products along with oxides of nitrogen, which unless handled properly can cause acid rain, whereas hydrogen only produces water.

The production of ammonia typically involves reforming natural gas to produce hydrogen, which is then reacted with nitrogen under high pressure and temperature. In this process, nitrogen is typically extracted from the air cryogenically using an air separation unit (ASU) or pressure swing adsorption (PSA). This process is energy intensive and releases carbon dioxide, undermining the environmental benefits of using hydrogen as a clean energy source. If electrolytic hydrogen is used instead, and the production process is powered by renewable electricity, then the resulting ammonia will also be renewable (green ammonia). Extracting hydrogen from ammonia at the point of use through cracking requires temperatures above 400 deg C[124] and hence does have CO2 emissions depending on the combustion process. Large scale cracker technology is still at the nascent stages of development.

Despite these challenges, ammonia is considered a preferred carrier for hydrogen for several reasons. It has a high hydrogen content by weight. Liquid ammonia contains 105 - 136 kg/kL of hydrogen (depending on temperature, but in any event 17.6% by weight). In comparison, liquid hydrogen contains only 71 kg/kL of hydrogen.[125] This makes ammonia efficient for storing and transporting hydrogen, as a smaller volume of ammonia can carry a significant amount of hydrogen. Ammonia also benefits from an existing infrastructure for production, storage, and transportation, primarily due to its extensive use in the fertilizer industry. This existing infrastructure can be repurposed for the handling and distribution of ammonia as a hydrogen carrier. Finally, ammonia has a lower risk of flammability compared to pure hydrogen, making it safer for storage and transport.

However, it is essential to recognize that ammonia is a hazardous substance, and precautions must be taken when handling, storing, and using it. Accidental releases can have severe consequences, including fatalities. Its toxic and flammable nature requires caution and adherence to safety protocols to ensure safe handling and prevent accidents. Overall, ammonia plays a significant role in various industries, ranging from agriculture to energy, and its potential as a renewable energy carrier drives ongoing research and development. Recently, state-run V O Chidambaranar (VOC) Port, located in Tamil Nadu's Thoothukudi district, has become the first port in India to handle green ammonia with the arrival of three 20" tank containers loaded

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[124] Review of the Decomposition of Ammonia to Generate Hydrogen | Industrial & Engineering Chemistry Research (acs.org)

[125] Potential Roles of Ammonia in a Hydrogen Economy

with the fuel from the port of Damietta in Egypt for Tuticorin Alkali Chemical and Fertilisers Ltd.[126]

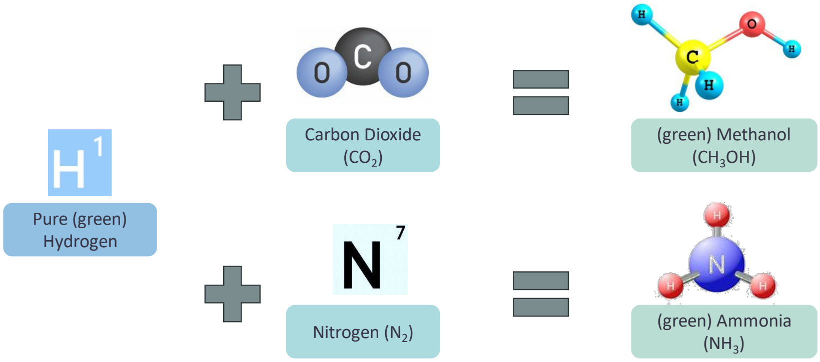

Figure 23: Production of (green) hydrogen derivatives considered in the study

Methanol: Methanol, a clear, odorless, and volatile liquid, is typically produced by reforming natural gas, with global production reaching around 111 million tons annually.[127] In India, the demand was approximately 2.26 million ton in 2021.[128] It is primarily met through imports from countries such as Saudi Arabia, Qatar, Oman, Iran, and UAE, which account for nearly 92% of its consumption. This is advantageous to India as it is cheaper to import methanol due to its reliance on imported natural gas.

However, the process of converting hydrogen to methanol has its challenges. The conversion involves multiple steps[129], resulting in energy losses and reduced overall efficiency similar to ammonia and hydrogen. Secondly, specific catalysts[130] and operating conditions[131] are required for methanol synthesis, and the use of carbon dioxide as a feedstock raises environmental concerns. Thus, finding sustainable sources of carbon dioxide, such as capturing and utilizing industrial emissions or utilizing renewable sources like biomass, is crucial for reducing the carbon footprint of methanol production. Lastly, the ignition point of methanol is relatively low, around 464 deg C. While this makes it potentially hazardous, it is generally safe to handle with proper safety precautions.

Despite these challenges, methanol is one of the preferred carrier for hydrogen due to several reasons. It has a higher energy density than hydrogen (15.6 MJ/L), making it more practical for storage and transport. It can be easily distributed and utilized

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[126] https://infra.economictimes.indiatimes.com/news/ports-shipping/voc-port-becomes-first-indian-port-to-handle-green-ammonia-import/103918209

[127] Methanol Production Globally | Statista

[128] Chemanalyst | India Methanol Market.

[129] Including hydrogenation of carbon dioxide to produce carbon monoxide, followed by the reaction of carbon monoxide with hydrogen to form methanol.

[130] The selection and optimization of catalysts can impact the reaction rate, selectivity, and overall efficiency of the process.

[131] Elevated temperatures and pressures are required to facilitate the chemical reactions effectively.

within existing infrastructure, such as pipelines and storage facilities, which are already established for conventional fuels. It can also serve as a versatile chemical feedstock and fuel. It can be used in fuel cells to produce electricity, as a blending component in gasoline, or as a precursor for various chemicals and materials. This versatility makes methanol a valuable intermediate energy carrier with diverse application potential. In the shipping industry, the orderbook for methanol-fueled or ready containerships continues to grow with both China and Japan reporting landmark orders. The recent batches of smaller vessels join the approximately 150 methanol-fueled containerships scheduled to be delivered in the next five years.[132] Additionally, the conversion process can be coupled with carbon capture technologies to reduce GHGs.

Overall, converting hydrogen to methanol provides a pathway to store, distribute, and utilize hydrogen in more efficiently, enabling its integration into existing infrastructure and facilitating the transition towards a sustainable and low-carbon energy system. It will thus, reduce India's dependability on imports and contribute to India's mission of blending methanol with gasoline. Table 9 below provides a comparison between compressed hydrogen gas, liquid hydrogen, ammonia, and methanol.

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[132] https://maritime-executive.com/article/methanol-orderbook-grows-with-landmark-deals-in-japan-and-china

Table 9: Comparison of different hydrogen and hydrogen derived energy carriers

Parameter	Compressed Hydrogen Gas	Liquid Hydrogen	Ammonia	Methanol
Chemical Composition	Pure hydrogen	Pure hydrogen	NH_3	CH_3OH
Energy density [MJ/L][133]	4.5 (LHV); 5.3 (HHV) at 69 MPa, 25 deg C	8.4 (LHV); 10.0 (HHV)	11.5	15.6
Ignition point [deg C][134]	500	858	630[135]	464
Minimum ignition energy [mJ]	0.017[136]	0.019[21]	680[137]	0.140[138]
Pros	• High purity • Carbon free • No need for dehydrogenation and purification • Versatile applications • Rapid refueling	• High energy density, purity, and hydrogen content • Carbon free • No need for dehydrogenation and purification • Negligible or minimal energy loses during regassification • Versatile applications • Rapid refueling	• Feasibility for immediate application • High energy density and hydrogen content • Moderately flammable • Carbon free • Potential for utilizing existing infrastructure • Minimal losses during transportation • Partially existing regulation	• Can be stored in liquid under ambient conditions • Minimal infrastructure adjustments required for storage and transportation (mostly in place)

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[133] Frontiers | Ammonia as a Suitable Fuel for Fuel Cells (frontiersin.org); Fuels - Higher and Lower Calorific Values (engineeringtoolbox.com)
[134] Engineering Toolbox
[135] Ammonia Thermodynamic Properties, Engineering Toolbox
[136] Microsoft Word - No4066_Edited.doc (iop.org)
[137] Haase, H. (1977) Electrostatic Hazards, Their Evaluation and Control, Verlag Chemie, Weinheim
[138] Berufsgenossenschaften, Richtlinien Statische Elektrizität, ZH1/200 (1980), Bonn

Parameter	Compressed Hydrogen Gas	Liquid Hydrogen	Ammonia	Methanol
		• Commercialized liquefaction and well-established technology		
Cons	• Highly flammable • Difficult for long-term storage • Risk of leakage • Need for further development and scale up of infrastructure	• Highly flammable • Extremely low temperature requirement (-253 deg C) for storage and transportation • High energy requirements for liquefaction and maintaining cryogenic temperatures • Requires boil-off control (0.2-0.3%/d in well-insulated tanker and up to 3%/d in truck) • Limited storage duration due to boil-off and evaporation • Risk of leakage and potential for embrittlement of materials • High costs associated with cryogenic	• Toxic & corrosive • Lower reactivity compared to hydrocarbons • Treatment and management by certified professionals required • High energy consumption for dehydrogenation • Need for hydrogen purification • Potential NOx emissions when used as shipping fuel and not completely combusted	• Toxic & Corrosive • Highly flammable • Contains carbon • Immature technology for renewable methanol production • Carbon (CO and CO2) emissions during decomposition (steam reforming) • Need for further hydrogen purification • Incomplete combustion/ incineration can generate formaldehyde

Parameter	Compressed Hydrogen Gas	Liquid Hydrogen	Ammonia	Methanol
		infrastructure and handling - Limited availability of storage and refueling facilities - Safety concerns related to handling and transportation of cryogenic liquids - Need for further development and scale up of infrastructure		

Annexure 2: Overview of the Value Chain considered for the Study

Stage 1: Energy and Feedstock

- Renewable Energy (RE): Renewable energy sources such as solar, wind, hydro, or geothermal power are used to generate electricity. These sources are considered green because they produce minimal or no greenhouse gas emissions during operation. It includes the transmission and distribution of electricity.
- Biomass: Biomass feedstocks serve as the essential raw materials for producing bioenergy, biofuels, and green hydrogen. They include a variety of organic sources, such as trees, crops, and organic waste materials—for instance, agricultural residues, municipal solid waste, and food waste. These materials are suitable for gasification, a process that transforms biomass into syngas, which can then be processed to extract hydrogen. It is crucial to emphasize the importance of using second-generation (Gen 2) and third generation (Gen 3) biomass feedstocks for hydrogen production. First-generation (Gen 1) feedstocks, which include crops like corn, wheat, and sugarcane, pose environmental concerns such as deforestation, water resource depletion, and land use changes. Conversely, Gen 2 and Gen 3 feedstocks offer more sustainable benefits. Gen 2 feedstocks, which are non-food based, support a circular economy, while Gen 3 feedstocks, derived from algae, boast a higher yield without the need for arable land, fertilizers, or pesticides. Algae's ability to grow in a variety of environments, including wastewater and saltwater, and its use of CO2 for growth position it as a particularly sustainable and promising option. Furthermore, the byproducts from algae have potential uses across various industries, amplifying the sustainability of Gen 3 feedstocks.

Stage 2: Hydrogen Production

- Electrolysis: In this process, electricity is used to split water into hydrogen (H_2) and oxygen (O_2) through electrolysis. Electrolysers consist of stacks, where each stack is made of multiple cells. The cell typically consists of an anode and a cathode separated by an electrolyte membrane/ diaphragm. When an electric current is passed through the water, hydrogen gas is produced at the cathode, while oxygen gas is released at the anode. While the term "electrolyser" typically refers to the entire device used for electrolysis, it consists of several key components in addition to electrolysis unit. Here are two important components of an electrolyser:
    - Water Purification System: Electrolysis requires a source of water, typically deionized or purified water, to undergo the splitting process

  and produce hydrogen. The water purifier ensures that the water input is free from impurities that could potentially affect the electrolysis process or damage the electrolyser. Water purification methods may involve filtration, reverse osmosis, distillation, or ion exchange to remove contaminants such as minerals, salts, organic compounds, or particulate matter. This ensures the purity of the water used for electrolysis, minimizing the risk of unwanted reactions or deposits within the electrolyser.

  - Balance of Systems (BoS): The balance of systems refers to the auxiliary components and subsystems that support the operation and efficiency of the electrolyser. These components are not directly involved in the electrochemical reactions but are crucial for the overall functioning of the system. However, in case of alkaline electrolyzer; where the electrolyte circulation and maintaining the conductivity is crucial for the reaction. BoS components may include a rectifier, a power supply, a control system, safety systems, gas-water separators, hydrogen drying units, hydrogen purification units, purge valves, heat exchangers and cooling systems, and water circulation and treatment.

  These components, along with the electrodes, electrolyte, and cell stack, form the complete electrolyser system. Each component plays a crucial role in enabling the efficient and reliable production of hydrogen through the electrolysis of water.

- Gasification: Biomass can undergo gasification, a thermochemical process that converts the feedstock into a syngas containing hydrogen, carbon monoxide (CO), and other gases. Gasification occurs are relatively high temperatures 800 – 1200 deg C depending on the kind of biomass used. The processes involved here are biomass feedstock preparation, feed pre-treatment, gasification, syngas cooling, syngas conversion to hydrogen using water-gas shift reactors, hydrogen purification using PSA. Additionally, the balance of system consists of control systems, steam supply, safety systems, valves, heat exchangers, cooling systems, etc.

Stage 3: Hydrogen Transformation

- Purification: The produced hydrogen may contain impurities or other gases, so it undergoes purification processes to remove contaminants and obtain high-purity hydrogen. The transformation of pure hydrogen to different physical forms involves specific processes and technologies. The three common methods are compressed gas, cryogenic liquid, and solid-state. Each transformation method offers specific advantages and is suitable for different applications based on factors such as storage capacity, energy density, safety requirements, and transportation considerations. The choice of hydrogen transformation method depends on the needs of the intended application.

  - Compressed Gas: Compressing hydrogen gas involves increasing its pressure with the help of a compressor. It typically consists of a motor, pistons, and valves that compress the gas and store it in high-pressure storage tanks or cylinders.
  - Cryogenic Liquid: Hydrogen can also be transformed into a cryogenic liquid state by cooling it to exceptionally low temperatures below boiling point (-252.87 deg C) by using a cryocooler or liquefaction system.
  - Cryo-compressed: Hydrogen can be stored in a hybrid method combining both compressed and liquid state storage. Hydrogen is stored at cryogenic temperatures (typically 70 – 200K) and elevated pressure (typically 100 – 500 bar). The benefits of such tanks are that a higher effective storage density of H2 and reduced system size could be achieved rather than spending on the energy and cost for a complete hydrogen liquefaction, thereby even achieving a longer driving range. Here the tank is designed to hold both the cryogenic liquid and also withstand the internal pressure.
  - Solid-State: Solid-state storage of hydrogen involves incorporating hydrogen molecules into solid materials, such as metal hydrides or complex chemical compounds.
- Derivatives: Hydrogen can be used as a feedstock to produce other valuable chemicals such as methanol and ammonia. These processes involve combining hydrogen with other elements or compounds to form the desired derivative products.

Stage 4: Hydrogen Storage & Transport

- Storage: Hydrogen can be stored in various ways, including compressed gas cylinders, liquid hydrogen tanks, or solid-state materials. These storage methods ensure the safe and efficient retention of hydrogen until it is needed.
  - High-Pressure Storage: The compressed hydrogen gas is stored in specially designed high-pressure cylinders or tanks. These containers are typically made of high-strength steel or composite materials to withstand high pressures. It can be stored and transported at high pressures, making it suitable for applications that require gaseous hydrogen, such as fueling stations for hydrogen-powered vehicles or industrial processes.
  - Cryogenic Storage: The liquid hydrogen is stored in cryogenic storage tanks that are well-insulated to maintain extremely low temperatures. These tanks are typically vacuum-insulated and have specialized safety features to handle cryogenic temperatures and prevent excessive

evaporation or leaks. It has a higher energy density compared to compressed gas, allowing for more efficient storage and transportation. However, extremely high energy (0.33 kWhel/kWhH2)[139] is required to compress it at low temperature. It is commonly used in aerospace applications, scientific research, and certain industrial processes.

- <u>Absorption/Desorption:</u> Solid-state hydrogen storage materials can absorb and desorb hydrogen gas. When exposed to hydrogen under certain temperature and pressure conditions, these materials can chemically bond with the hydrogen molecules, storing them within their structure. The stored hydrogen can be released when needed by applying heat or reducing the pressure. Table 10 below categories different types of metal hydrides as an example of solid-state storage.

Table 10: Hydrogen density of different metal hydrides

Category	Example	Gravimetric H_2 density[140] [wt %]	Volumetric H_2 density[141] [kg/m³]
Elemental Metal Hydride	Magnesium Hydride (MgH_2)	7.6	151
	Aluminum Hydride (AlH_2)	10.1	126
Intermetallic Hydride	Titanium Iron Hydride (TiFe)	2.1	108
Complex Metals	Lithium Borohydride ($LiBH_4$)	18.5	88
Alanates	Sodium Alanate, ($NaAlH_4$)	8.1	96

These materials offer high storage capacity and can provide a safe and reversible means of storing hydrogen. It is being researched and developed for applications where high-density hydrogen storage and safety are critical, such as portable fuel cells, hydrogen-powered vehicles, and stationary energy storage.

- <u>Derivatives:</u> Both ammonia and methanol offer viable solutions for storing hydrogen, each with its own advantages and challenges.

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[139] https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[140] This refers to the amount of hydrogen (in kg) that can be released from 1kg of the hydride. The values are approximate.

[141] It is a measure of concentration of hydrogen (in kg) in relation to the volume it occupies.

    Deciding on the appropriate storage method depends on factors such as specific application requirements, infrastructure availability, safety considerations, and environmental impact. Continued research and development efforts are necessary to optimize these storage methods and unlock the full potential of hydrogen as a clean energy source.

    - <u>Ammonia:</u> It can serve as a storage medium for hydrogen because it can be easily liquefiable under moderate pressures and has relatively high energy density compared to compressed hydrogen gas. Moreover, existing infrastructure (including pipelines, storage facilities, and shipping vessels) can be utilized, making ammonia a viable carrier for hydrogen in established systems. Further, ammonia is a stable compound with a higher ignition point compared to hydrogen gas allowing risk reduction of accidental ignition. Lastly due to the wide applicability of ammonia in fertilizer production and chemical synthesis, processes are available for recovering hydrogen but the scale up of the cracker technology is still in R&D as stated earlier. Challenges associated with ammonia as a hydrogen carrier include its toxicity, corrosiveness, and the need for additional conversion steps to extract hydrogen from ammonia. Safety measures and further research are required to address these challenges effectively.
    - <u>Methanol:</u> Methanol also shows potential as a hydrogen carrier as it is a liquid at room temperature and atmospheric pressure. This makes it convenient for storage and transport without the need for high pressure vessels or cryogenic systems. Methanol also offers a higher energy density enabling efficient storage and transportation of a larger quantity of hydrogen. Moreover, the existing infrastructure can be utilized (such as storage tanks and fueling stations) as it is. However, the challenges associated with methanol as a hydrogen carrier include the efficiency of methanol reforming processes.

- <u>Transportation:</u> Once hydrogen is produced and stored, it needs to be transported to end-use applications. This can involve pipelines, trucks, or ships, depending on the volume of hydrogen, distance, infrastructure availability, safety considerations, and cost-effectiveness. Different modes of transportation may be employed based on regional infrastructure, scale of operations, and specific requirements of the hydrogen supply chain.
    - <u>Pipelines:</u> Large volumes of hydrogen are transported over long distances using pipelines made of hydrogen-compatible materials (steel

  or composite materials). Hydrogen is often compressed before entering the pipeline to increase its density and facilitate transportation. Compressor stations maintain pressure, while safety measures like leak detection systems and automated shut-off valves ensure safe transport.
  - Rail: Hydrogen is transported in specialized containers or railcars, such as high-pressure cylinders or cryogenic tanks. Safety features such as pressure relief devices and safety valves and proper handling protocols including labelling of hydrogen containers are required to prevent overpressure situations.
  - Sea: Hydrogen can be transported as a cryogenic liquid on specialized ships with insulated tanks and safety systems. Alternatively, hydrogen can be converted into ammonia, allowing for easier transportation on existing ammonia carriers. International safety regulations and standards for the transport of hazardous materials apply to hydrogen shipments by sea. Proper handling, stowage, and emergency response protocols are followed to ensure safe transportation.
  - Road: Specially designed trucks with high-pressure cylinders or cryogenic tanks transport hydrogen gas or liquid. Safety features and hydrogen leak detection systems ensure secure transport.

Stage 5: Hydrogen End-use Applications

- Industry: Hydrogen can be used as a clean energy source in industrial processes, such as refining, chemical manufacturing, and metal production. It can also be utilized as a reducing agent in various industrial applications.
- Transport: Hydrogen can be used as a fuel for various modes of transportation, including fuel cell vehicles (FCVs), hydrogen-ICE powertrains, trains, and potentially even aircraft. Hydrogen fuel cells convert hydrogen into electricity, providing a zero-emission alternative to internal combustion engines.
- Buildings: Hydrogen can be used for heating, cooking, and electricity generation in buildings. It can be directly burned in furnaces or used in fuel cells/gas-turbines/internal-combustion-engines to produce electricity and heat.
- Power Generation: Hydrogen can be utilized in gas turbines or fuel cells to generate electricity. It offers a flexible energy storage solution and can be combined with intermittent renewable energy sources to provide a stable power supply.

The value chain of green hydrogen production involves various stakeholders, from renewable energy providers, electrolyser manufacturers, and hydrogen producers to storage and distribution companies, as well as end-users in different sectors. This integrated chain allows for the efficient production, storage, and utilization of green hydrogen, contributing to the decarbonization of energy systems and the reduction of greenhouse gas emissions.

Annexure 3: Renewable Energy Directive

Renewability (Article 5):

To be classified as renewable RFNBOs must meet specific criteria. They must be exclusively produced using renewable energy, excluding biomass and nuclear energy. Additionally, RFNBOs should achieve a 70% reduction in GHG emissions compared to the benchmark for fossil equivalents.

Additionality (Article 5):

The principle of additionality requires additional deployment of renewable electricity for RFNBO production. Producers can consider the electricity used in an electrolyser for hydrogen production additional if certain conditions are met. Initially, the renewable electricity for hydrogen production should be generated in the same installation. However, producers can now source electricity from the grid if they can verify its green origin through power-purchase agreements (PPA) from renewable installations. There are additional criteria for renewable energy plants:

- The plants must be new and have started operating within the past 36 months.
- The plants must be unsupported, meaning they have not received operating or investment support.
- The European Parliament has agreed to a transition period, exempting installations commissioned before January 1, 2028, from proving additionality. Investments made before 2028 are also exempted until 2038 to qualify as renewable hydrogen.

Temporal Correlation (Article 6):

Temporal correlation is essential to ensure that renewable electricity generation aligns with RFNBO production. The following requirements are proposed:

- Hydrogen production should take place in the same calendar month as the generation of renewable electricity until December 2029.
- Starting from January 2030, hydrogen production should align with the hour of renewable electricity generation.
- The hydrogen production period should coincide with a one-hour period when the day-ahead price of the relevant bidding zone is either below 20 €/MWh or below 0.36 times the price for a certificate of 1 ton of CO2 equivalent.

Alternatively, if the RFNBO is from renewable electricity from a new storage asset, it should be located behind the same network connection point as the electrolyser, or the installation generating renewable electricity should have been charged during the same calendar month in which the electricity under the renewables power purchase agreement was produced.

Geographical Correlation (Article 7):

Geographical correlation ensures that renewable electricity generation is connected to RFNBO production. The proposed requirements include:

- The electrolyser and renewable electricity plants should be in the same bidding zone.
- If located in interconnected bidding zones, the electricity prices in those zones should be equal to or higher than the prices in the electrolyser's bidding zone.
- In the case of offshore bidding zones, the renewable electricity plants should be interconnected to the electrolyser's bidding zone.
- The concept of bidding zones aims to prevent dependence on fossil-based generation and potential curtailment of renewable electricity production. Countries without bidding zones may be allowed if they have equivalent concepts that align with the objectives of the delegated acts.

The second delegated act pertains to the methodology for calculating greenhouse gas (GHG) savings, proposing a detailed scheme for assessing the life-cycle emissions of renewable hydrogen and recycled carbon fuels. These calculations will ensure compliance with the GHG reduction threshold specified in the RED II. Both acts are now open for a four-week public consultation period, concluding on June 17. The Commission encourages all citizens and stakeholders to share their comments on these documents.

Annexure 4: Regulatory Agencies

Europe

Table 11: Examples of EU regulations[142]

System	Regulation	Summary
Overarching EU climate and energy legislations	Renewable Energy Directive 2018 (RED II)	
	European Climate Law	REGULATION (EU) 2021/1119 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')
	Hydrogen and Decarbonized Gas Market Package	
Technical regulations	Directive for the Deployment of Alternative Fuels Infrastructure of 2014, and the follow-up Regulation proposal	
	ATEX	Equipment for potentially explosive atmospheres directive 2024/34/EU
	PED	Pressure equipment Directive 2014/68/EU
	GAR	Gas appliance regulation 2016/426/EU
Gas infrastructure and repurposing	Gas Directive for the common European Market	
	Proposal for a Regulation on guidelines for trans-European energy infrastructure amending Regulations (EC) No 715/2009, (EU) 2019/942 and (EU) 2019/943 and Directives 2009/73/EC and (EU) 2019/944, and	

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[142] 2023-03-01_ECH2A ROADMAP on Hydrogen Standardisation_ (3).pdf

System	Regulation	Summary
	repealing Regulation (EU) No 347/2013	
	The new Gas Directive proposal:	Proposal for a Directive on common rules for the internal markets in renewable and natural gases and hydrogen (revision of Directive (EU) 2019/692 amending Directive 2009/73/EC concerning common rules for the internal market in natural gas), COM/2021/803 final, especially: Article 19 (Cross-border coordination on gas quality) Article 20 (Hydrogen blends at interconnection points between Union Member States in the natural gas system)
	A Gas Regulation proposal	Proposal for a Regulation of the European Parliament and of the Council on the internal markets for renewable and natural gases and for hydrogen (recast) COM/2021/804 final (revision of Regulation (EC) No 715/2009)
	Gas Network Codes for interoperability and data exchange (NC INT) – including gas quality aspects	
Industrial - Feedstock	European Emission Trade System 2018/410 (ETS)	
	The 'Green Taxonomy' Regulation 2020/852	
	Industrial Emission Directive 2010/75/EU (IED)	
	Proposal for a Regulation establishing a carbon border adjustment mechanism COM (2021) 564 (CBAM)	
Industrial Heating	Gas Appliance Regulation 2016/426/EU (GAR)	
	Medium Combustion Plant Directive EU 2015/2193 (MCPD)	

System	Regulation	Summary
	Industrial Emission Directive 2010/75/EU (IED)	
	Machinery Directive 2006/42/EC	
	Pressure Equipment Directive 2014/68/EU	
	Eco-design Regulation EU/813 & 814/2013	
Mobility	Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure - Alternative Fuels Infrastructure Directive (AFID).	
	Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council (AFIR).	
	Sustainable and Smart Mobility Strategy	
	Regulations and standards are addressed by UNECE GTR (Global Technical Regulation). The scope of phase two of the GTR 13 (Global Technical Regulation concerning hydrogen and fuel cell vehicles) is dedicated to heavy duty vehicles (buses, long haul trucks).	
Railways	The Rolling Stock - Locomotive and Passenger Technical Specification for Interoperability, established in accordance with Chapter 2 of the	

System	Regulation	Summary
	Interoperability Directive and specifically its Article 10 on innovative solutions,	
	The Common Safety Methods, established in accordance with Article 6 of the Railway Safety Directive.	
Aviation	Proposal for a regulation of the European Parliament and of the Council on ensuring a level playing field for sustainable air transport (Refuel EU Aviation proposal)	

US

Table 12: Examples of regulatory activities by U.S. agencies relevant to hydrogen production, storage, and delivery[143]

System	Agency	Regulation	Summary
Production	EPA	40 CFR Part 98	Defines source categories and emissions thresholds for a hydrogen production facility
	DOE	IIJA Sec 40314 (Sec 822)	Directs DOE to develop a clean hydrogen production standard as a point of reference for specified BIL programs
Storage	FAA	14 CFR Part 420	Dictates the separation distance requirements for storage of liquid hydrogen and any incompatible energetic liquids
	FERC	18 CFR Part 157	Issuance of certificates of public convenience and necessity to prospective companies providing energy services or constructing and operating interstate natural gas pipelines and storage facilities.
	OSHA	29 CFR Part 1910	Dictates the safety of the structural components and operations of gaseous and liquid hydrogen storage and

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[143] DOE National Clean Hydrogen Strategy and Roadmap (energy.gov)

System	Agency	Regulation	Summary
			delivery
Transportation by Pipeline	BSEE	43 USC Part 29	Manages compliance programs governing oil, gas, and mineral operations on the Outer Continental Shelf (OCS)
	FERC	18 CFR Part 153, 157, and 284	Applications for authorization to construct, operate, or modify facilities used for the export or import of natural gas. Issuance of certificates of public convenience and necessity to prospective companies providing energy services or constructing and operating interstate natural gas pipelines and storage facilities. Regulation of natural gas transportation in interstate commerce.
	PHMSA	49 CFR Part 192, 195	Prescribes minimum safety requirements for pipeline facilities, pipelines, and the transportation of gas or hazardous liquids within the limits of the outer continental shelf
	USCG	33 CFR Part 154	Regulations for facilities transferring hazardous materials back and forth from a vessel to a facility
Transportation by Rail	PHMSA	49 USC 5117 and 49 CFR Part 172, 173, 174, 179, 180	Lists and classifies hazardous materials for transportation and prescribes the requirements for papers, markings, labeling, and vehicle placarding. Provides requirements for preparing hazardous materials for shipment as well inspection, testing, and other requirements for transportation of hazardous materials in or on rail cars, including construction & usage instructions for DOT-113A60W tank cars. Gives the authority to authorize a variance that is still at the same safety level, special permit is required to use an alternative fuel that does not have a safety standard
Transportation by Road	FHWA	23 CFR Part 924	Regulates highway safety which includes bridges, tunnels, and other associated elements
	FMCSA	49 CFR Part 356, 389, 397	Motor carrier routing requirements, general motor carrier safety regulations, and transportation of hazardous materials
	FTC	16 CFR Part 306	Describes the certification and posting of automotive fuel ratings in commerce

System	Agency	Regulation	Summary
Transportation by Waterways	PHMSA	49 CFR Part 172, 173, 177, 178, 180	Lists and classifies hazardous materials for transportation, and prescribes requirements for papers, markings, labeling, and vehicle placarding. Provides requirements for preparing hazardous materials for shipment, and inspection, testing, and other requirements for transportation of hazardous materials via public highways (including transportation containers)
	PHMSA	49 CFR Part 172, 173, 176, 178, 180	Lists and classifies hazardous materials for transportation and prescribes the requirements for papers, markings, labeling, and vehicle placarding. Provides requirements for preparing hazardous materials for shipment, as well inspection, testing, and other requirements for containers and other requirements for transportation by vessel
	USCG	33 CFR Part 154, 156 and 46, CFR Part 38, 150, 151, 153, 154	Regulations for transferring hazardous materials back and forth from a vessel to a facility. Transfer of oil or hazardous material on the navigable waters or contiguous zone of the U.S. Requirements for transportation of liquified or compressed flammable gases, including incompatibility of hazardous materials and rules for containers Regulations for ships and vessels carrying bulk cargo, including bulk liquified gases as cargo, residue, or vapor

Table 13: Examples of regulatory activities by U.S. agencies relevant to hydrogen end-use

System	Agency	Regulation	Summary
Auxiliary Power and Alternative Power Supply	FAA	14 CFR Part 23, 25, 27, 29, Subpart E	Requirements for electrical generating systems including auxiliary and backup power for airplanes and rotorcraft
	FHWA	49 CFR Part 390	Regulates additional equipment on commercial vehicles to ensure it does not reduce the overall safety of the vehicle

	FRA	49 CFR Part 229	Regulations for electrical systems, generators, protection from hazardous gases from exhaust and batteries, and crashworthiness for locomotives
	USCG	46 CFR Part 111	Regulations for power supply systems on ships
Chemical and Industrial Use	EPA	40 CFR Part 98	Requires reporting of GHG emissions due to combustion or use of products in a process
	OSHA	29 CFR Part 1910	Dictates the safety of the structural components and operations of gaseous and liquid hydrogen in terms of storage as well as delivery
Electricity Production	DOE	10 CFR Part 503, 504	Prohibits any new baseload powerplant without the ability to use coal or another alternative fuel as a primary energy source, and may prohibit existing powerplants from using petroleum or natural gas as a primary energy source
	FERC	18 CFR Part 292	Regulations regarding small power production and cogeneration facilities.
Import/Export Terminals	USCG	33 CFR Part 154, 156	Regulations for self-propelled vessels that contain bulk liquified gases as cargo, cargo residue, or vapor. Transfer of oil or hazardous materials on the navigable waters or contiguous zone of the U.S.
Residential & Commercial Heating	DOE	10 CFR Part 431	Provides regulation of commercial heaters, hot water boilers, and similar heating appliances
Use in Aviation	FAA	14 CFR Part 23, 25,26, 27, 29, 33	Provides requirements and airworthiness standards for airplanes and rotorcraft
Use in Consumer and Commercial Vehicles	FHWA	23 CFR Part 924	Regulates highway safety which includes bridges, tunnels, and other associated elements
	NHTSA	49 CFR 571	Provides Federal Motor Vehicle Safety Standards for motor vehicles and motor vehicle equipment
Use in Maritime	FTA	49 USC Chapter 53	Requirements for National Public Transportation Safety Plan for public transportation that receives federal funding
	USCG	46 CFR Parts 24–196	Regulation of vessel construction for both passenger and cargo applications as well as general fuel requirements based on the flash point of the fuel

Use in Rail	FRA	49 CFR Part 229, 238	Locomotive safety design and crashworthiness requirements, including safety requirements for passenger locomotives
	FTA	49 CFR Part 659, 674	Provides guidance for rail fixed guideway systems and the oversight of safety, including hazard management and safety and security plans and review. Mandates state safety oversight of fixed guideway public transportation systems

Japan

Table 14: Regulatory bodies of Japan[144]

Regulatory Body	Role
Industrial and Product Safety Policy Group, Commerce and Information Policy Bureau, Ministry of Economy, Trade, and Industry	Administers the High-Pressure Gas Safety Act.
Water and Air Environment Bureau, Ministry of Environment	Administers the Air Pollution Control Act, Noise Regulation Act, and the Vibration Regulation Act.
Ministry of Land, Infrastructure and Transport and Tourism	Administers the Road Vehicle Act, the Road Act and the Building Standards Act.
Fire and Disaster Management Agency, Ministry of Internal Affairs and Communications	Administers the Fire Services Act.
Each prefecture	Manages permission and notification under the High-Pressure Gas Safety Act.

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[144] Hydrogen law and regulation in Japan | CMS Expert Guides

Annexure 5: Development of ISO Standards

ISO (International Organization for Standardization) is a globally recognized, independent, non-governmental organization consisting of 168 national standards bodies. Its primary purpose is to facilitate collaboration among experts from various domains to exchange knowledge and create voluntary, consensus-based International Standards that are relevant to the market. These standards promote innovation, provide practical solutions to global challenges, and contribute to the overall improvement of processes, products, and services on a global scale. By promoting international collaboration and standardization, ISO plays a crucial role in improving quality, safety, and efficiency across various industries and sectors.

ISO standard development is guided by key principles that ensure effective and inclusive processes:

- **Addressing market needs:** ISO standards are developed in response to specific requests from industry or stakeholders who recognize a need for standardization. National members of ISO typically communicate these requests to initiate the development process.
- **Global expert input:** ISO standards are developed by groups of experts from around the world who are part of technical committees (TCs). These experts bring their expertise to the table and collectively determine the scope, definitions, and content of the standard.
- **Multi-stakeholder engagement:** TCs consist of industry experts, as well as representatives from consumer associations, academia, NGOs, and government bodies. This multi-stakeholder approach ensures that various perspectives are considered during the development of the standard.
- **Consensus-based approach:** ISO standards are developed through a consensus-based approach. All stakeholders could provide feedback and contribute to the process. Comments and input from different perspectives are considered to reach a consensus on the final standard.

By adhering to these principles, ISO ensures that its standards are relevant, credible, and widely accepted, promoting global harmonization, and facilitating international trade and cooperation.

Each ISO deliverable is initially assigned to a specific standards development track, which sets the time for the project. The tracks are typically 18, 24, or 36 months in duration, depending on the complexity and scope of the standard (as represented in

Figure 24[145]). Regardless of the chosen track, the development process for ISO standards follows a set of defined stages. These stages include:

- **<u>Proposal stage:</u>** The need for a new standard or the revision of an existing one is identified, and a proposal is submitted to ISO.
- **<u>Preparatory stage:</u>** A working group (WG) is set up by the parent committee to develop a working draft (WD). The working draft is circulated among the relevant TC members for their input and feedback. Consensus is sought, and multiple iterations may occur to refine the draft.
- **<u>Committee stage (optional):</u>** During the committee stage, the draft developed by the working group is shared with the members of the parent committee. The committee draft (CD) is circulated for review and comments using the Electronic Balloting Portal. Successive CDs may be circulated until consensus is reached on the technical content. This stage ensures that input and feedback from committee members are incorporated to refine the draft and achieve consensus.
- **<u>Enquiry stage:</u>** The Draft International Standard (DIS) is submitted to the ISO Central Secretariat by the Committee Manager. It is then distributed to all ISO members for a voting and commenting period of 12 weeks. Approval of the DIS requires a two-thirds majority of positive votes from the participating members of the Technical Committee/Subcommittee (TC/SC) and no more than one-quarter of the total votes cast being negative. If the DIS is approved without any technical changes, the project proceeds directly to publication. However, if technical changes are introduced during the voting and commenting process, the Final Draft International Standard (FDIS) stage becomes mandatory.
- **<u>Approval stage:</u>** This stage is automatically skipped if the Draft International Standard (DIS) has been approved without any technical changes. However, if technical changes are made to the draft following comments received during the DIS stage, the FDIS stage becomes mandatory as per the ISO/IEC Directives Part 1, 2.6.4. During the FDIS stage, the Committee Manager submits the FDIS to the ISO Central Secretariat (ISO/CS). The FDIS is then circulated to all ISO members for an 8-week voting period. The Submission Interface should be used to send the draft to ISO/CS. To be approved, the FDIS requires a two-thirds majority of positive votes from the participating members of the Technical Committee/Subcommittee (TC/SC), with no more than one-quarter of the total votes cast being negative.

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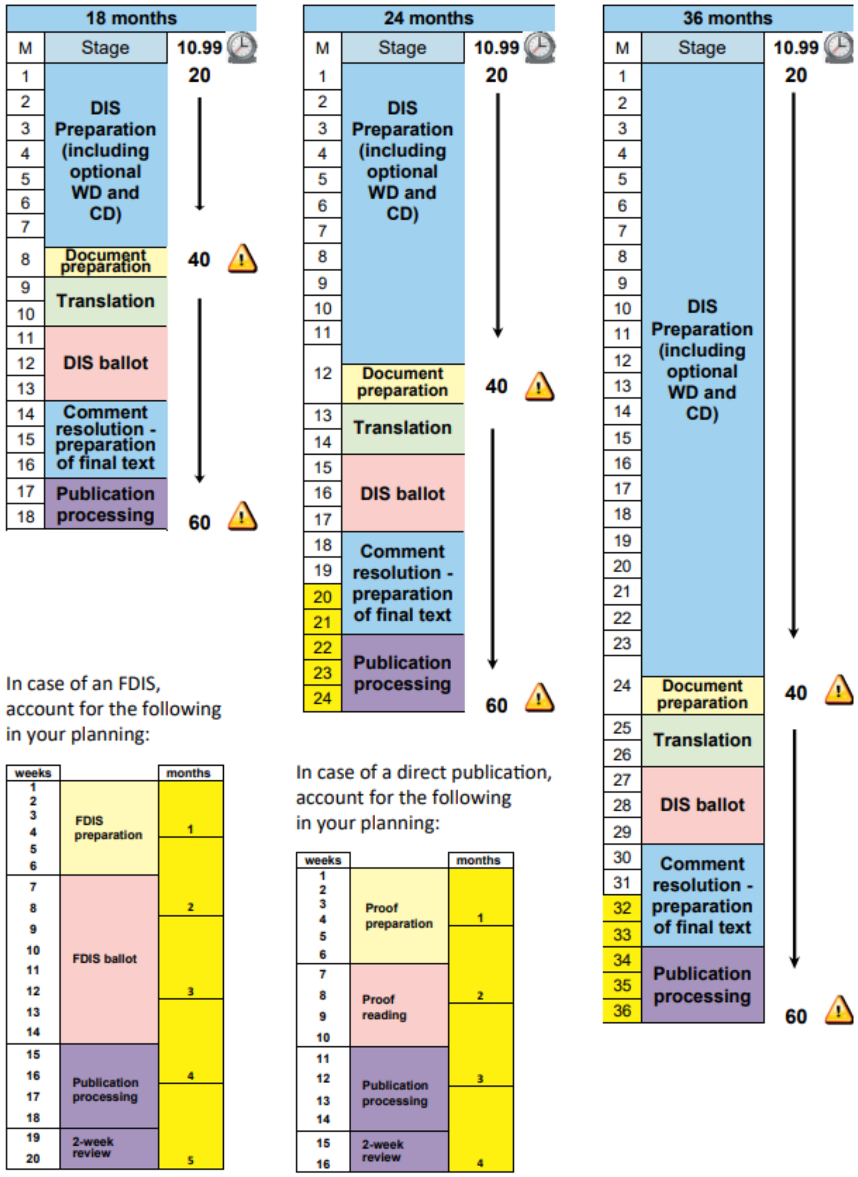
[145] Stages and Resources for Standards Development, ISO

- **Publication stage:** During this stage, the secretary submits the final document for publication using the Submission Interface. If the standard has successfully passed the Approval stage, the project manager may submit the project leader's responses to member body comments on the Final Draft International Standard (FDIS). At this point, only editorial corrections are permitted to the final text. The ISO Central Secretariat is responsible for publishing the document as an International Standard. Before the standard is officially published, committee managers and project leaders have a two-week sign-off period to review and provide their final approval.

Throughout these stages, input, and consensus from stakeholders, including industry experts, consumer groups, academia, and government representatives, are integral to the development process. This collaborative approach ensures that ISO standards reflect the diverse perspectives and needs of the global community.



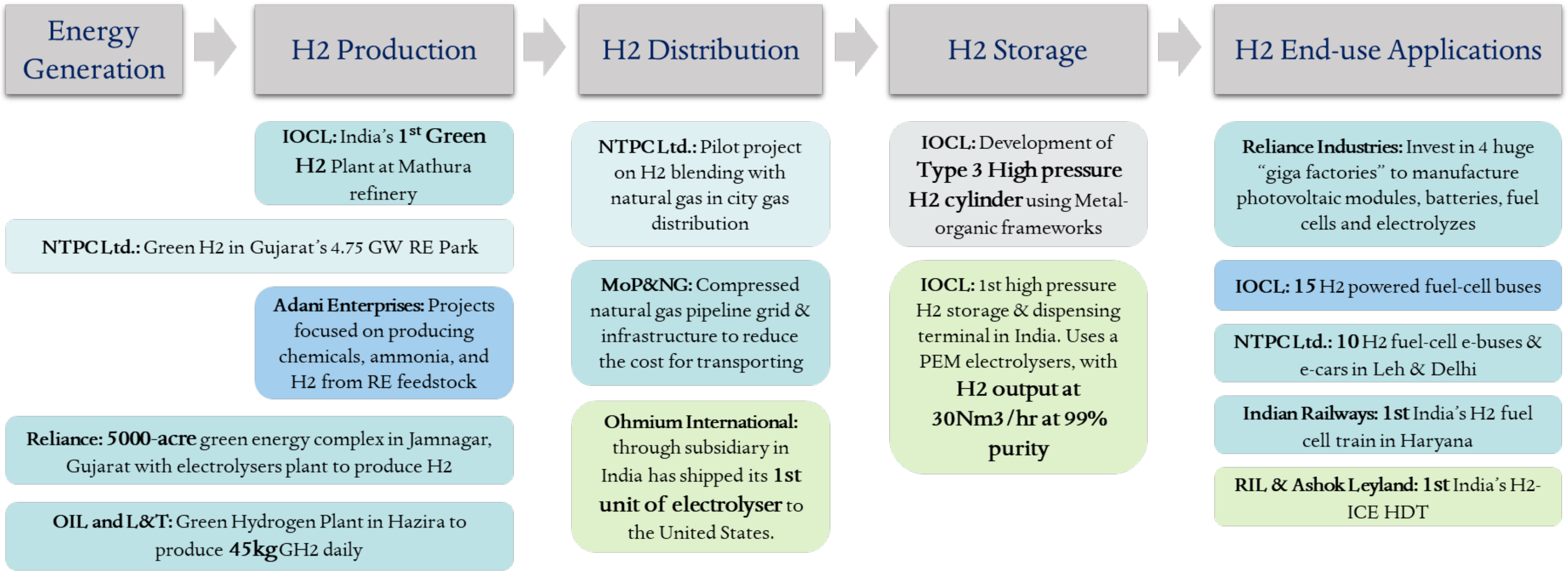
In case of an FDIS, account for the following in your planning:

In case of a direct publication, account for the following in your planning:

⏰	The clock starts when NP approved (at stage 10.99)
⚠	Months marked as limit dates. Missing these dates means action is needed to avoid eventual cancellation of the project
🟦	ISO Technical Committee time Document being developed in the relevant committee.
🟨	ISO/CS time Document preparation
🟩	ISO Member body time Document translation.
🟥	ISO Member body time Document circulated to all ISO member bodies for ballot.
🟪	ISO/CS & Committee Manager time Publication processing* *Translation, if needed, is done in parallel

Figure 24: Timeframe of projects defined by ISO

Annexure 6: Key Projects across the Hydrogen value chain



Energy Generation → H2 Production → H2 Distribution → H2 Storage → H2 End-use Applications

H2 Production

IOCL: India's 1st **Green H2** Plant at Mathura refinery

NTPC Ltd.: Green H2 in Gujarat's 4.75 GW RE Park

Adani Enterprises: Projects focused on producing chemicals, ammonia, and H2 from RE feedstock

Reliance: 5000-acre green energy complex in Jamnagar, Gujarat with electrolysers plant to produce H2

OIL and L&T: Green Hydrogen Plant in Hazira to produce **45kg** GH2 daily

H2 Distribution

NTPC Ltd.: Pilot project on H2 blending with natural gas in city gas distribution

MoP&NG: Compressed natural gas pipeline grid & infrastructure to reduce the cost for transporting

Ohmium International: through subsidiary in India has shipped its **1st unit of electrolyser** to the United States.

H2 Storage

IOCL: Development of **Type 3 High pressure H2 cylinder** using Metal-organic frameworks

IOCL: 1st high pressure H2 storage & dispensing terminal in India. Uses a PEM electrolysers, with **H2 output at 30Nm3/hr at 99% purity**

H2 End-use Applications

Reliance Industries: Invest in 4 huge "giga factories" to manufacture photovoltaic modules, batteries, fuel cells and electrolyzes

IOCL: 15 H2 powered fuel-cell buses

NTPC Ltd.: 10 H2 fuel-cell e-buses & e-cars in Leh & Delhi

Indian Railways: 1st India's H2 fuel cell train in Haryana

RIL & Ashok Leyland: 1st India's H2-ICE HDT

This list is not exhaustive

Planned | Announced | Signed MoU | Operational | Under Development

***Source**: Adapted from News Articles, compiled by Authors*

Annexure 7: Stakeholders involved in the Green Hydrogen Value Chain in India[146]

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
Energy & Feedstock	**Energy**	RE Generation	Regulations & Policy Planning	MNRE	1. **Formulating policies and programs:** Developing and implementing policies and programs for the promotion and development of renewable energy sources in India. 2. **Renewable energy capacity expansion:** Facilitating the expansion of renewable energy capacity in the country through the deployment of solar, wind, biomass, hydro, and other renewable energy technologies. 3. **Research and development:** Encouraging research and development activities in renewable energy technologies to promote innovation and improve efficiency.
				MoP	1. **Grid integration and off-take:** Ensuring smooth integration of renewable energy into the power grid and enabling the off-take of renewable energy by distribution companies and other stakeholders. 2. **Renewable purchase obligations (RPOs):** Implementing and enforcing Renewable Purchase Obligations (RPOs) to ensure that a specific percentage of power consumption is sourced from renewable energy. 3. **Policy coordination and regulatory support:** Coordinating with other ministries and regulatory bodies to create an enabling policy and regulatory environment for renewable energy growth.
				MoEFCC	1. **Environmental clearances:** Granting environmental clearances and approvals for renewable energy projects while ensuring compliance with environmental regulations and sustainable development principles. 2. **Climate change mitigation:** Contributing to climate change mitigation efforts through the promotion of renewable energy sources, which help reduce greenhouse gas emissions associated with conventional energy generation.
				MoF (DEA)	1. **Financial incentives and subsidies:** Designing and implementing financial incentives, subsidies, and tax benefits to promote investment in renewable energy projects and make them economically viable. 2. **Budget allocation and fund management:** Allocating budgets and managing funds for renewable energy initiatives, including schemes and programs aimed at promoting the adoption and deployment of renewable energy technologies.

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[146] Guidelines roads and powerlines, MOEF; CEA functions; Amendments in NPB, MoPNG; PIB; National Green Hydrogen Mission, MNRE, 2023

Stages of Value Chain	Category	Stakeholder	Role: Responsibility
		NITI Aayog	1. **Policy formulation and strategic planning:** Assisting in the formulation of policies and strategic planning for the development and promotion of renewable energy in India. 2. **Technology assessment and roadmap:** Conducting technology assessments and preparing roadmaps to guide the adoption of new and emerging renewable energy technologies, ensuring their effective integration into the energy sector. 3. **Stakeholder engagement and coordination:** Engaging with various stakeholders, including industry, academia, and civil society, to promote collaboration and coordination in the renewable energy sector.
	Execution (Standardization Bodies)	BIS	**Develop technical standards:** Developing and publishing national standards related to renewable energy technologies, including specifications for equipment, systems, and performance testing methods.
		CEA	**Grid integration and regulations:** Formulating technical standards and guidelines for grid integration of renewable energy projects, including grid codes, testing procedures, and requirements for interconnection.
	Others	National Institute of Solar Energy (NISE)	**Research and development:** Conducting research and development activities to support the development and deployment of solar energy technologies, including performance testing and evaluation of solar PV systems.
		National Institute of Wind Energy (NIWE)	**Research and development:** Conducting research and development activities to support the development and deployment of wind energy technologies, including wind resource assessment, turbine testing, and performance evaluation
		Solar Energy Corporation of India (SECI)	**Project development and implementation:** Establishing technical specifications and guidelines for the development, procurement, and implementation of solar energy projects, including standards for project design and installation.
		Central Power Research Institute (CPRI)	**Testing and certification:** Testing and certifying renewable energy equipment and systems to ensure compliance with technical standards and specifications, including performance testing, reliability assessment, and certification.
Electricity Transmis	Regulations & Policy Planning	MoP	1. **Policy Implementation and regulation:** Implement policies and regulations to ensure delivery of renewable energy for Green Hydrogen production at least possible costs. 2. **Project Implementation:** work with State Governments, Distribution

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
					Companies, Regulators, and technical institutions to align the electricity ecosystem for large scale Green Hydrogen production
				MoEFCC	**1. Policy Implementation and regulation:** A framework of policies and guidelines for managing roads and powerlines in important natural areas in the country. It includes guidelines for creating, designing, realigning, removing, restoring, and maintaining roads and powerlines, as well as measures to mitigate any negative impacts on the natural environment. The framework prioritizes the overall policy goal of protecting natural areas of importance in the country.
			Execution (Standardization Bodies)	BIS	**Develop technical standards:** Developing and publishing national standards related to renewable energy technologies, including specifications for equipment, systems, and performance testing methods.
				CEA	**Responsibilities:** Specify the grid standards for operation and maintenance of transmission lines, specify the conditions for installation of meters for transmission and supply of electricity, advise the central government, collect, and record the data, promote research in matters, advise the appropriate government and the appropriate commission on technical matters.
		Electricity Distribution	Regulations & Policy Planning	MoP	**1. Policy Implementation and regulation:** Implement policies and regulations to ensure delivery of renewable energy for Green Hydrogen production at least possible costs. **2. Project Implementation:** work with State Governments, Distribution Companies, Regulators, and technical institutions to align the electricity ecosystem for large scale Green Hydrogen production
				MoEFCC	**1. Policy Implementation and regulation:** A framework of policies and guidelines for managing roads and powerlines in important natural areas in the country. It includes guidelines for creating, designing, realigning, removing, restoring, and maintaining roads and powerlines, as well as measures to mitigate any negative impacts on the natural environment. The framework prioritizes the overall policy goal of protecting natural areas of importance in the country.
				BIS	**Develop technical standards:** Developing and publishing national standards related to renewable energy technologies, including

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
			Execution (Standardization Bodies)		specifications for equipment, systems, and performance testing methods.
				CEA	**Responsibilities:** Advise the central government, collect, and record the data, promote research in matters, advise the appropriate government and the appropriate commission on technical matters.
			Industry Players	State Discoms	**Function:** Operate the local electricity distribution infrastructure, including substations, transformers, and power lines. Also, responsible for metering and billing customers for their electricity usage, managing customer service, and maintaining the distribution network to ensure that it is safe and dependable.
		Waste Biomass	Regulations & Policy Planning	MoPNG	**Responsibility:** With respect to Biomass, it notifies oil companies to sell Ethanol Blended Petrol up to a certain level, Amend or prepare National Policy related with Biofuels.
			Execution (Standardization Bodies)	BIS	**Develop technical standards:** Plays a role in regulating and standardizing the use of waste biomass at National Level. It also develops and maintains standards for various products and processes related to waste biomass, such as biofuels, biogas, and biomass stoves.
			Industry Players	Biomass Suppliers	**Function:** Supply the Biomass in loose form filled in the carriage vehicles (closed/covered containers), unload in RE Generation site, ensure it is made of agro residue, adhere to the technical requirements indicated by plant operator.
Hydrogen Production	**Converter + Electrolyser**	H2 Generators	Regulations & Policy Planning	MoST (DST & DSIR)	**Technological research and development:** Promoting research and development in the field of electrolysis technologies for hydrogen generation, including the development of advanced materials, efficient electrolysers, and innovative processes.
				MoPNG	**Infrastructure development and integration:** Facilitating the development of necessary infrastructure, including hydrogen storage and distribution systems, to support the integration and utilization of hydrogen generated through electrolysis.
				MoHIPE	**Industry collaboration and support:** Collaborating with relevant industries and stakeholders to promote the adoption of hydrogen generators for electrolysis, supporting the establishment of manufacturing capabilities, and fostering industry-academia partnerships.
				PNGRB	**Regulatory body:** Regulating and overseeing the activities related to the production, distribution, and marketing of hydrogen, including setting

Stages of Value Chain	Category	Stakeholder	Role: Responsibility
			guidelines and standards for hydrogen generators, and ensuring compliance with regulatory requirements.
		CPCB	**Environmental standards and monitoring:** Establishing and enforcing environmental standards and regulations for the operation of hydrogen generators, including emissions monitoring, pollution control, and environmental impact assessments.
	Execution (Standardization Bodies)	BIS	**Technical standards development:** Developing and publishing technical standards and specifications for electrolysers used in hydrogen generation, ensuring quality, safety, and performance compliance.
	Others	Central Electrochemical Research Institute (CECRI)	**Electrolyser research and development:** Conducting research and development activities to advance electrolyser technologies, including efficiency enhancement, cost reduction, and material improvements, to support the deployment of efficient and reliable electrolysers for hydrogen generation.
		Indian Institute of Technology (IIT)	**Electrolyser technology innovation:** Conducting research, innovation, and development of novel electrolyser technologies, exploring new materials, system designs, and process optimization for improved performance and efficiency in hydrogen generation.
		Council of Scientific and Industrial Research (CSIR)	**Electrolyser technology development:** Undertaking R&D activities focused on electrolyser technologies, including advancements in materials, catalysts, and manufacturing processes, to improve the efficiency, durability, and cost-effectiveness of electrolysers for hydrogen generation.
		National Accreditation Board for Certification Bodies (NABCB)	**Certification of electrolysers:** Accrediting and certifying bodies to evaluate and certify electrolysers for conformity with technical standards, ensuring compliance with quality, performance, and safety requirements.
		National Physical Laboratory (NPL)	**Calibration and testing of electrolysers:** Providing calibration services and testing facilities to assess the performance, accuracy, and reliability of electrolysers used in hydrogen generation, ensuring adherence to technical specifications and standards.
		Central Power Research Institute (CPRI)	**Performance testing and certification:** Conducting performance testing and certification of electrolysers to verify their technical specifications, efficiency, and compliance with safety standards, ensuring reliability and adherence to quality requirements.

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
	Balance of systems	Water Quality	Regulations & Policy Planning	MoST (DST, DSIR, DBT)	**Research and development:** Promoting research and development activities related to water treatment technologies and processes for electrolysis, including the development of efficient and sustainable methods to purify water for use in electrolysis.
				Ministry of Jal Shakti	**Water resource management:** Ensuring the availability and sustainable management of water resources for electrolysis processes, considering the water requirements, allocation, and conservation measures.
				CPCB	**Water quality monitoring and regulation:** Monitoring and regulating the quality of water used in electrolysis processes, conducting water sampling, analysis, and setting water quality standards to ensure compliance and prevent environmental pollution.
			Execution (Standardization Bodies)	BIS	**Technical standards development:** Developing and publishing technical standards and specifications for water quality in electrolysers used for hydrogen generation, ensuring compliance with water purity, safety, and performance requirements.
			Others	Central Electrochemical Research Institute (CECRI)	**Electrolyser water treatment research:** Conducting research and development activities to optimize water treatment technologies and processes for electrolysers, ensuring the removal of impurities, maintenance of water quality, and prevention of scale and fouling.
				Indian Institute of Technology (IIT)	**Electrolyser water treatment innovation:** Conducting innovative research and development in water treatment for electrolysers, exploring advanced purification techniques, filtration methods, and sustainable approaches to ensure the availability of high-quality water for electrolysis.
				National Accreditation Board for Certification Bodies (NABCB)	**Certification of water treatment systems:** Accrediting and certifying bodies to evaluate and certify water treatment systems for electrolysers, ensuring compliance with technical standards, performance requirements, and quality assurance measures for maintaining water quality.
				National Environmental Engineering Research Institute (NEERI)	**Water quality assessment and research:** Conducting research, assessment, and monitoring of water quality for electrolysers, analyzing the impact of electrolysis operations on water resources, and suggesting mitigation measures to maintain water quality standards.
		Electrical	Regulations & Policy Planning	MoST (DST)	**Research and development:** Promoting research and development activities related to electrical installations for electrolysis, including advancements in power electronics, electrical safety standards, and

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
					system integration to enhance the efficiency, reliability, and safety of electrolysis systems.
				MoF	**Financial incentives and subsidies:** Designing and implementing financial incentives, subsidies, and tax benefits to promote investment in electrical infrastructure for electrolysis, making it economically viable and attractive for stakeholders.
				CEA	**Electrical system planning and regulation:** Regulating and overseeing the electrical system planning, grid connectivity, and technical standards for electrolysis systems, ensuring compliance with safety requirements, power quality standards, and grid code regulations.
			Execution (Standardization Bodies)	BIS	**Technical standards development:** Developing and publishing technical standards and specifications for electrical installations in electrolysers used for hydrogen generation, ensuring compliance with safety, performance, and electrical code requirements.
			Others	Central Power Research Institute (CPRI)	**Electrical system research and testing:** Conducting research, testing, and evaluation of electrical components and systems used in electrolysers, ensuring compliance with technical standards, safety regulations, and power quality requirements.
				Indian Institute of Technology (IIT)	**Electrolyser electrical system innovation:** Conducting research and development activities to improve electrical system designs, power electronics, and control mechanisms for electrolysers, aiming to enhance efficiency, reliability, and system integration.
				National Accreditation Board for Certification Bodies (NABCB)	**Certification of electrical installations:** Accrediting and certifying bodies to evaluate and certify the compliance of electrical installations for electrolysers with technical standards, safety regulations, and electrical code requirements, ensuring adherence to quality and safety standards.
	Gasifier	H2 Generators	Regulations & Policy Planning	PNGRB	**Responsibility:** It gives approval for blending level with PNG
				CPCB	**Development of classification of Industry:** Classification of Industrial Sectors (Red, Orange, Green and White Categories).
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for hydrogen generators, such as specifications for safety, performance, and environmental impact. For Manufacturer, it also provides certification services for hydrogen generators, which includes testing and inspection to ensure that they meet the required standards.

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
		Gasifiers	Regulations & Policy Planning	PNGRB	**Responsibility:** Prepares Technical Standards and Specifications including Safety Standards for Petroleum Refineries and Gas Processing Plants.
				CPCB	**Development of classification of Industry:** Make Odor related classification of Industrial Sectors (Red, Orange, Green and White Categories). Odor to be added in Classification.
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for hydrogen generators, such as specifications for safety, performance, and environmental impact. For Manufacturer, it also provides certification services for Gasifiers, which includes testing and inspection to ensure that they meet the required standards.
Transformation	**Pure H2**	Gaseous (compressed)	Regulations & Policy Planning	CPCB	**Development of classification of Industry:** Classification of Industrial Sectors (Red, Orange, Green and White Categories).
			Execution (Standardization Bodies)	BIS	**Technical standards development:** develops and maintains standards for hydrogen transformation into gaseous (compressed) form, such as specifications for safety, performance, and environmental impact.
			Industry Players	R&D Institutes	**Role:** Develop systems that can store large amounts of hydrogen at low temperatures, high pressure without contamination, pumps that can pump compressed hydrogen at low temperature, reduce the cost of cryogenic equipment
		Cryogenic	Regulations & Policy Planning	CPCB	**Development of classification of Industry:** Classification of Industrial Sectors (Red, Orange, Green and White Categories).
			Execution (Standardization Bodies)	BIS	**Technical standards development:** develops and maintains standards for hydrogen transformation into cryogenic form, such as specifications for safety, performance, and environmental impact.
			Industry Players	R&D Institutes	**Role:** Develop system that can store large amounts of hydrogen at low temperatures, pumps that can pump liquid hydrogen at low temperature, reduce the cost of cryogenic equipment
		Solid (Metal Hydrides)	Regulations & Policy Planning	CPCB	**Development of classification of Industry:** Classification of Industrial Sectors (Red, Orange, Green and White Categories).
			Execution (Standardization Bodies)	BIS	**Technical standards development:** develops and maintains standards for hydrogen transformation into solid (metal hydrides) form, such as specifications for safety, performance, and environmental impact.

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
			Industry Players	R&D Institutes	**Role:** Work on improving hydrogenation properties of metal hydrides, hydrogen-storage capacity, kinetics, cyclic behavior, toxicity, pressure, and thermal response properties
	H2 Derivatives	Green Methanol	Regulations & Policy Planning	MoC&F	**Responsibility:** Encourage the use of locally produced, environmentally friendly ammonia fertilizers to gradually replace imported fertilizers and the fossil fuel-based feedstocks (natural gas and ammonia) used to make fertilizers, enable its designated entities to purchase green ammonia to generate mass demand.
				CPCB	**Standard Operating Procedure Development:** CPCB to prepared Standard Operating Procedure for Hazardous Gas,
			Execution (Standardization Bodies)	BIS	**Technical standards development:** develops and maintains standards for Green Methanol H2 Derivative, such as specifications for safety, performance, and environmental impact.
			Industry Players	Petrochemical Companies	**Role:** Make agreements and MoU on green methanol production with other stakeholders, develop ultra-efficient catalysis to mass-produce green methanol, Provide green methanol at sustainable prices, opt for the feasible transportation strategies of produced H2 Derivative, identify industrial clusters in need of H2 derivative and develop own facilities to ensure minimal interfere from outside
		Green Ammonia	Regulations & Policy Planning	MoC&F	**Responsibility:** Encourage the use of locally produced, environmentally friendly ammonia fertilizers to gradually replace imported fertilizers and the fossil fuel-based feedstocks (natural gas and ammonia) used to make fertilizers, enable its designated entities to purchase green ammonia to generate mass demand.
				CPCB	**Standard Operating Procedure Development:** CPCB to prepared Standard Operating Procedure for Hazardous Gas,
			Execution (Standardization Bodies)	BIS	**Technical standards development:** develops and maintains standards for Green Ammonia H2 Derivative, such as specifications for safety, performance, and environmental impact.
			Industry Players	Petrochemical Companies	**Role:** Make agreements and MoU on green methanol production with other stakeholders, develop ultra-efficient catalysis to mass-produce green Ammonia, Provide green Ammonia at sustainable prices, opt for the feasible transportation strategies of produced H2 Derivative, identify industrial clusters in need of H2 derivative and develop own facilities to ensure minimal interfere from outside.

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
Storage & Transport	Storage (UG/OG)	Gaseous	Regulations & Policy Planning	PNGRB	**Responsibility:** Prepares Technical Standards and Specifications including Safety, Safety Standards for Gas Storage, Handling and Bottling Facilities
				MoF (DEA)	**Responsibility:** Updates Harmonized Master List of Infrastructure Sub-sectors
				PESO	**Role and Responsibility:** 1. Grant of approval, licenses for manufacture of explosives, authorization of explosives, storage of explosives, import/export of explosives, transport of explosives by road and packaging for explosives 2. Carries out inspection and audit of the new premises for verification/endorsement at the time of grant of licenses/approvals and periodic inspections of the licensed/approved premises. 3. Approval of manufacturing units of cylinders, valves & LPG regulators, and designs of these equipment's 4. Regularly undertakes safety audits of gas installations, filling plants, CNG fueling stations, cylinder, valve, and regulator manufacturing units, etc.
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient storage of hydrogen in gaseous form, including the design, construction, and operation of hydrogen storage systems, as well as the safety and environmental impact, BIS also provides certification services for hydrogen storage systems, which includes testing and inspection to ensure that these systems meet the required standards.
				PESO	**Responsibility:** Scrutiny and approval of site, layout, and construction plans for Storage installations for compressed gases in pressure vessels, Explosives storage premises, storage sheds, Storage sheds for filled gas cylinders,
		Cryogenic	Regulations & Policy Planning	PNGRB	**Responsibility:** Prepares Technical Standards and Specifications including Safety, Safety Standards for Gas Storage, Handling and Bottling Facilities
				MoF (DEA)	**Responsibility:** Updates Harmonized Master List of Infrastructure Sub-sectors
				PESO	**Role and Responsibility:** 1. Grant of approval, licenses for manufacture of explosives,

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
					authorization of explosives, storage of explosives, import/export of explosives, transport of explosives by road and packaging for explosives 2. Carries out inspection and audit of the new premises for verification/endorsement at the time of grant of licenses/approvals and periodic inspections of the licensed/approved premises. 3. Approval of manufacturing units of cylinders, valves & LPG regulators, and designs of these equipment's 4. Regularly undertakes safety audits of gas installations, filling plants, CNG fueling stations, cylinder, valve, and regulator manufacturing units, etc.
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient storage of hydrogen in gaseous form, including the design, construction, and operation of hydrogen storage systems, as well as the safety and environmental impact, BIS also provides certification services for hydrogen storage systems, which includes testing and inspection to ensure that these systems meet the required standards.
				PESO	**Responsibility:** Scrutiny and approval of site, layout, and construction plans for Storage installations for compressed gases in pressure vessels, Explosives storage premises, storage sheds, Storage sheds for filled gas cylinders,
		Solid	Regulations & Policy Planning	PNGRB	**Responsibility:** Prepares Technical Standards and Specifications including Safety, Safety Standards for Gas Storage, Handling and Bottling Facilities
				MoF (DEA)	**Responsibility:** Updates Harmonized Master List of Infrastructure Sub-sectors
				PESO	**Role and Responsibility:** 1. Grant of approval, licenses for manufacture of explosives, authorization of explosives, storage of explosives, import/export of explosives, transport of explosives by road and packaging for explosives 2. Carries out inspection and audit of the new premises for verification/endorsement at the time of grant of licenses/approvals and periodic inspections of the licensed/approved premises. 3. Approval of manufacturing units of cylinders, valves & LPG regulators, and designs of these equipment's 4. Regularly undertakes safety audits of gas installations, filling plants, CNG fueling stations, cylinder, valve, and regulator manufacturing units, etc.

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient storage of hydrogen in gaseous form, including the design, construction, and operation of hydrogen storage systems, as well as the safety and environmental impact, BIS also provides certification services for hydrogen storage systems, which includes testing and inspection to ensure that these systems meet the required standards.
				PESO	**Responsibility:** Scrutiny and approval of site, layout, and construction plans for Storage installations for compressed gases in pressure vessels, Explosives storage premises, storage sheds, Storage sheds for filled gas cylinders,
	Transport	By PIPELINE	Regulations & Policy Planning	MoPNG	**Role and Responsibility:** Encourage the use of green hydrogen in refineries and the distribution of city gas by both public and private sector organizations. Additionally, MoPNG will assist the Petroleum and Natural Gas Regulatory Board (PNGRB) in developing and facilitating regulations.
				MoF (DEA)	**Responsibility:** Updates Harmonized Master List of Infrastructure Sub-sectors
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient transport of hydrogen, including the design, construction, and operation of hydrogen transport systems, as well as the safety and environmental impact, BIS also provides certification services for hydrogen transport systems, which includes testing and inspection to ensure that these systems meet the required standards
				PESO	**Responsibility:** Scrutiny and approval of proposals of design, construction and laying of Petroleum Pipelines.
		By RAIL	Regulations & Policy Planning	MoRailways	**Responsibility:** Update list of Hazardous Commodities covered by CONCOR India (a Navratna PSU under MoRailways)
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient transport of hydrogen, including the design, construction, and operation of hydrogen transport systems, as well as the safety and environmental impact, BIS also provides certification services for hydrogen transport systems, which includes testing and inspection to ensure that these systems meet the required standards

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
				PESO	**Roles and Responsibility:** 1. Scrutiny and approval of design and construction of Explosives vans, Portable Explosives Magazines, Bulk mixing, and Delivery vehicle for site manufacture of explosives, vehicles for transport of compressed gases in pressure vessels and petroleum tank lorries. 2. Scrutiny and appraisal of proposals to import, export and transport explosives for grant of license thereof.
		By SEA	Regulations & Policy Planning	MoPSW	**Responsibility:** Enabling the development of the necessary infrastructure, such as storage bunkers, port operations equipment, and refueling facilities, and establishing India's export capabilities for green hydrogen and its derivatives. drive the use of hydrogen and its derivatives (ammonia and methanol) as ship propulsion fuel, and work to establish India as a hub for green hydrogen and derivative refueling.
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient transport of hydrogen, including the design, construction, and operation of hydrogen transport systems, as well as the safety and environmental impact, BIS also provides certification services for hydrogen transport systems, which includes testing and inspection to ensure that these systems meet the required standards
				PESO	**Roles and Responsibility:** 1. Scrutiny and approval of design and construction of Explosives vans, Portable Explosives Magazines, Bulk mixing, and Delivery vehicle for site manufacture of explosives, vehicles for transport of compressed gases in pressure vessels and petroleum tank lorries. 2. Scrutiny and appraisal of proposals to import, export and transport explosives for grant of license thereof.
		By ROAD	Regulations & Policy Planning	MoRTH	**Responsibility:** Promote the use of green hydrogen in the transportation industry, specifically for heavy-duty commercial vehicles and long-distance travel, by implementing regulations, standards, and codes. Additionally, technology development will be encouraged through pilot projects, testing facilities, and infrastructure support to facilitate the widespread adoption of green hydrogen in transportation.
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient transport of hydrogen, including the design, construction, and operation of hydrogen transport systems, as well as the safety and environmental impact, BIS also provides certification services for hydrogen transport systems, which

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
					includes testing and inspection to ensure that these systems meet the required standards
				PESO	**Roles and Responsibility:** 1. Scrutiny and approval of design and construction of Explosives vans, Portable Explosives Magazines, Bulk mixing, and Delivery vehicle for site manufacture of explosives, vehicles for transport of compressed gases in pressure vessels and petroleum tank lorries. 2. Scrutiny and appraisal of proposals to import, export and transport explosives for grant of license thereof.
End-use Application	**End use Conversions**	Regasification	Regulations & Policy Planning	PNGRB	**Responsibility:** Prepare Technical Standards and Specifications including Safety Standards for Petroleum Refineries and Gas Processing Plants
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
			Industry Players	Industries using GH2	**Responsibility:** Ensure regasification plant is designed to withstand the high pressure of gas, ensuring that the regasification plant is in an area that is well-ventilated, and ensuring that the regasification plant is equipped with safety features such as emergency shutdown systems
		Cracking	Regulations & Policy Planning	PNGRB	**Responsibility:** Prepares Technical Standards and Specifications including Safety Standards for Petroleum Refineries and Gas Processing Plants
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
			Industry Players	Ammonia Industry	**Responsibility:** Ensure cracking plant is designed to withstand the high pressure of gas, ensuring that the cracking plant is in an area that is well-ventilated, and ensuring that the cracking plant is equipped with safety features such as emergency shutdown systems
	Industry	Chemica	Regulations & Policy Planning	PNGRB	**Responsibility:** Prepares Technical Standards and Specifications including Safety Standards for Petroleum Refineries and Gas Processing Plants

Stages of Value Chain				Category	Stakeholder	Role: Responsibility
					MoEFCC	**Development of the criteria for categorization of industrial sectors:** MoEFCC develops the criteria based on the Pollution Index - Chemical comes in the red category.
					MoRTH	**Responsibility:** promote the use of green hydrogen in the transportation industry, specifically for heavy-duty commercial vehicles and long-distance travel, by implementing regulations, standards, and codes. Additionally, technology development will be encouraged through pilot projects, testing facilities, and infrastructure support to facilitate the widespread adoption of green hydrogen in transportation.
					MoC&I	Encourage investments, facilitate ease of doing business, and implement specific industrial and trade policy measures for low-cost production and trade of hydrogen and its derivatives, Undertake dialogue to facilitate global trade of hydrogen and its derivatives, formulate necessary policies and programmes for development of an ecosystem for manufacturing of specialized equipment
				Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
				Industry Players	Chemical Industries	**Responsibility:** Design safety features into hydrogen systems, Training work force in safe hydrogen handling practices, testing of hydrogen systems such as tank leak tests and garage leak simulations, and testing the air in the space from the outside before entering, other measures include testing the air in the space continuously during work operation, determining if an entry permit is required, Make sure rescue procedures, personnel, and equipment are in place
			Refinery	Regulations & Policy Planning	PNGRB	**Responsibility:** Prepares Technical Standards and Specifications including Safety Standards for Petroleum Refineries and Gas Processing Plants
					MoEFCC	**Development of the criteria for categorization of industrial sectors:** MoEFCC develops the criteria based on the Pollution Index - Refinery comes in the red category.
					MoRTH	**Responsibility:** Promote the use of green hydrogen in the transportation industry, specifically for heavy-duty commercial vehicles and long-distance travel, by implementing regulations, standards, and codes. Additionally, technology development will be encouraged through pilot projects, testing facilities, and infrastructure support to facilitate the widespread adoption of green hydrogen in transportation.

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
				MoC&I	Encourage investments, facilitate ease of doing business, and implement specific industrial and trade policy measures for low-cost production and trade of hydrogen and its derivatives, Undertake dialogue to facilitate global trade of hydrogen and its derivatives, formulate necessary policies and programmes for development of an ecosystem for manufacturing of specialized equipment
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
			Industry Players	Refineries	**Responsibility:** Design safety features into hydrogen systems, Training work force in safe hydrogen handling practices, testing of hydrogen systems such as tank leak tests and garage leak simulations, and testing the air in the space from the outside before entering, other measures include testing the air in the space continuously during work operation, determining if an entry permit is required, Make sure rescue procedures, personnel, and equipment are in place
		Iron & steel	Regulations & Policy Planning	MoS	**Responsibility:** drive green hydrogen adoption in the steel industry, find and support green hydrogen pilot projects for use in steel production, and implement policy changes to hasten the commercial production of green steel.
				MoEFCC	**Development of the criteria for categorization of industrial sectors:** MoEFCC develops the criteria based on the Pollution Index - Iron & steel comes in the red category.
				MoRTH	**Responsibility:** promote the use of green hydrogen in the transportation industry, specifically for heavy-duty commercial vehicles and long-distance travel, by implementing regulations, standards, and codes. Additionally, technology development will be encouraged through pilot projects, testing facilities, and infrastructure support to facilitate the widespread adoption of green hydrogen in transportation.
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
			Industry Players	Iron & Steel Industry	**Responsibility:** Design safety features into hydrogen systems, Training work force in safe hydrogen handling practices, testing of hydrogen systems such as tank leak tests and garage leak simulations, and testing the air in the space from the outside before entering, other measures include testing the air in the space continuously during work operation, determining if an entry permit is required, Make sure rescue procedures, personnel, and equipment are in place
		Cement	Regulations & Policy Planning	MoC&I	**Responsibility:** Develop essential policies and programs to establish an ecosystem to produce specialized equipment required in the green hydrogen value chain.
				MoEFCC	**Development of the criteria of categorization of industrial sectors:** MoEFCC develops the criteria based on the Pollution Index - Cement comes in the red category.
				MoRTH	**Responsibility:** Promote the use of green hydrogen in the transportation industry, specifically for heavy-duty commercial vehicles and long-distance travel, by implementing regulations, standards, and codes. Additionally, technology development will be encouraged through pilot projects, testing facilities, and infrastructure support to facilitate the widespread adoption of green hydrogen in transportation.
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
			Industry Players	Cement Industry	**Responsibility:** Design safety features into hydrogen systems, Training work force in safe hydrogen handling practices, testing of hydrogen systems such as tank leak tests and garage leak simulations, and testing the air in the space from the outside before entering, other measures include testing the air in the space continuously during work operation, determining if an entry permit is required, Make sure rescue procedures, personnel, and equipment are in place
	Mobility	Combustion	Regulations & Policy Planning	MoRTH	**Responsibility:** Promote technology development for the adoption of green hydrogen in the transportation sector through testing facilities, pilot projects, and support for infrastructure development. Enable adoption of green hydrogen in the transport sector through regulations, standards, and codes, primarily for heavy commercial vehicles and long-haul operations.

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
			Industry Players	ICE OEMs	**Responsibility:** Follow barrier concept (double-walled construction for non-welded connections on lines carrying H2 in the interior of the vehicle), provisions of shutoff and safety valves, mechanical over-dimensioning of components exposed to pressure, development of specific electrics and electronics for use with hydrogen - based on IEC61508
		Fuel Cell	Regulations & Policy Planning	MoRTH	**Role:** Assist in the gradual implementation of Fuel Cell Electric Vehicle (FCEV) buses and trucks through a pilot program, Investigate the feasibility of incorporating Green Hydrogen-based Methanol/Ethanol and other synthetic fuels derived from Green Hydrogen into automotive fuels through blending.
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
				ARAI	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
			Industry Players	EV/FCEV/Battery OEMs	**Responsibility:** Manage ignition source, mechanical integrity and reactive chemistry, leaks and flame detection systems, ventilation and flaring, inventory management and facility spacing and human factors
		Maritime	Regulations & Policy Planning	MEA	**Responsibility:** making efforts to establish partnerships with other nations and organizations, enable collaboration between government agencies, institutions, and industries, both domestically and internationally, to support the development of green hydrogen technology.
				MoPSW	**Responsibility:** Establishing India's export capabilities for green hydrogen and its derivates, Facilitate development of the required infrastructure including storage bunkers, port operations equipment, and refueling facilities,
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
					the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
			Industry Players	E/FC-Vessel/Ship/ Battery OEMs	**Responsibility:** Conduct testing of hydrogen systems—tank leak tests, garage leak simulations, and hydrogen tank drop tests, training in safe hydrogen handling practices
		Aviation	Regulations & Policy Planning	MEA	**Responsibility:** Making efforts to establish partnerships with other nations and organizations, enable collaboration between government agencies, institutions, and industries, both domestically and internationally, to support the development of green hydrogen technology.
				MoCA	**Responsibility:** Encourage usage of Sustainable Aviation Fuel, Instruct to prepare roadmap for achieving 100% Renewable Energy, Taking Initiatives pertaining to Use of Airspace, Performance Based Navigation, Continuous Descent Operations
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
			Industry Players	E/FC Jets	**Responsibility:** Conduct testing of hydrogen systems—tank leak tests, garage leak simulations, and hydrogen tank drop tests, training in safe hydrogen handling practices
	Buildings	Heating	Execution (Standardization Bodies)	BEE	**Functions:** 1. Create and support pilot projects and demonstrations and oversee their implementation. 2. Encourage the utilization of energy-efficient processes, equipment, devices, and systems. 3. Establish testing and certification procedures and promote the use of testing facilities. 4. Nodal Authority for accreditation of agencies for the monitoring, verification and certification for Green Hydrogen production projects
			Industry Players	Service Providers	**Responsibility:** Conduct testing of hydrogen systems—tank leak tests, garage leak simulations, and hydrogen tank drop tests, training in safe hydrogen handling practices

Stages of Value Chain			Category	Stakeholder	Role: Responsibility
	Power Generation	Combustion	Regulations & Policy Planning	MoP	**1. Policy Implementation and regulation:** Implement policies and regulations to ensure delivery of renewable energy for Green Hydrogen production at least possible costs. **2. Project Implementation:** Work with State Governments, Distribution Companies, Regulators, and technical institutions to align the electricity ecosystem for large scale Green Hydrogen production
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
				CEA	**Responsibilities:** Advise the Central Government, collect and record the data, promote research in matters, advise the Appropriate Government and the Appropriate Commission on technical matters
			Industry Players		**Responsibility:** Conduct testing of hydrogen systems—tank leak tests, garage leak simulations, and hydrogen tank drop tests, training in safe hydrogen handling practices
		Fuel Cell	Regulations & Policy Planning	MoP	**1. Policy Implementation and regulation:** Implement policies and regulations to ensure delivery of renewable energy for Green Hydrogen production at least possible costs. **2. Project Implementation:** Work with State Governments, Distribution Companies, Regulators, and technical institutions to align the electricity ecosystem for large scale Green Hydrogen production
			Execution (Standardization Bodies)	BIS	**Technical standards development & certifications:** Develops and maintains standards for the safe and efficient use of hydrogen, including the design, construction, and operation of hydrogen use systems, as well as the safety and environmental impact,
				CEA	**Responsibilities:** advise the Central Government, collect, and record the data, promote research in matters, advise the Appropriate Government and the Appropriate Commission on technical matters
			Industry Players	IOCL	**Responsibility:** Conduct testing of hydrogen systems—tank leak tests, garage leak simulations, and hydrogen tank drop tests, training in safe hydrogen handling practices

Annexure 8: Regulatory acts existing in India

- **Electricity Act, 2003[147]:** The Electricity Act of 2003 is an important legislation in India that governs the generation, transmission, distribution, and trading of electricity in the country. It introduced significant reforms in the power sector and aimed to promote competition, efficiency, and sustainability in the electricity industry. The Act facilitated the creation of a competitive electricity market by allowing open access to transmission and distribution networks, encouraging private participation in power generation, and promoting the establishment of independent regulatory bodies. It also emphasized the promotion of renewable energy sources and the development of a sustainable power sector.
- **Petroleum and Natural Gas Regulatory Board (PNGRB) Act, 2003[148]**: The Petroleum and Natural Gas Regulatory Board (PNGRB) Act of 2003 is a legislation enacted by the Government of India to regulate the downstream activities of the petroleum and natural gas sector. It establishes the PNGRB as a regulatory authority responsible for granting licenses, regulating tariffs, ensuring fair competition, and promoting the development of the sector. While the PNGRB Act primarily focuses on the regulation of petroleum and natural gas, its relevance to the green hydrogen landscape lies in its potential application to hydrogen infrastructure.
- **Pollution control acts[149]**: Pollution control acts are a set of legal frameworks and regulations implemented by governments to mitigate and manage environmental pollution. These acts have the potential to play a crucial role in the green hydrogen landscape as they help ensure the sustainable and responsible production, use, and disposal of hydrogen while minimizing its environmental impacts.
- **Environmental Protection Act, 1986[150]**: It is a crucial environmental legislation in India that provides a framework for the protection and improvement of the environment. It empowers the central government to take measures to prevent and control environmental pollution and lays down provisions for the management of hazardous substances, environmental impact assessments, and the conservation of natural resources.
- **Land Acquisition Act, 2013[151]**: It is a legislation enacted by the Government of India to regulate the acquisition of land for various purposes, including

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[147] Electricity Act, 2003

[148] PNGRB Act, 2003

[149] The Air (Prevention And Control Of Pollution) Act, 1981; The Water (Prevention And Control Of Pollution) Act, 1974;

[150] The Environment (Protection) Act, 1986

[151] The Right To Fair Compensation And Transparency In Land Acquisition, Rehabilitation And Resettlement Act, 2013

infrastructure development, industrial projects, and public welfare initiatives. The Act provides a legal framework for the acquisition, compensation, and rehabilitation of landowners and affected persons when their land is acquired for public purposes. In the context of the green hydrogen landscape, the Land Acquisition Act of 2013 becomes relevant when considering the establishment of hydrogen production facilities, infrastructure development, and related projects.

- **Central Motor Vehicle Rules, 1989**[152]: It is a set of regulations formulated by the Government of India to govern various aspects of motor vehicles' registration, licensing, safety, and operation. These rules provide a framework for ensuring road safety, vehicle standards, and compliance with environmental norms. By incorporating provisions specific to green hydrogen-powered vehicles within the Central Motor Vehicle Rules, 1989, the Indian government can create a regulatory framework that supports the development, deployment, and safe operation of these vehicles.

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[152] CMVR Rules, 1989

Annexure 9: Gaps and Recommendations of existing Regulations as applicable to Green Hydrogen

Table 15: Regulatory gaps evaluated in the acts w.r.t green hydrogen value chain[153]

Stages of Value Chain			Power sector legislation	Gas sector legislation	Industry legislation	Environmental legislation	Land and water legislation	Transport legislation
Energy & Feedstock	**Energy**	RE Generation	🟩			🟩	**Gap:** Harmonized Master List of Infrastructure Sub-sectors list does not mention the RE generation specifically **Recommendation**: Under energy sector, RE generation projects can be added	
		Electricity Transmission				🟩		
		Electricity Distribution				🟩		
Hydrogen Production	**Converter + Electrolyser**	H2 Generators		**Gap:** T4S Regulations are not present for hydrogen gas production plants	**Gap:** Green hydrogen production is not present in classification of industrial sectors from CPCB **Recommendation:** CPCB can revise classification of industrial sectors			

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[153] Consultant Analysis

Stages of Value Chain			Power sector legislation	Gas sector legislation	Industry legislation	Environmental legislation	Land and water legislation	Transport legislation
				at this stage **Recommendation**: PNGRB can prepare the T4S Regulations for hydrogen gas production plants	(red, orange, green and white categories). green hydrogen generation industry can be in white category just like solar power generation through PV cells, wind power and mini hydel power (less than 25 MW).			
	Balance of systems	Water Quality			**Gap:** Water quality criteria (designated-best-use) for hydrogen production is not categorized. **Recommendation**: CPCB can update water quality criteria (designated-best-use) for hydrogen production		**Gap:** The Environment (Protection) Rules, 1986 - SCHEDULE – VI to be applicable on water quality from hydrogen production industry **Recommendation**: The Environment (Protection) Rules, 1986 - SCHEDULE – VI can be mandated on water quality from hydrogen	

Stages of Value Chain			Power sector legislation	Gas sector legislation	Industry legislation	Environmental legislation	Land and water legislation	Transport legislation
					🟧		production industry	
		Elec. Installation	🟩					
	Gasifier	H2 Generators		**Gap**: T4S Regulations are not present for hydrogen gas production plants at this stage **Recommendation**: PNGRB can prepare the T4S Regulations for hydrogen gas production plants	**Gap:** Green hydrogen production is not present in classification of industrial sectors from CPCB **Recommendation:** CPCB can revise classification of industrial sectors (red, orange, green and white categories). The green hydrogen generation industry can be in white category just like solar power generation through PV cells, wind power and mini hydel power (less than 25 mw).			
		Odorization		**Gap**: T4S Regulations for refineries and gas processing plants are in draft stage **Recommendation**: PNGRB can approve the T4S Regulations for refineries and gas processing plants for odorization				

Stages of Value Chain			Power sector legislation	Gas sector legislation	Industry legislation	Environmental legislation	Land and water legislation	Transport legislation
Transformation	Pure H2	Gaseous (compressed)		**Gap:** Existing T4S Regulations for compressed/ cryogenic/ solid (metal hydride) hydrogen are not present **Recommendation**: PNGRB can make T4S Regulations for compressed/ cryogenic/ solid (metal hydride) hydrogen		**Gap:** Green hydrogen transformation is not present in classification of industrial sectors from CPCB **Recommendation**: CPCB can revise classification of industrial sectors (red, orange, green and white categories). green hydrogen transformation industry can be in white category.		
		Cryogenic						
		Solid (Metal Hydrides)						
	H2 Derivatives	Green Methanol		**Gap:** Existing T4S Regulations for green methanol/ ammonia are not present **Recommendation**: PGNRB can make T4S Regulations for green methanol/ ammonia		**Gap:** Standard operating procedure for green methanol/ ammonia are not present **Recommendation**: CPCB can update standard operating procedure for hazardous gas –		
		Green Ammonia						

Stages of Value Chain			Power sector legislation	Gas sector legislation	Industry legislation	Environmental legislation	Land and water legislation	Transport legislation
				🟥		green methanol/ ammonia	🟩	
	Carbon Capture			**Current Progress:** Draft of 2030 roadmap for CCUS is prepared by MoPNG		**Gap:** Policy framework do not exist **Recommendation**: Policy framework can be made at national level	🟩	
Storage & Transport	Storage (UG/OG)	Gaseous		Static and Mobile Pressure Vessels (Unfired) Rules (**SMPV Rules**), 2016 are applicable for handling the hydrogen vessels	**Gap:** Green hydrogen storage facility is not present in classification of industrial sectors from CPCB **Recommendation**	Part 2 - List of Hazardous and Toxic Chemicals of the **MSIHC** (Manufacture, Storage, and Import of Hazardous	**Gap:** Harmonized Master List of Infrastructure Sub-sectors list does not mention the green hydrogen storage facility	
		Cryogenic						

Stages of Value Chain			Power sector legislation	Gas sector legislation	Industry legislation	Environmental legislation	Land and water legislation	Transport legislation
		Solid			: CPCB can revise classification of industrial sectors (red, orange, green and white categories). green hydrogen storage facility can be in white category just like solar power generation through PV cells, wind power and mini hydel power (less than 25 mw).	Chemical) Rules, 1989 covers hydrogen	**Recommendation**: Under list, hydrogen storage facility projects can be added	
	Transport	By PIPELINE					**Gap:** Harmonized Master List of Infrastructure Sub-sectors list does not mention the hydrogen transport facility **Recommendation**: Under list, hydrogen transport facility projects can be added	PGNRB to update contract carrier natural gas pipelines regulations w.r.t. hydrogen

Stages of Value Chain			Power sector legislation	Gas sector legislation	Industry legislation	Environmental legislation	Land and water legislation	Transport legislation
		By RAIL		🟩				**Current Progress:** Covered in CONCOR India list of hazardous commodities
		By SEA		🟩				**Gap:** No current legislation identified **Recommendation:** New legislation is required
		By ROAD		🟩				
End-use Application	**End use Conversions**	Regasification		**Gap:** For establishing & operating terminals & T4S Regulations for green hydrogen are not present separately. **Recommendation:** PNGRB can provide regulations on "Registration for establishing & operating (LNG) terminals" & T4S Regulations for green hydrogen				
		Cracking						
	In	Chemical			🟧	🟩	🟩	

Stages of Value Chain			Power sector legislation	Gas sector legislation	Industry legislation	Environmental legislation	Land and water legislation	Transport legislation
		Refinery			Current standard set by Indian legislation only allows for hydrogen storage at pressures of around 300 bars, despite industry calls for the pressure limit to be increased to at least 700 bars, which is seen as vital for economic viability in certain applications.	🟩	🟩	
		Iron & steel				🟩	🟩	
		Cement				🟩	🟩	
	Mobility	Combustion		🟩		🟩		🟩
		Fuel Cell		🟩		🟩		🟩
		Maritime		🟩		🟩		**Gap:** Covered in NGHM 2023, but current development to promote green hydrogen as fuel is absent **Recommendation**: MoPSW can collaborate with MoPNG to explore possibilities of

Stages of Value Chain			Power sector legislation	Gas sector legislation	Industry legislation	Environmental legislation	Land and water legislation	Transport legislation
				🟩		🟩		use of hydrogen and its derivatives in shipping
		Aviation		🟩		🟩		**Gap:** Covered in NGHM 2023, but current development to promote green hydrogen as fuel is absent **Recommendation**: MoCA can collaborate with MoPNG to explore possibilities of use of hydrogen and its derivatives in aviation
	Semi- Mobile	Off-Highway Applications		🟩		MoRTH has notified emission norms for Agricultural Tractors, Construction Equipment Vehicles, and other stationary equipment such as forklift, etc.		🟩

Table 16: Evaluation category for existing legislations

Legend[154]	
🟩	Current legislation is Applicable
🟧	Current legislation needs Marginal Adjustment to be applicable for Green H2
🟥	New Specific legislation are needed
	Not Applicable

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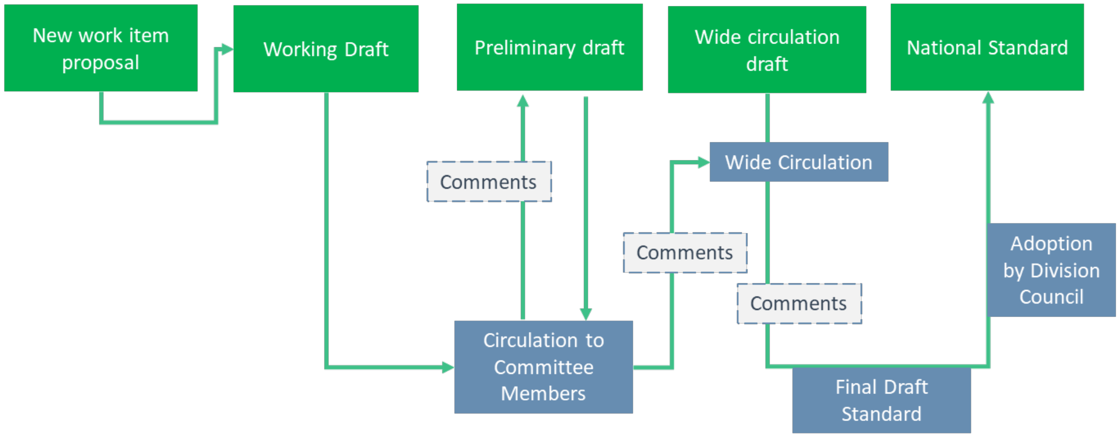
[154] Consultant Analysis

Annexure 10: Objective Mapping of Technical Standards

Objective 1: Safety & Reliability	Objective 2: Sustainability	Objective 3: Performance	Objective 4: Gas Quality	Objective 5: Design
Safety	GO	Measurement	Purity	Bunkering
Material compatibility	Emissions/GHG	Efficiency	Gas family/test gases	Refueling
Leakage		Certification	Quality measurement	Storage
Odorization				Pipes
				Valves
				Seals

Annexure 11: Methodology for Development of BIS Standards[155]

		Proposal stage	Preparatory stage	Committee stage	Approval stage	Publication stage	Total Time
Priority I	Indigenous Standard			12 Weeks	12 Weeks	12 Weeks	36 Weeks
	Adoption of ISO/IEC Standard				12 Weeks	12 Weeks	24 Weeks
Priority II	Indigenous Standard			20 Weeks	28 Weeks	24 Weeks	72 Weeks
	Adoption of ISO/IEC Standard				20 Weeks	16 Weeks	36 Weeks
Priority III	Indigenous Standard			30 Weeks	32 Weeks	34 Weeks	96 Weeks



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[155] Manual for Standard Formulation, BIS, 2022

The technical committees within the Bureau of Indian Standards (BIS) are organized in a hierarchical structure comprising Division Councils, Sectional Committees, Subcommittees, Panels, and Working Groups. Each committee operates under the authority of the committee that establishes it, defining its scope of work and structure. These committees are also responsible for supervising the activities of the committees functioning under them and coordinating their work with other relevant technical committees within BIS. The Standards Advisory Committee, empowered by the Governing Council of BIS, serves as the constituting committee for Division Councils. The Division Councils, in turn, oversee the activities of the Sectional Committees, which are responsible for the Subcommittees, Panels, and Working Groups operating under them. In some cases, Panels or Working Groups may also be established under a Division Council or a Subcommittee, as needed.

BIS technical committees are representative of a balance of the following stakeholder interests:

- **Consumers:** Organized buyers, consumer organizations, NGOs (with public interest objective) and user groups including government organizations and PSUs.
- **Government/Regulatory Bodies:** Central/State Government Ministries and their departments and regulators
- **Industry:** Manufacturing and service industry (including government organizations and PSUs), consultancy organizations, industry/manufacturer associations, etc.
- **Technologists:** R&D organizations, scientific institutes, academic and technical institutions, professional bodies/institutes, testing/ calibration laboratories, accreditation bodies and experts (persons in individual capacity)

Committee structure:

1. **Standards Advisory Committee:**
    - Organizes national standardization work.
    - Consists of Bureau and Divisional Councils, Sectional Committees, Subcommittees, Panels, and Working Groups.
    - Defined by the BIS Advisory Committees Regulations, 2018.
2. **Division Council:**
    - Formulates standards in specific areas of industries and technologies.
    - Approved by the Standards Advisory Committee.
    - Normally limited to 40 members.
    - Head of the technical department of BIS serves as the Member Secretary.
    - Chairpersons of Sectional Committees may be invited to meetings.
    - Constitution and functions governed by BIS Rules, 2018.
3. **Sectional Committees:**
    - Established by Division Councils or the Standards Advisory Committee.
    - Deal with specific fields not covered by Division Councils.

- Constitution defined by BIS Rules, 2018.
- Scope of work determined by the Division Council.
- Size typically restricted to around 30 members.
- Emphasis on non-industry representation.

4. **Subcommittees:**
    - Created by Sectional Committees as needed.
    - Focus on specific areas defined by the parent Sectional Committee.
    - Relevant/need for Subcommittee reviewed periodically.
5. **Panels:**
    - Established by Sectional Committees to work on specific topics or groups of related standards.
    - Composed of individual subject experts, not organizations.
    - Ad-hoc in nature and disbanded upon task completion.
    - Report to the parent Subcommittee, Sectional Committee, or Division Council.
    - Balance of representation not required.
    - Convener appointed by the parent committee, responsible for the panel's secretariat.
    - Covered under BIS Rules, 2018.
6. **Working Groups:**
    - Similar to Panels in constitution.
    - Set up by Sectional Committees, Subcommittees, or Panels.
    - Tasked with time-bound assignments related to standards.
    - Convener appointed similarly to Panels.
    - Covered under BIS Rules, 2018.

Standard formulation process

1. **Proposal Stage:** Requests for new Indian Standards or revisions/amendments to existing standards are submitted online through the Standards Portal. The proposal is analysed by the Member Secretary and considered by the Sectional Committee for approval. If the proposal is rejected, the proposer is informed of the decision.
2. **Prioritization of Work:** The Sectional Committee assigns priority to approved subjects based on urgency and complexity. Projects are categorized as Priority I, II, or III, determining the timeline for completion.
3. **Preparatory Stage:** A draft standard, called the Working Draft (WD), is prepared in accordance with the general principles of a standard. It is then modified to become a Preliminary Draft (P Draft). Information relevant to the subject is gathered during this stage.
4. **Committee Stage:** The P Draft is circulated to all members of the Sectional Committee and concerned subcommittees/panels for comments. Technical comments are reviewed, and decisions are made on resolving them. If there are no or only editorial comments, the P Draft can proceed to the next stage.

Otherwise, technical comments are discussed in a Sectional Committee meeting for approval to proceed.

5. **Approval Stage:** The P Draft is revised to become a Wide Circulation Draft (WC Draft) and is circulated for public comments. Stakeholders and interested parties are invited to provide feedback. Comments received are reviewed, disposed of, and considered for incorporation into the standard. In case of lack of consensus or substantial changes, a second WC Draft may be issued. However, under specific situations, wide circulation can be waived off if the subject is non-controversial or urgently needed.
6. **Finalization of Draft Standard:** The Sectional Committee considers all comments and finalizes the draft standard with or without changes, following the principle of consensus. The decision to adopt the draft as an Indian Standard is made by the Sectional Committee.

Annexure 12: Gaps and Recommendations for Standards under different categories

Category 0 (Existing Standards Up to Date)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations
Hydrogen Production	**Balance of Systems: Electrical Installations**	No similar abstract available		**IS 16724: 2018** Explosive Atmospheres - Electrical Installations Design, Selection and Erection (Electrical installation in explosive atmosphere)	No gap identified	No recommendation
	Balance of Systems: Pumps	No similar abstract available		**IS 5639: 1970** Pumps Handling Chemicals and Corrosive Liquids (Technical requirement for rotodynamic pumps for handling corrosive liquids)	No gap identified	No recommendation
Hydrogen Transformation	**Natural Gas: Metrology**	**ISO 6145-1:2019** Gas analysis - Preparation of calibration gas mixtures using dynamic volumetric methods	Provides basic information to support an informed choice for one or another method for the preparation of	**IS 16249: Part 1: 2021** Gas Analysis — Preparation of Calibration Gas Mixtures Using Dynamic Methods	No gap identified	No recommendation

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations
		ISO/CEN (International/ EU)	calibration gas mixtures	(Methods for preparation of calibrated gas mixtures)		
Hydrogen Storage & Transport	**Storage: Gas Cylinders**	**ISO 19881: 2018; ISO (International)**	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 liters of water and an upper working pressure limit of 70 Mpa	**IS 8198: 2004** Steel Cylinders for Compressed Gases (Atmospheric Gases, H2, High Pressure Liquefiable Gases and Dissolved Acetylene Gases) - Code of Practice (Inspection, testing and maintenance of portable steel cylinders)	No gap identified	No recommendation

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations
	Storage: Gas Cylinders	No similar abstract available		**IS 5903: 2014** Recommendation for Safety Devices for Gas Cylinders (Design, construction, testing of safety devices for gas cylinders)	No gap identified	No recommendation
	Storage: Gas Cylinders	No similar abstract available		**IS 15975: 2020** Gas Cylinders — Conditions for Filling Gas Cylinders (General requirement for filling single gas cylinders)	No gap identified	No recommendation
	Storage: Gas Cylinders	No similar abstract available		**Gas cylinder rule, 2016 (PESO)** (Guidelines for the filling, possession, and transport of gas cylinder)	No gap identified	No recommendation
Hydrogen End-use application	**Mobility – Road Vehicles: CH2NG**	No similar abstract available		**IS 17314: 2019** H2 Enriched Compressed Natural Gas (HCNG) for Automotive Purposes — Specification	No gap identified	No recommendation

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations
				(H2 and natural gas blend as a fuel for vehicles)		

Category 1 (Existing Standards requiring Light Updates)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
Hydrogen Production	**Balance of Systems: Electrical Installations**	**NFPA 497;** NFPA (US)	Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas	**IS 5572: 2009** Classification of hazardous areas (other than mines) having flammable gases and vapors for electrical installation (Classification of flammable gas area for	Quantitative classification of zones instead of qualitative classification is required	Quantitative classification can reduce the ambiguity in classification of zones. NFPA 497 can be referenced for the revision of IS 5572: 2009 with specific reference to India	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
				electrical installation)			
	Balance of Systems: Water	**ASTM D1193-91**; ASTM (US)	Describes the required characteristics of reagent waters	**IS 1070: 1992** Reagent grade water-specification (Distilled or De ionized water with no detectable amount of element. It prescribes the test for the quality of water)	This standard doesn't provide the limits for sodium, chloride, and TOC.	Limits which are discussed in ASTM D1193-91 can be added to this existing Indian standard or it can be adopted as a separate standard	BIS (CPCB)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Gasifier: H2 Generators	**ISO 16110-1: 2007, ISO 16110-2: 2010;** ISO (International)	Applies to packaged, self-contained or factory matched H2 generation systems with a capacity of less than 400 m3/h at 0 °C and 101,325 kPa. Applicable to H2 production using hydrocarbon fuels, including biomass	**IS 16512 (Part 1): 2016** H2 Generators using Fuel Processing Technologies (Construction, safety, and performance of fuel processing technologies)	This standard does not provide specifications or guidelines for effectively utilizing resources and managing effluents.	This standard can be updated to include protocols for efficient resource use and effluent management	BIS (CPCB)
Hydrogen Transformation	**Energy/ H2 Carrier (incl. Derivatives): Blends**	**ISO 14687** H2 fuel quality — Product specification (harmonized with CEN 17214); ISO/CEN (International/ EU)	H2 and gas minimum quality control for vehicular & stationary purposes and measurement methodologies, purity of H2, Wobbe index from	**IS 16061: 2021** H2 fuel quality product specification (Fuel quality of H2 fuel for heating, power generation, vehicular or	Discusses the fuel quality required for the application of heating, power generation, vehicular or stationary purpose. No detail on the fuel quality of hydrogen as	H2 quality specification as feedstock for industrial applications to be discussed	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			repurposed infrastructure	stationary purpose)	feedstock for industrial application is mentioned.		
	Energy/ H2 Carrier (incl. Derivatives): Cryogenic Fluids & Compressed Gases	No similar abstract available		**IS 1090: 2002** Compressed H2 Specification (Specification of different grades of compressed H2)	1) Classification of compressed H2 gas for fuel application not discussed 2) Gas chromatography is not included in the determination of H2 (annex A)	1) Specification of compressed H2 as fuel is discussed in IS 16061: 2021 standard. Comparison to be made in both the standards and relevant modifications to be made 2) Gas Chromatography method can be added to annex A	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
Hydrogen Storage & Transport	**Storage: Gas Cylinders**	**EN ISO 11114-1** Gas cylinders - Compatibility of cylinder and valve materials with gas contents - Part 1: Metallic materials; CEN (EU)	Compatibility of cylinder and valve materials with gas contents - metallic materials	**IS/ ISO 11114-1** Gas cylinders- Compatibility of cylinder and valve materials with gas contents- part 1: Metallic materials (Material compatibility of metallic cylinders and valves with various gases)	1) Chemical composition of various materials for gas cylinder and valves in clause 6.3.2 to be specified 2) Heat treatment and tempering temperature in clause 6.3.2 to be specified 3) Permeation rate of H2 onto metallic material to be specified and permeation limit to be decided	1) These factors can influence the degree of H2 embrittlement on the material 2) ISO 17081: 2014 which discuss the method for measuring H2 permeation in metals can be utilized	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Transport: Gas Cylinders	**EN ISO 11114-4** Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting steels resistant to H2 embrittlement; CEN (EU)	Material testing standards	**IS/ ISO 11114-4** Transportable gas cylinders —Part 4: Test methods for selecting steels resistant to H2 embrittlement (Qualitative methods to measure the H2 embrittlement resistance of steel)	H2 permeation rate method with a limiting value can also be added to this list	ISO 17081: 2014 standard can be utilized to measure H2 permeation value	BIS (PESO)
	Transport: Gas Cylinders	**EN 12862** Transportable gas cylinders - Specification for the design and construction of refillable transportable welded aluminium	Specification for the design and construction of refillable transportable welded aluminum alloy gas cylinders	**IS 17613: 2021** Gas cylinders refillable welded aluminum alloy cylinders design construction and testing (Material, design and	1) The effect of H2 onto the welded part of cylinder to be investigated 2) Effect of ambient conditions especially moisture on stress corrosion	1) Welded regions are prone to H2 cracking due to its homogenous microstructure. Tests to evaluate the mechanical properties of weld must be developed 2) Test under various moisture	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		alloy gas cylinders; CEN (EU)		testing of refillable welded aluminum alloy cylinders)	cracking to be evaluated.	content to be performed	
	Transport: Pipelines	**CEN/TS XXX (WI 00234096) EN 17124** Hydrogen Fuel - Product Specification And Quality Assurance - Proton Exchange Membrane (PEM) Fuel Cell Applications for Road Vehicles; CEN (EU)	H2 quality in pipelines	**IS 16061: 2021** H2 fuel quality product specification (Fuel quality of H2 fuel for heating, power generation, vehicular or stationary purpose)	This standard doesn't mention the fuel quality of H2 as feedstock for industrial application	H2 quality specification as feedstock for industrial applications to be discussed	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Transport: Valves	**EN 334** Gas pressure regulators for inlet pressure up to 10 MPa (100 bar); CEN (EU)	Specifies constructional, functional, testing, marking, sizing and documentation requirements of gas pressure regulators: for inlet pressures up to 100 bar and nominal diameters up to DN 400; operating temperature range - 20 °C to +60 °C	Similar to **IS 3224: 2021** Valve fittings for compressed gas cylinders excluding liquefied petroleum gas LPG cylinders specification (Material, design and testing of valve fittings for refillable aluminum and steel cylinders)	1) H2 venting from the pressure relief devices not mentioned which is crucial for safety 2) H2 embrittlement not discussed	1) H2 vent protocol should be in accordance with the 'CGA G 5.5 – H2 vent system' standard. 2) Effect of H2 embrittlement on valve leakage to be investigated.	BIS (PESO)
	Transport: Valves	**EN 13774:2013** Valves for gas distribution systems with maximum operating pressure less than or equal to 16 bar -	Seals with metal isolating valves used for gas distribution systems with maximum operating pressure up to 16 bar, and				BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		Performance requirements; CEN (EU)	which operate with fuel gases of the first, the second and the third family, in accordance with EN 437				
Hydrogen End-use Applications	**Industry: Heat**	**ISO 14687:2019** H2 fuel quality — Product specification; ISO/ CEN (International/ EU)	Minimum quality characteristics of H2 fuel as distributed for utilization in vehicular and stationary applications	**IS 16061: 2021** H2 fuel quality product specification (Fuel quality of H2 fuel for heating, power generation, vehicular or stationary purpose)	Doesn't mention the fuel quality of H2 as feedstock for industrial application	H2 quality specification as feedstock for industrial applications to be discussed	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Mobility – Road Vehicles: Fuel Cell	**IS/ISO 23828: 2013** Fuel cell road vehicles - Energy consumption measurement - Vehicles fuelled with compressed H2; ISO (International)	Energy consumption of fuel cell cars and trucks	**IS/ISO 23828: 2013** Fuel cell road vehicles - Energy consumption measurement - Vehicles fueled with compressed H2 (Energy consumption of fuel cell cars and trucks)	A minimum of 4 H2 consumption tests (2 each on RESS depleted and fully charged) are required for linear correction method which is not mentioned in the Annex H	This statement can be added to the annex H	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell			**AIS-157** Safety and procedural requirement of type approval of compressed gaseous H2 fuel cell vehicle (Requirements of compressed	1) Max. working pressure value is missing (For e.g., 1.25x NWP) in clause 3.25 2) Break away device which disconnects nozzle from dispenser when tension limit exceeds (Vehicle movement during	1) Formula can be added to clause 3.25 2) Break away device should be discussed in the clause 4.1	BIS (ARAI)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
				H2 fuel cell vehicles)	refueling) not mentioned		
	Applications: Fuel	**ISO 14687** H2 fuel quality — Product specification (harmonized with CEN 17214); ISO/ CEN (International/ EU)	Minimum quality characteristics of H2 fuel as distributed for utilization in vehicular and stationary applications	**IS 16061: 2021** H2 fuel quality product specification (Fuel quality of H2 fuel for heating, power generation, vehicular or stationary purpose)	Doesn't mention the fuel quality of H2 as feedstock for industrial application	H2 quality specification as feedstock for industrial applications to be discussed	BIS

Category 2 (Existing Standards requiring Major Updates)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
Hydrogen Production	**Electrolyser: H2 Generators**	**ISO 22734:2019** H2 generators using water electrolysis process - Safety requirements;	Construction, safety, and performance requirements of modular or factory matched H2 gas generation appliances, herein	**IS 16509: 2020** H2 Generators Using Water Electrolysis —	1) High temperature SOE not included 2) Min power input or	1) SOE should be included 2) SOE operate at very high temperature (500-1000°C)	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		ISO/CEN (International/ EU)	referred to as H2 generators, using electrochemical reactions to electrolyze water to produce H2	Industrial, Commercial And Residential Applications (Construction, safety, and performance of electrolyzers)	capacity to the electrolyzer to be specified. Essential for green H2 generation due to the intermittent sun/wind availability 3) Min and max operating temperature of the electrolyzer to be specified 4) Corrosive environment (30% KOH) in alkaline electrolyzers not discussed in this standard 5) ASME 31.12 which is specific for H2 piping can be referenced in OISD working standard instead of ISO 15649	which requires special safety requirement (on leakage) as the auto-ignition temperature of H2 in air is around 585°C 3) Lifetime of the electrolyzer can be affected due to the fluctuating load to the electrolyzer. Power input range must be identified 4) Operating temperature range to be mentioned 5) Requirement for handling of corrosive liquid to be specified. 6) ASME 31.12 referenced OISD standard to include guidelines on electrolyser to be adopted 7) ASTM D1193-91 can	

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
					(Petroleum and Natural gas Industries piping) which is mentioned in this standard 6) IS 1070:1992 doesn't provide the limits for sodium, chloride, and TOC 7) Methods to measure the efficiency of the electrolyser is not mentioned 8) Key performance indicators such as current density, efficiency, production rate, purity of H2, cost, lifetime etc. of various electrolysers are not	be adopted 8) Electrical efficiency (ratio of heating value of H2 to electricity consumed) and voltage efficiency (ratio of thermodynamic voltage to operating voltage) to be mentioned in the standard 9) Key performance indicators (KPI) act as metric to evaluate the performance of electrolyzers over time. CEN/CLC JTC 6 can be adopted as it provides the list and specification of KPI 10) These testing procedures can be added to the clause 5.2.11 which discuss	

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
					discussed. 9) Testing procedures relevant to electrolyzer when operated at dynamic load condition are not discussed in the standards. 10) Test procedures to evaluate the response time of various electrolyser not mentioned. 11) Guidelines on electrolyser installation, operation and maintenance is missing	about performance test. 11) Evaluation of response time of various electrolyser is essential for green H2 system 12) The guidelines related to installation, operation, and maintenance to be added to the standard	

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Gasifier: Odorization	**ISO/TR 16922** Natural gas - Guidelines for odorizing gases; ISO (International)	Specifications and guidelines for the methods to be used in the odorization of natural gas under a safety point of view.	**IS 15319: 2020** Natural Gas — Organic Components Used as Odorants — Requirements and Test Methods (Requirement and test methods for odorants suitable for natural gas and its substitute gas)	1) Suitability of odorant for H2 gas to be investigated 2) Effect of odorant (predominantly sulfur based) on catalyst poisoning of fuel cell to be explored. 3) Chemical reaction between odorant and H2 to be investigated	1) The standards discuss about the odorant for natural gas but the suitability of these odorants in H2 gas and the ease of propagation to be investigated 2) Catalyst poisoning due to odorant to be minimized 3) Non-sulfur-based odorants such as acrylates exhibit unsaturated bonds which can undergo addition reaction in presence of the metal catalyst leading to odorant depletion. This phenomenon has to	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
						investigated and can be added to this standard	
	Balance of Systems: H2 Detection Apparatus	**ISO 26142:2010;** ISO (International)	Defines the performance requirements and test methods of H2 detection apparatus that is designed to measure and monitor H2 concentrations in stationary applications.	**IS 16253: 2016** H2 Detection Apparatus - Stationary Applications (Performance requirement and test methods for H2 detectors)	1) H2 detectors of varying sensing mechanism (Electrochemical sensor, combustible gas sensor, palladium thin film sensors etc.) with its transduction mechanism, advantages, and disadvantage	1) Details of various H2 sensor type to be added to the standard 2) Testing requirement for liquid H2 leakage detection sensors to be developed. 3) Installation guidelines of the sensors to be added to the standard	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
					to be mentioned in the standard 2) H2 detection for liquid H2 leakage not discussed 3) Guidelines for installation of sensors not discussed		
	Balance of Systems: Explosive Atmosphere	**IEC 60079 series** Explosive atmospheres IEC (International)	Specifications and guidelines for the methods to be used in the odorization of natural gas under a safety point of view.	**IS /IEC 60079: Part 0: 2017** **IS/IEC 60079: Part 1-2: 2014** Explosive atmospheres part 1 Equipment protection by flameproof enclosures part 2 Equipment protection	Doesn't discuss about the equipment protection by explosion proof enclosures	Protection technique for explosion proof equipment is required as we are dealing with highly flammable H2 gas; A special risk assessment procedure for assemblies like compressors intended for use in hydrogen applications	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
				by enclosure **IS/IEC 60079: Part 29: Sec 1-2: 2016**: Gas detector **IS/IEC/TS 60079: Part 40: 2015**: Requirement for process sealing between flammable process liquid and electrical system (Construction, testing of equipment, with flameproof enclosure, gas detector and process seal)		may be included	

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
Hydrogen Transformation	**Natural Gas**	**EN ISO 10715:2022** Natural gas — Sampling guideline; ISO/CEN (International/ EU)	Means for ensuring that samples of natural gas and its substitutes that are conveyed into transmission and distribution grids are representative of the mass to which they are allocated	**IS 15125: 2002** Natural Gas - Sampling Guidelines (Adaptation of gas analysis methods – sampling guidelines)	This standard is specific to sampling of natural gas	Similar standard can be adopted for sampling of H2 gas	BIS (PNGRB)
	Gas Families: H2 Concentration	No Standards yet; CEN (EU)	Sensors for concentration monitoring H2 and H2NG	**IS 16253: 2016** H2 Detection Apparatus - Stationary Applications (Performance requirement and test methods for H2 detectors)	Concentration monitoring of H2 can be done with the help of H2 detectors as discussed in IS 16253: 2016. 1) H2 detectors of varying sensing mechanism (Electrochemical sensor, combustible gas sensor, palladium thin film	1) Details of various H2 sensor type to be added to the standard 2) Testing requirement for liquid H2 leakage detection sensors to be developed. 3) Installation guidelines of the sensors to be added to the standard	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
					sensors etc.) with its transduction mechanism, advantages, and disadvantage to be mentioned in the standard 2) H2 detection for liquid H2 leakage not discussed 3) Guidelines for installation of sensors not discussed		
Hydrogen Storage & Transport	**Storage: Gas Cylinders**	**EN ISO 11114-2;** CEN (EU)	Compatibility of cylinder and valve materials with gas contents - non-metallic materials	**IS/ ISO 11114-2** Gas cylinders-Compatibility of cylinder and valve materials with gas contents-part 2: Non-	The delamination of FRP and degradation of resin under H2 gas not discussed	The delamination of FRP and degradation of resin under H2 gas shall be investigated	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
				metallic materials (Material compatibility of non-metallic cylinders and valves with various gases)			
	Storage: Gas Cylinders	**EN 16753**; CEN (EU)	Periodic inspection and testing, in situ (without dismantling) of refillable seamless steel tubes of water capacity between 150 l and 3,000 l, used for compressed gases	**IS 8451: 2009** Periodic inspection and testing of high-pressure gas cylinders-code of practice (Requirement for periodic inspection and testing to gas cylinders)	The standard doesn't discuss about the non-destructive testing like acoustic emission test	More non-destructive inspection testing to be added to the standard so the continuous operation will not be hindered	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Storage: Gas Cylinders	**EN ISO 7866:2012/A1:2020**; ISO/ CEN (International/ EU)	Refillable seamless aluminum alloy gas cylinders - design, construction, and testing	**IS 15660: 2017** Refillable Transportable Seamless Aluminum Alloy Gas Cylinders – Specification (Material, design and testing of aluminum alloy cylinder)	1) 'Embrittlement resistance test' for the cylinder to be added in the testing section for H2 and other embrittling gas 2) Effect of ambient conditions especially moisture and pressure on stress corrosion cracking to be evaluated	1) IS/ ISO 11114-4 can be followed to determine the pass/ fail criteria for gas cylinder on H2 embrittlement. This can be specified in the testing section 2) Existing standard discusses the susceptibility to stress corrosion by testing the sample under corrosive environment, similarly, test under various moisture content and pressure to be performed	BIS (PESO)
	Storage: Gas Cylinders	**EN ISO 9809-1**; ISO/ CEN (International/ EU)	Design, construction and testing of refillable seamless quenched and tempered steel cylinders and tubes with tensile	**IS 7285: Part 2: 2017** Quenched and Tempered Steel	1) The cylindrical shell thickness calculation formula	1) Examine both standard's calculation for the cylindrical shell thickness and choose the	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			strength less than 1,100 MPa	Cylinders With Tensile Strength Less Than 1,100 Mpa (Material, design and testing of Quenched and tempered steel cylinder)	differs from that in ISO 9809-3:2019 and ISO 9809-1:2019 standard 2) 'Embrittlement resistance test' for the cylinder to be added in the prototype testing section for H2 and other embrittling gas	one with least error 2) IS/ ISO 11114-4 can be followed to determine the pass/ fail criteria for gas cylinder on H2 embrittlement. This can be specified in the prototype testing section	
	Storage: Gas Cylinders	**EN ISO 9809-3;** ISO/ CEN (International/ EU)	Design, construction and testing of refillable seamless normalized steel cylinders and tubes	**IS 7285: Part 1: 2018** Refillable Seamless Steel Gas Cylinders-Specification Part 1 Normalized Steel Cylinders (Material, design and testing of normalized			

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
				steel cylinder)			
	Transport: Gas Cylinders	**EN 12245**; CEN (EU)	Design, construction and testing of fully wrapped transportable composite cylinders	**IS 16646: 2017** Transportable refillable fully wrapped composite cylinder for LPG-specification (Fully wrapped fiber reinforced composite cylinders for liquefied petroleum gas)	This standard deals with LPG and a similar standard to be made for H2 gas	Standard to be developed for H2 gas. EN 17339 can be utilized for the standard development	BIS (PESO)
	Transport: Gas Cylinders	**EN 1964-3**; CEN (EU)	Specification for the design and construction of refillable transportable seamless steel gas cylinders of water capacities from 0.5 liter up to and including 150 liters - Cylinders made of seamless stainless	**IS 7285: Part 2: 2017** Quenched and Tempered Steel Cylinders With Tensile	1) The cylindrical shell thickness calculation formula differs from that in ISO 9809-3:2019	Similar content is discussed in ISO 9809-4 standard. 1) Examine both standard's calculation for the cylindrical	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			steel with an Rm value of less than 1,100 Mpa	Strength Less Than 1,100 Mpa (Material, design and testing of Quenched and tempered steel cylinder)	and ISO 9809-1:2019 standard 2) 'Embrittlement resistance test' for the cylinder to be added in the prototype testing section for H2 and other embrittling gas	shell thickness and choose the one with least error 2) IS/ ISO 11114-4 can be followed to determine the pass/ fail criteria for gas cylinder on H2 embrittlement. This can be specified in the prototype testing section	
Hydrogen End-use Applications	**Mobility – Road Vehicles: Fuel Cell**	**JARI S 001/ 002;** JARI (Japan)	Technical Standard for Containers of Compressed H2 Vehicle Fuel Devices, valves, and PRD	**IS/ISO 12619: Part 2: 2014** Road Vehicles Compressed Gaseous H2 (CGH2) and Hydrogen Natural Gas Blend Fuel System	1) Fuel system integrity check after crash of vehicle to be investigated 2) Fuel system for liquid H2 for road vehicles not available	1) Protocol for integrity check of fuel system to be developed 2) Fuel system for liquid H2 standard to be developed which can either be combined with this existing standard or	BIS (ARAI)
	Mobility – Road Vehicles: System Components	**ISO 12619** Road vehicles – CGH2; ISO (International)	General requirements and definitions of CGH2 and H2/natural gas blends fuel system components, intended for use on the types of motor vehicles defined in ISO 3833				

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Mobility – Road Vehicles: System Components	**ISO 21266** Road vehicles – CGH2; ISO (International)	Test methods for checking the minimum safety requirements specified in ISO 21266-1. Applicable to the functionality of the fuel systems designed to operate on CGH2 and H2/natural gas blends of motor vehicles as defined in ISO 3833	Components (H2 and natural gas blend as a fuel for vehicles)		separate standard can be made	

Category 3 (Adopt International Standard with No/Minor Revision)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
Hydrogen Production	**Balance of Systems: H2 Systems**	**NFPA 2;** NFPA (US)	H2 technologies Code	**IS 16749: 2018** Basic Considerations for the Safety of H2 Systems (Describes the properties of H2, its Safety	This standard deals with basic safety concerns of H2 whereas detailed safety requirements are	NFPA 2 code to be referenced. However, with certain changes in environmental conditions (temperature), pressure	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Balance of Systems: H2 Systems	**ISO/TR 15916:2015;** ISO (International)	Guidelines for the use of H2 in its gaseous and liquid forms as well as its storage in either of these or other forms (hydrides)	concerns, hazards, and risks) **IS 15201: 2018** Hydrogen Code of Safety (Physical and chemical properties of H2 and the prevention of hazards related to its use, storage, handling, labelling, and Transportation)	discussed in NFPA 2 This standard doesn't include safety requirements for production phase of hydrogen, and operation of manufacturing facilities.	requirements, and safety regulations in India, the code may be embedded to IS 16749: 2018. Safety distances must be adjusted accordingly. Comprehensive modifications are necessary to ensure safety and meet regulatory requirements in India. Further, production phase safety requirements should also be specified after due diligence	
	Balance of Systems: Piping Systems	**ASME B31.12;** ASME (US)	Requirements for piping in gaseous and liquid H2 service and pipelines in gaseous H2 service.	OISD is developing standard on piping.	No reference on the specifications for electrolyser systems	ASME 31.12 H2 piping standard to be referenced in the OISD standard that is currently being developed on piping. The specifications for electrolyser	BIS (PNGRB)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
						systems should be included.	
Hydrogen Transformation	**Energy/ H2 Carrier (incl. Derivatives): Cryogenic Fluids & Compressed Gases**	**NFPA 55**; NFPA (US)	Compressed Gases and Cryogenic Fluids Code	Partially related to **IS 5931: 1970** Code of safety for handling cryogenic liquids (Safe handling of cryogenic liquid including H2)	Briefly describes precautions to be taken while handling cryogenic liquid whereas a detailed guideline for installation, storage, use and handling of cryogenic and compressed gas is discussed in NFPA 55 code	NFPA 55 code to be referenced as it cannot be directly adopted. However, with certain changes in environmental conditions (temperature), pressure requirements, and safety regulations in India, the code may be embedded to IS 5931: 1970. Safety distances must be adjusted accordingly. Further, comprehensive	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
						modifications are necessary to ensure safety and meet regulatory requirements in India.	
Hydrogen Storage &Transport	**Storage: Gas Cylinders**	**EN ISO 11114-5;** CEN (EU)	Compatibility of cylinder and valve materials with gas contents - test methods for evaluating plastic liners	No Indian standard available	No Indian standard available	EN ISO 11114-5 standard to be adopted as it is	BIS (PESO)
	Storage: Gas Cylinders	**EN 17533;** CEN (EU)	Cylinders and tubes for stationary storage of gaseous H2	No Indian standard available which directly specifies gaseous H2 stationary storage	No Indian standard available which directly specifies gaseous H2 stationary storage	EN 17533 standard to be adopted as it is but regulatory adjustments are required as PESO doesn't approve for tube storage	BIS (PESO)
	Storage: Gas Cylinders	**EN ISO 18119, 11623;** ISO/ CEN (International/ EU)	Gas cylinders - Seamless steel and seamless aluminum-alloy gas cylinders and tubes - Periodic	IS 16017: 2013 Transportable Gas Cylinders - Periodic Inspection and Testing of Seamless	No periodic inspection and testing standard for composite cylinders	ISO 11623 standard can be adopted as it is	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			inspection and testing; Gas cylinders - Composite construction - Periodic inspection and testing	Aluminum Alloy Gas Cylinders (Periodic inspection and testing of seamless aluminum alloy transportable gas cylinders)			
	Storage: Tanks	**ASME STP/PT-0005;** ASME (US)	Design Factor Guidelines for High-Pressure Composite H2 Tanks	No Indian standard available	No Indian standard available	ASME STP/PT-0005 standard to be adopted as it is	BIS (PESO)
	Storage: Tanks	**ASME/STP-PT-01;** ASME (US)	Data Supporting Composite Tank Standards Development for H2 Infrastructure Applications	No Indian standard available	No Indian standard available	ASME/STP-PT-01 standard to be adopted as it is	BIS (PESO)
	Transport: Gas Cylinders	**EN 720-1** Transportable gas cylinders; CEN (EU)	Gases and gas mixtures - properties of pure gases	No Indian standard available	No Indian standard available	EN 720-1 standard can be adopted as it is	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Transport: Gas Cylinders	**EN 1089-3 Transportable gas cylinders;** CEN (EU)	Gas cylinder identification - color coding excluding LPG	No Indian standard available	No Indian standard available	EN 1089-3 standard can be adopted as it is	BIS (PESO)
	Transport: Gas Cylinders	**EN 14513 Transportable gas cylinders;** CEN (EU)	Pressure relief device bursting disc pressure relief devices (excluding acetylene gas cylinders)	No Indian standard available	No Indian standard available	EN 14513 standard can be adopted as it is	BIS (PESO)
	Transport: Gas Cylinders	**EN 14638-3:2010/AC;** CEN (EU)	Experimental methods justified design for refillable welded receptacles of a capacity not exceeding 150 liters - welded austenitic stainless-steel cylinders	No Indian standard available	No Indian standard available	EN 14638-3:2010/AC standard can be adopted as it is	BIS (PESO)
	Transport: Cryogenic Vessels	**ISO 21029 -1, -2, ISO 20421-1;** Transportable vacuum insulated	Design, fabrications, inspection, tests, and	No Indian standard available	No Indian standard available	All the mentioned standards are under development/	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		vessels; ISO (International)	operational requirements			consideration by BIS	
	Transport: Pipelines	**ISO 3183** Petroleum and natural gas industries; ISO/ CEN (International/EU)	Specifies requirements for the manufacture of two product specification levels (PSL 1 and PSL 2) of seamless and welded steel pipes for use in pipeline transportation systems in the petroleum and natural gas industries	**IS/ISO 3183: 2019** Petroleum and Natural Gas Industries-Steel Pipe for Pipeline Transportation Systems (Steel pipe for pipeline transportation systems)	This pipeline standard is more particular for the petroleum and natural gas transportation whereas ASME 31.12 which is more specific for H2 pipelines and ASME STP-PT-006 design of H2 pipeline can be adopted	ASME 31.12 and ASME STP-PT-006 standards which deal with H2 pipeline can be adopted as it is	BIS (PNGRB)
	Transport: Pipelines	**EN 12279:2000** Gas supply systems - Gas pressure regulating installations on service lines -	Contains the relevant functional requirements for gas pressure regulating installations	Partially similar to **IS/ISO 12619**	IS/ISO 12619 is related to transport applications whereas EN 12279 is related to	EN 12279:2000 standard shall be adopted as it is	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		Functional requirements; CEN (EU)	forming a part of the service lines in gas supply systems. Maximum upstream operating pressure is equal to or less than 16 bar and the design flow rate is equal to or less than 200 m³/h (normal m3/h)		stationary applications.		
	Transport: Pipelines	**EN 15001-1/-2:2009** Gas Infrastructure; CEN (EU)	Specifies detailed functional requirements for design, choice of materials, construction, inspection and testing of industrial gas installation pipes and assemblies with an operating	No Indian standard available	No Indian standard available	Pipelines specific for hydrogen is discussed in ASME 31.12 and can be adopted as it is	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			pressure higher than 0.5 bar				
	Transport: Pipelines	**ASME B31.12;** ASME (US)	Part GR contains definitions and requirements for materials, welding, brazing, brazing, heat treating, forming, testing, inspection, examination, operation, and maintenance; Part IP includes requirements for components, design, fabrication, assembly, erection, inspection,	**IS/ISO 3183: 2019** Petroleum and Natural Gas Industries - Steel Pipe for Pipeline Transportation Systems (Recommendation of the Steel Tubes, Pipes and Fittings)	This pipeline standard is more particular for the petroleum and natural gas transportation whereas ASME 31.12 which is more specific for hydrogen pipelines and ASME STP-PT-006 design of H2 pipeline can be adopted	ASME 31.12 and ASME STP-PT-006 standards to be referenced in OSID working standard for piping which deal with H2 pipeline can be adopted as it is	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			examination, and testing of piping; Part PL sets forth requirements for components, design, installation, and testing of H2 pipelines.				
	Transport: Valves	**EN ISO 10297:2014/Amd 1:2017** Amendment 1: Pressure drums and tubes; EN ISO 11117 Gas cylinders; EN ISO 15996 Gas cylinders; EN ISO 23826 Gas cylinders; ISO/ CEN (International/ EU)	Specification, design, and testing of cylinder valves	No Indian standard available	No Indian standard available	All the listed standards can be adopted as it is. However, for tube storage regulatory adjustments are required as PESO doesn't approve for tube storage	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Cross-cutting: Material Compatibility	**EN 13480-2** Metallic industrial piping - Part 2: Materials; CEN (EU)	Requirements for materials (including clad materials) for industrial piping	No Indian standard available	No Indian standard available	ASME 31.12 standard can be utilized for piping as it specific for H2 and to be referenced in OISD working standard	BIS (PNGRB)
	Cross-cutting: LH2	**EIGA Doc 06/19;** EIGA (EU)	Safety in storage, handling, and distribution of liquid H2	No Indian standard available	No Indian standard available	Detailed guidelines are provided in NFPA 55 code	BIS (PESO)
	Cross-cutting: Infrastructure	**EN 1776** Gas infrastructure - Gas measuring systems; CEN (EU)	Functional requirements for the design, construction, testing, (de) commissioning, operation, maintenance and, calibration, with provisions for all new gas measuring systems and any major changes of	No Indian standard available	No Indian standard available	EN 1776 standard can be adopted as it is	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			existing systems				
	Cross-cutting: Infrastructure	**EN 12186:2014** Gas infrastructure - Gas pressure regulating stations for transmission and distribution; CEN (EU)	Functional requirements for gas pressure regulating stations, which form part of gas transmission or distribution systems	No Indian standard available	No Indian standard available	EN 12186:2014 standard can be adopted as it is	BIS (PESO)
	Cross-cutting: Infrastructure	**EN 12327:2012** Gas infrastructure - Pressure testing, commissioning, and decommissioning procedures; CEN (EU)	Common principles for pressure testing, commissioning, and decommissioning of gas infrastructures		No Indian standard available	EN 12327:2012 standard can be adopted as it is	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Cross-cutting: Infrastructure	**JIS B 1045;** JSA (Japan)	Connecting components – preload tests for detecting H2 embrittlement – parallel plates	**IS 17445: 2020 Fasteners —** Preloading Test for the Detection of Hydrogen Embrittlement — Parallel Bearing Surface Method (Fasteners Preloading test for the detection of H2 embrittlement)	Stress durability test which evaluates the delayed fracture of fasteners due to the H2 embrittlement can be added as an alternate test for detection of H2 embrittlement in fasteners	Stress durability test part which is discussed in ISO 7961:1994 standard can be added to this standard	BIS
	Cross-cutting: Pressure Vessel	**EN 13445-1:2021** Unfired pressure vessels - Part 1: General; CEN (EU)	Terms, definitions, quantities, symbols, and units that are used throughout the EN 13445 series and gives general information on the design and manufacturing	**IS 2825: 1969** Code for unfired pressure vessels (Construction requirements for the design, fabrication, inspection, testing and certification of	ASME KD-10 standard for gaseous H2 pressure vessels can serve as a suitable alternative to the IS 2825-1969 code	ASME BPV Section VIII Division 3 Part KD-10 is already under development/ consideration by BIS	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			of vessels under this standard	fusion welded unfired pressure vessels in ferrous as well as in non-ferrous metals)			
	Cross-cutting: Pressure Vessel	**EN 13480-2:2019** Metallic industrial piping - Part 2: Materials; CEN (EU)	Requirements for materials (including metallic clad materials) for industrial piping and supports covered by EN 13480-1 manufactured from of metallic materials.				
Hydrogen End-use Applications	**Mobility – Road Vehicles: Fuel Cell**	**ISO 23273** Fuel cell road vehicles - Safety specifications - Protection against H2 hazards for vehicles fuelled	Essential requirements for FCVs w.r.t the protection of persons and the environment inside and outside the vehicle against	No Indian standard available	No Indian standard available	ISO 23273 standard is already under development/ consideration by BIS	BIS (ARAI)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		with compressed H2; ISO (International)	H2 related hazards. Applies only to such FCV where compressed H2 is used as fuel for the fuel cell system				
	Mobility – Road Vehicles: Fuel Cell	**JIS C 8824** Testing Methods for Environment of EMC for Small Polymer Electrolyte Fuel Cell System; JSA (Japan)	Testing methods for environment of the stationary and portable small polymer electrolyte fuel cell power system	No Indian standard available	No Indian standard available	JIS C 8824 standard can be adopted as it is	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**JIS C 8825** Testing Methods for EMC of Small Polymer Electrolyte Fuel Cell Power Systems; JSA (Japan)	Addresses electromagnetic compatibility issues for output less than 10 kW	No Indian standard available	No Indian standard available	JIS C 8825 standard can be adopted as it is	BIS (ARAI)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Mobility – Road Vehicles: Fuel Cell	**JIS C 8827** Testing Procedure of Islanding Prevention Methods for Utility Interconnected Small Polymer Electrolyte Fuel Cell Power Systems Power Conditioners; JSA (Japan)	Testing procedure of islanding prevention measures for utility-interconnected power conditioners in the stationary small polymer electrolyte fuel cell power system	TED 26 is developing these component/ testing standards	TED 26 is developing these component/ testing standards	JIS C 8827 standard can be adopted as it is	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**JIS C 8831**; JSA (Japan)	Safety Evaluation Test for Stationary Polymer Electrolyte Fuel Cell Stack			JIS C 8831 standard can be adopted as it is for safety testing of PEM fuel cell	BIS (ARAI, BEE)
	Mobility – Road Vehicles: Fuel Cell	**JIS C 8832**; JSA (Japan)	Performance Test for Stationary Polymer Electrolyte Fuel Cell Stack			JIS C 8832 standard can be adopted as it is for performance testing of PEM fuel cell	BIS (ARAI, BEE)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Mobility – Road Vehicles: Fuel Cell	**JIS C 8841-1/-2/-3;** JSA (Japan)	Small Solid Oxide Fuel Cell Systems: Rules, Safety codes, Safety, Performance, and Environmental Testing Methods	No Indian standard available	No Indian standard available	All the listed standards can be adopted as it is for general rules, safety, and performance testing of SOE fuel cell	BIS (ARAI, BEE)
	Mobility – Road Vehicles: Fuel Cell	**JIS C 8800;** JSA (Japan)	Glossary of Terms for Fuel Cell Power systems	No Indian standard available	No Indian standard available	JIS C 8800 standard can be adopted as it is	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**JIS B 8576;** JSA (Japan)	H2 metering Systems for Motor Vehicles	No Indian standard available	No Indian standard available	JIS B 8576 standard can be adopted as it is	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**NFPA 853;** NFPA (US)	Standard for the Installation of Stationary Fuel Cell Power Systems	No Indian standard available	No Indian standard available	NFPA 853 standard can be referenced for indigenous standard for India	BIS (ARAI)
	Mobility – Road Vehicles:	**EIGA Doc 15/06;** EIGA (EU)	Gaseous H2 Stations	No Indian standard available	No Indian standard available	EIGA Doc 15/06 to be adopted as it is. OISD 179	BIS (ARAI)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Fueling Station					may be repurposed	
	Mobility – Road Vehicles: Fueling Station	**JPEC-S 003;** JARI (Japan)	Standard for hydrogen fueling protocol	No Indian standard available	No Indian standard available	JPEC-S 003 standard to be adopted as it is	BIS (ARAI)
	Mobility – Road Vehicles: Fueling Station	**SAE J 2601;** SAE (US)	Fueling Protocols for Light Duty Gaseous H2 Surface Vehicles	No Indian standard available	No Indian standard available	SAE J 2601 standard can be reference for indigenous standard in India (single fuel station)	BIS (ARAI)
	Aviation: Fuel Cell	**SAE AIR 6464** H2 Fuel Cells – Aircraft Fuel Cell Safety Guidelines; SAE (US)	Information for installation of PEM H2 fuel cells on-board aircraft for the purposes of supplying auxiliary power	No Indian standard available	No Indian standard available	SAE AIR 6464 standard can be referenced along with SAE AS 7373 and SAE AS 6679 for indigenous standard in India	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Maritime: H2 Systems	**ISO/TR 15916;** ISO/ CEN/ CENELAC (International/ EU)	Basic considerations for the safety of H2 systems	**IS 16749: 2018 Basic** Considerations for the Safety of H2 Systems (Describes the properties of H2, its Safety concerns, hazards, and risks)	This standard deals with basic safety concerns of H2, it does not include safety of LOHC & LIHC in maritime transport, storage and use, and leakage related safety risks	A chapter on LOHC & LIHC guidelines may be added to the existing standard regarding safety, handling, storage and use in maritime transport	BIS
	Safety: Inspection	**CGA C-6.4** Methods for External Visual Inspection of Natural Gas Vehicle (NGV) and H2 Gas Vehicle (HGV) Fuel Containers and Their Installations; CGA (US)	Information and procedures for the periodic visual examination and inspection of natural gas and H2 fuel containers and the condition of the installation	No Indian standard available	No Indian standard available	CGA C-6.4 to be adapted as it is	BIS (ARAI)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Vocabulary: Fuel	**CGA H-4** Terminology Associated with H2 Fuel Technologies; CGA (US)	H2 technology descriptions; Glossary of H2 and fueling terms	No Indian standard available	No Indian standard available	CGA H-4 to be adapted as it is	BIS (ARAI)
	Safety: Inspection	**CGA C-6.4** Methods for External Visual Inspection of Natural Gas Vehicle (NGV) and H2 Gas Vehicle (HGV) Fuel Containers and Their Installations; CGA (US)	Information and procedures for the periodic visual examination and inspection of natural gas and H2 fuel containers and the condition of the installation	No Indian standard available	No Indian standard available	CGA C-6.4 to be adapted as it is	BIS (ARAI)

Category 4 (Adopt International Standard with Involved Revision)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
Hydrogen Production	**Balance of Systems: Air Compressors/ Compressed Air Systems**	**Several;** ISO (International)	Systems for H2 drying, separation, compression and purification; product and functional standards for the components and operation of these systems	No standard on separation, drying, and purification of H2 are available	Several standards for compressors are available on Indian standard but no standard on separation, drying, and purification of H2 are available	ISO/TS 19883: 2017 can be adopted as it describes the safety measures and design of pressure swing adsorption for separation & purification of H2	BIS
	Environmental Impact Plants	**EIGA DOC 122/18;** EIGA (EU)	Environmental impacts of H2 plants	No Indian standard available	No Indian standard available	Most of the environmental impact and safety guidelines are available in NFPA 2 code. NFPA 2 shall be referenced	BIS
Hydrogen Transformation	**Energy/ H2 Carrier (incl. Derivatives): Blends**	**EN 16726** Gas infrastructure - Quality of gas - Group H (EN 16723-1 Natural gas and biomethane for use in transport and biomethane for injection in the natural gas	Specifies gas quality characteristics, parameters, and their limits, for gases classified as group H that are to be transmitted, injected into and from storages, distributed and utilized.	No Indian standard available	No Indian standard available	Standard can be adopted to Indian context with blend % of H2 as differentiator	BIS (PNGRB)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		network - Part 1: Specifications for biomethane for injection in the natural gas network); CEN (EU)					
Hydrogen Storage & Transport	**Storage: Gas Cylinders**	**EN ISO 9809-2**; ISO/ CEN (International/ EU)	Design, construction and testing of refillable quenched and tempered steel cylinders and tubes with tensile strength greater than or equal to 1,100 MPa	No Indian standard available	No Indian standard available	EN ISO 9809-2 can be adopted to Indian context after rectifying the gaps discussed in IS 7285: Part 2: 2017. Specific regulatory adjustment for tubes required	BIS (PESO)
	Storage: Gas Cylinders	**EN ISO 9809-4**; ISO/ CEN (International/ EU)	Design, construction and testing of refillable stainless-steel cylinders with an Rm value of less than 1,100 MPa	Similar content is discussed in ISO 9809-2 standard	Similar content is discussed in ISO 9809-2 standard	Similar content is discussed in ISO 9809-2 standard	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Storage: Gas Cylinders	**several: ISO 11119-1, -2, -4 and -4; ISO 11515 etc.;** ISO/ CEN (International/ EU)	Gas cylinders - Design, construction and testing of refillable composite gas cylinders and tubes	No Indian standard available	No Indian standard available	All the listed standards can be adopted to Indian context with testing ambient condition as differentiator	BIS (PESO)
	Storage: Bulk Liquid	**CGA P-28;** CGA (US)	OSHA Process Safety Management and EPA Risk Management Plan Guidance Document for Bulk Liquid H2 Systems	No Indian standard available	No Indian standard available	CGA P-28 can be adopted to Indian context with ambient condition as differentiator	BIS (PESO)
	Storage: Cryogenic Tank	**EIGA Doc 24/18;** EIGA (EU)	Vacuum insulated cryogenic storage tank systems pressure protection devices	No Indian standard available	No Indian standard available	EIGA Doc 24/18 can be adopted to Indian context with ambient condition as differentiator	BIS (PESO)
	Storage: Cryogenic Tank	**CGA H-3;** CGA (US)	Standard for Cryogenic H2 Storage	No Indian standard available	No Indian standard available	EN 17339 can be adopted to Indian context with testing ambient condition as differentiator	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Transport: Gas Cylinders	**EN 17339**; CEN (EU)	Fully wrapped carbon composite cylinders and tubes for hydrogen	No Indian standard available	No Indian standard available	EN 12257 can be adopted to Indian context with testing ambient condition as differentiator, but regulatory adjustments are required for tubes	BIS (PESO)
	Transport: Gas Cylinders	**EN 12257**; CEN (EU)	Seamless hoop wrapped composite gas cylinders	No Indian standard available	No Indian standard available	EN 12257 can be adopted to Indian context with reference or working temperature as differentiator	BIS (PESO)
	Transport: Gas Cylinders	**EN 13807**; CEN (EU)	Design, manufacture, identification, and testing of battery vehicles and multiple-element gas containers (MEGCs)	No Indian standard available	No Indian standard available	EN 13807 can be adopted to Indian context but the effect of H2 onto the weld to be investigated	BIS (PESO)
	Transport: Gas Cylinders	**EN 13322-1:2003/A1, A2**; CEN (EU)	Design, manufacture, identification, and testing of refillable welded steel gas cylinders - Design and construction –	No Indian standard available	No Indian standard available	EN 13322-1:2003/A1 can be adopted to Indian context but the effect of H2 onto	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			carbon and stainless steel			the weld to be investigated	
	Transport: Gas Cylinders	**EN 14208**; CEN (EU)	Design and construction specification for welded pressure drums up to 1,000 liters capacity for the transport of gases	No Indian standard available	No Indian standard available	EN 14208 can be adopted to Indian context but the effect of H2 onto the weld to be investigated	BIS (PESO)
	Transport: Pipelines	**EN 12732:2021**; CEN (EU)	Requirements for the production and testing of weld joints for the installation and modification, including in-service welding, of onshore gas infrastructure steel pipelines and pipework	No Indian standard available	No Indian standard available	Similar to EN 13322 Part 2	BIS (PESO)
	Transport: Piping	**CGA G-5.4-2019**; CGA (US)	Describes the specifications and general principles recommended for CH2 and LH2 piping systems	No Indian standard available	No Indian standard available	CGA G-5.4-2019 Can be adopted to Indian context with ambient condition as differentiator for LH2	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Transport: Piping	**CGA G-5.5-2014;** CGA (US)	Design guidelines for H2 vent systems for CH2 and LH2 systems and provides recommendations for safe operation of such vents. The standard is intended for those who design, install, and maintain H2 vent systems	No Indian standard available	No Indian standard available	CGA G-5.5-2014 can be adopted to Indian context with ambient condition as differentiator for LH2	BIS
	Transport: Bulk Transport	**CGA H-5-2020;** CGA (US)	Minimum requirements for siting, selection of equipment, installing, initiating, maintaining, and removing CH2 and LH2 bulk H2 supply systems.	No Indian standard available	No Indian standard available	CGA H-5-2020 can be adopted to Indian context with ambient condition as differentiator for LH2	BIS
	Cross-cutting: Safety Devices	**EN 14382;** CEN (EU)	Gas safety shut-off devices for inlet pressure up to 10 MPa (100 bar)	IS 16009:2013 is available for LPG (Shut valve standards)	Specific to LPG and not for H2	Available for LPG, but necessary amendments shall be made to use valves for H2	BIS (PESO)
	Cross-cutting:	**EN 17928-1** Gas	Functional requirements for	IS 15125: 2002	No Indian standard	All the listed standards can be	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Infrastructure	infrastructure - Injection stations - Part 1 General requirements EN 17928-3 Gas infrastructure - Injection stations -Part 3: Specific requirements regarding the injection of H2 fuel gas CEN (EU)	stations for the injection of biomethane, substitute natural gas (SNG) and H2 fuel gas into gas transmission and distribution systems operated with fuel gases (natural gas, biomethane, SNG, hydrogen fuel gas, fuel gas mixtures) ensuring interoperability	Natural Gas - Sampling Guidelines (Adaptation of gas analysis methods - sampling guidelines)	available for H2 injection systems	adopted to Indian context with ambient condition as differentiator	
	Cross-cutting: Material Compatibility	**EN 682:2002/A1:2005 Elastomeric** seals - Materials requirements for seals used in pipes and fittings carrying gas and	Requirements for elastomeric materials used in seals for supply pipes and fittings, ancillaries, and valves at operating temperatures in general from - 5 °C up to 50 °C and in special cases from - 15 °C up to 50 °C, for LPG and derivatives	No Indian standard available	No Indian standard available	EN 682:2002/A1:2005 can be adopted to Indian context with testing ambient condition as differentiator	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		hydrocarbon fluids; CEN (EU)					
	Cross-cutting: Material Compatibility	**EN 377:1993/A1:1996** Lubricants for applications in appliances and associated controls using combustible gases except those designed for use in industrial processes; CEN (EU)	Requirements and methods of test for lubricants to be used in gas appliances of all categories including auxiliary equipment mounted or intended to be mounted on such appliances and which may be in contact with combustible gases, except those designed for use in industrial processes	No Indian standard available	No Indian standard available	EN 377:1993/A1:1996 can be adopted to Indian context with testing ambient condition as differentiator	BIS
	Cross-cutting: Material Compatibility	**EN 377:1993/A1:1996** Lubricants for applications in appliances and associated	Requirements and methods of test for lubricants to be used in gas appliances of all categories including auxiliary equipment mounted	No Indian standard available	No Indian standard available	EN 377:1993/A1:1996 can be adopted to Indian context with testing ambient condition as differentiator	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		controls using combustible gases except those designed for use in industrial processes; CEN (EU)	or intended to be mounted on such appliances and which may be in contact with combustible gases, except those designed for use in industrial processes				
	Cross-cutting: Material Compatibility	**EN 751 series** Sealing materials for metallic threaded joints in contact with 1st, 2nd and 3rd family gases and hot water Part 1: Anaerobic jointing compounds Part 2: Non-hardening jointing compounds Part 3: Uncentered PTFE tapes; CEN (EU)	Requirements and test methods for jointing compounds suitable for sealing threaded metallic joints	No Indian standard available	No Indian standard available	EN 751 series can be adopted to Indian context with testing ambient condition as differentiator	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Cross-cutting: Material Compatibility	**ISO 10229:1998** Evaluation of resistance of steel products to hydrogen induced cracking (HIC); ISO (International)	Method of evaluation of the susceptibility to H2 induced cracking (HIC) of steel products with nominal thicknesses equal to or greater than 6 mm	No Indian standard available	No Indian standard available	The test mentioned in the standard doesn't replicate the real service condition. ISO 10229:1998 can be adopted with closer service condition	BIS
	Cross-cutting: Material Compatibility	**ISO 17081:2014** Method of measurement of H2 permeation and determination of H2 uptake and transport in metals by an electrochemical technique; CEN (EU)	Method for evaluating H2 uptake in metals, based on measurement of steady-state H2 flux. It also describes a method for determining effective diffusivity of H2 atoms in a metal and for distinguishing reversible and irreversible trapping	No Indian standard available	No Indian standard available	ISO 17081:2014 can be adopted to Indian context as it is. Method of permeation on non-metallic material also to be looked into	BIS
	Cross-cutting: Cryogenic	**EIGA Doc 133/14**; EIGA (EU)	Cryogenic vaporization systems - prevention of	No Indian standard available	No Indian standard available	EIGA Doc 133/14 can be adopted to Indian context with ambient	BIS (PESO)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			brittle fracture of equipment and piping			condition as differentiator	
	Cross-cutting: Cryogenic	**EIGA Doc 151/15**; EIGA (EU)	Prevention of Excessive Pressure during Filling of Cryogenic Vessels	No Indian standard available	No Indian standard available	EIGA Doc 151/15 can be adopted to Indian context with ambient condition as differentiator	BIS (PESO)
	Cross-cutting: Infrastructure	**Several standards;** CEN (EU)	Standards and technical rules linked to retrofitting/blending and repurposing of new pipelines, underground gas storages and LNG terminals	No Indian standard available	No Indian standard available	Can be adopted to Indian standard by putting % H2 in the blend as differentiator	BIS (PNGRB)
	Cross-cutting: Infrastructure	**Several standards;** CEN (EU)	Technical standards for infrastructure planning, infrastructure operation and infrastructure maintenance	No Indian standard available	No Indian standard available	Building norms for H2 storage to be made by putting safety as primary concern	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Cross-cutting: Infrastructure	**JIS Z 3118**; JSA (Japan)	Method for measurement of amount of H2 evolved from steel welds	No Indian standard available	No Indian standard available	ISO 17081 standard which discuss about the method to evaluate the amount of H2 being diffused into steel resembles with JIS Z 3118 standard	BIS
	Cross-cutting: Compressor	**EN 12583:2022** Gas supply systems - Compressor stations; CEN (EU)	Specific functional requirements for the design, construction, operation, maintenance, and disposal activities for safe and secure gas compressor stations	No Indian standard available	No Indian standard available	EN 12583:2022 can be adopted to Indian context with output pressure as differentiator	BIS
Hydrogen End-use Applications	**Industry: Heat**	**EN 16726** Gas infrastructure - Quality of gas - Group H; CEN (EU)	Gas quality characteristics, parameters, and their limits, for gases classified as group H that are to be transmitted, injected into and from storages, distributed and utilized	No Indian standard available	No Indian standard available	EN 16726 can be adopted to Indian context with blend % of H2 as differentiator	BIS (PNGRB)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Industry: Heat	**CEN/TS XXX (WI 00234096)** Gas infrastructure — Quality of gas — Hydrogen used in converted/ rededicated gas systems; CEN (EU)	Purity of H2/ impurities like inert gases/Wobbe index from repurposed infrastructure	No Indian standard available	No Indian standard available	Similar to EN 16726	BIS
	Mobility – Road Vehicles: Fuel Cell	**EN 17124;** CEN (EU)	H2 fuel - product specification and quality assurance - PEM fuel cell applications for road vehicles	No Indian standard available	No Indian standard available	EN 17124 standard can be adopted to Indian context as it discusses about the methodology for H2 fuel quality assurance in refueling stations	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**IEC 62282** Fuel cell technologies; IEC (International)	Uniform terminology in the forms of diagrams, definitions and equations related to fuel cell technologies in all applications including but not limited to stationary power,	No Indian standard available	No Indian standard available	IEC 62282 standard can be adopted to Indian context with ambient condition as differentiator. This standard discusses about safety requirements and	BIS (ARAI)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
			transportation, portable power, and micro power applications.			testing of fuel cell module, SOE fuel cell, polymer electrolyte fuel cell etc.	
	Mobility – Road Vehicles: Fuel Cell	**JIS C 62282-3-100**; JSA (Japan)	Testing Methods of Power Conditioner for Grid Interconnected Small Fuel Cell Power Systems	No Indian standard available	No Indian standard available	IEC 62282-3-100:2019 already under development/ consideration by BIS	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**JIS C 62282-3-200**; JSA (Japan)	Test Methods For the Stationary Fuel Cell Power System - Performance	No Indian standard available	No Indian standard available	Similar to IEC 62282-3-200:2015 standard	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**JIS C 62282-3-200**; JSA (Japan)	Stationary Fuel Cell Power Systems – Installation	No Indian standard available	No Indian standard available	Similar to IEC 62282-3-300:2012 standard	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**JIS C 62282-4-101**; JSA (Japan)	Fuel cell power system for electrically powered trucks – Safety	No Indian standard available	No Indian standard available	Similar to IEC 62282-4-101:2022 standard	BIS (ARAI)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Mobility – Road Vehicles: Fuel Cell	**JIS C 62282-4-102**; JSA (Japan)	Fuel cell power system for electrically powered trucks – Performance test methods	No Indian standard available	No Indian standard available	Similar to IEC 62282-4-102:2022 standard	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**JIS C 62282-5-100**; JSA (Japan)	Portable Fuel Cell Power Appliances – Safety	No Indian standard available	No Indian standard available	Similar to IEC 62282-5-100:2018 standard	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**JIS C 62282-6-200**; JSA (Japan)	Micro fuel cell power systems - performance test methods	No Indian standard available	No Indian standard available	Similar to IEC 62282-6-200:2016 standard	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**CGA G-5.3** Commodity Specification for Hydrogen; CGA (US)	Commodity specification for gaseous and liquid H2 including H2 for fuel cell applications. Methods of analysis and sampling technique, quality verifications, typical use tables, etc.	No Indian standard available	No Indian standard available	CGA G-5.3 standard can be adopted to Indian context with ambient condition as differentiator	BIS (ARAI)
	Mobility – Road Vehicles: Fuel Cell	**SAE J2719**; SAE (US)	H2 Fuel Quality for Fuel Cell Vehicles	No Indian standard available	No Indian standard available	Similar content is discussed in IS 16061: 2021 H2 fuel quality product	BIS (ARAI)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
						specification standard	
	Mobility – Road Vehicles: Fuel Cell	**SAE J2579;** SAE (US)	Standard for Fuel Systems in Fuel Cell and Other H2 Vehicles	No Indian standard available	No Indian standard available	Similar to ISO 23273 standard	BIS (ARAI)
	Mobility – Road Vehicles: Dispensing Equipment	**EN ISO 17268:2020** Gaseous hydrogen land vehicle refuelling connection devices; ISO (International)	Design, safety, and operation characteristics of gaseous H2 land vehicle (GHLV) refuelling connectors.	**IS/ISO 17268: 2020** GHLV Refuelling Connection Devices (Design, safety, and operation of refuelling connectors for GHLV)	1) This standard only addresses the safety and design of refuelling connectors whereas the safety, design, and operation of H2 fueling station is not mentioned 2) The testing condition temperature (20°C) shown in section 7.2 is different from that of SAE J2600 standard (15°C)	1) ISO 19880-1, -3, -5, -8: 2020 standard that provides the minimum requirements and safety precautions for the hydrogen refueling stations is already under development/ consideration by BIS. SAE J2601 can be further investigated and compared with ISO 19880. 2) The test condition temperature variation in both	BIS (ARAI)
	Mobility – Road Vehicles: Dispensing Equipment	**EN 17127** Outdoor hydrogen refuelling points dispensing gaseous H2 and incorporating filling protocols;	Minimum requirements to ensure the interoperability of H2 refuelling points, including refuelling protocols that dispense gaseous hydrogen to road vehicles				

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		CEN (EU)			3) Break away device which disconnects nozzle from dispenser when tension limit exceeds (Vehicle movement during refuelling) not discussed in the clause 5 No Indian standard available	the standard to be investigated 3) Safety of nozzle with breakaway device to be added in the clause 5 CGA G-5.3 standard can be adopted to Indian context with ambient condition as differentiator	
	Mobility – Road Vehicles: Dispensing Equipment	**SAE J2600;** SAE (US)	Compressed H2 Surface Vehicle Fueling Connection Devices				
	Mobility – Road Vehicles: LH2 Dispensing Equipment	**EN ISO 17268** GHLV refuelling connection devices; CEN (EU)	Design, safety, and operation characteristics of GHLV refuelling connectors consisting of the following components, as applicable: — receptacle and protective cap (mounted on vehicle); — nozzle; — communication hardware	No Indian standard available	No Indian standard available	ISO 21010: 2017 & ISO 21028: 2016 (Material compatibility), ISO 21014:2019 (Insulation performance), ISO 21009-1:2022 (Static cryogenic vessel) can be adopted to Indian context with ambient condition as differentiator.	BIS (ARAI)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
	Mobility – Road Vehicles: LH2 Dispensing Equipment	**ISO 13984** LHLV fueling system interface; ISO (International)	Characteristics of LH2 refuelling and dispensing systems on land vehicles of all types to reduce the risk of fire and explosion during the refuelling procedure and provide a reasonable level of protection from loss of life and property	No Indian standard available	No Indian standard available	However, to adopt standards related to refillable cylinders independent mechanism device is required to ensure proper traceability in automotive purposes. ISO 21029-1, -2: 2018; ISO (Transportable cryogenic vessel) is under development/ consideration under BIS	
	Mobility – Road Vehicles: LH2 Fuel Tank	**ISO 13985** LH2 - Land vehicle fuel tanks; ISO (International)	Construction requirements for refillable fuel tanks for LH2 used in land vehicles as well as the testing methods required for protection from fire and explosion	**IS/ISO 13985: 2006** LH2 – Land Vehicles Fuel Tanks (Construction of refillable fuel tank for LH2 for vehicles)	Major part of this standard deals with cryogenic system which India lack standards		
	Aviation: Turbine	**ASTM D7566** Standard Specification for Aviation Turbine Fuel	Minimum property requirements for aviation turbine fuel that contain synthesized	No Indian standard available	No Indian standard available	ASTM D7566 to be adopted to Indian context based on Indian aviation norms	BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations	Responsible Body
		Containing Synthesized Hydrocarbons; ASTM (US)	hydrocarbons and lists acceptable additives for use in civil operated engines and aircrafts				
	Aviation: Turbine	**ASTM D4504** Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives; ASTM (US)	Performance requirements and test methods for melded polyethylene open-head, self-supporting, and nonreusable pails used in packaging and transporting non-hazardous goods, may be in liquid, solid, past, granular, or powder form	No Indian standard available	No Indian standard available	ASTM D4504 to be adopted to Indian context based on Indian aviation norms	BIS

Category 5 (Develop Standards – No International Standards Available)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)
Hydrogen Production	**Electrolysers**	**No Standard yet**; CEN/ CENELAC (EU)	Development of measurements and test procedures, key performance indicators - frequency, voltage control, other grid service requirements of grid operators, oxygen quality	**Gap in International standards identified** However, standard for efficiency of alkaline and PEM Water electrolysis system is under development/consideration as indigenous Indian standard by BIS.
	Material Compatibility	**No Standard yet**; CEN (EU)	Plastic materials (such as low-density polyethylene LLDPE for low pressure hydrogen pipe and fittings)	ASTM standards are followed and considered applicable. They are referenced in the IS standards. Specifically, G142 standards are available for both hydrogen and natural gas. However, the question arises whether it is necessary to adopt separate standards for India or if the existing ASTM standards suffice.
	Production Facility	**No Standard yet**; CEN (EU)	All possible H2 production facilities including their components, devices, connections, single cells, stacks, generators, etc. such as - catalytic/electrolysers - thermal/pyrolysis, water shift reactor - steam methane reforming with CCS	**Gap in International standards identified**
	Terminology	**No Standard yet**; No Standardization Body assigned	No consistency in H2 classification based on its production method. Required to provide certainty by clarifying the emissions threshold	**MNRE has highlighted the CO2 emissions criteria as 2kgCO2e/ kg H2 for India.**

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)
			associated with different hydrogen production technologies. Low carbon hydrogen should be defined.	
Hydrogen Transformation	**Energy/ H2 Carrier (incl. Derivatives): Fuel**	**No Standard yet**; CEN (EU)	Purification of H2 fuel gases divers' aspects e.g., pressure swing absorption	**Gap in International standards identified**
	Energy/ H2 Carrier (incl. Derivatives): Liquid H2	**No Standard yet**; CEN/ CENELAC (EU)	LH2 - safety topics - harmonized safety distances on liquification plants	**Gap in International standards identified**
	Energy/ H2 Carrier (incl. Derivatives): Liquid H2	**No Standard yet**; CEN (EU)	LH2 - safety topics - mitigation strategies and risk assessment	**Gap in International standards identified**
	Energy/ H2 Carrier (incl. Derivatives): Green Ammonia	**No Standard yet**; CEN (EU)	Standards needed for the handling of H2 and derivatives when using H2 terminals and injecting into the H2 grid to avoid issues at interconnection points. Here: H2 terminal for the transformation of liquid H2 or liquid ammonia or LOHC into gaseous H2. Here to add also LIHC and solid-state forms	**Gap in International standards identified**
	Low Carbon/ Green/ Liquid H2: Vocabulary	**Hydrogen Storage & Transport**	Definition and standards for certifying low carbon and green H2 as well as liquid H2 – either as an end product or for logistics reasons	**Gap in International standards identified**
Hydrogen Storage & Transport	**Transport: LNG**	**No Standard yet**; ISO/ CEN (International/ EU)	Adaptation of standards on LNG transport to liquefied H2	**Gap in International standards identified**

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)
Hydrogen End-use Applications	**Industry: Heat**	**No Standard yet**; No Standardization Body assigned	Gas quality measurement devices for industry	**Gap in International standards identified**
	Industry: Refining	**No Standard yet**; No Standardization Body assigned	Labelling of renewable/low carbon ammonia	**Gap in International standards identified**
	Industry: Refining	**No Standard yet**; No Standardization Body assigned	Ammonia production metrology for determining GHG emissions	**Gap in International standards identified**
	Industry: Iron & Steel Production	**No Standard yet**; No Standardization Body assigned	Current industrial gas processes (process equilibrium, process control, for the industry sectors identified as sensitive gas customers: metal and steel industry, etc.)	**Gap in International standards identified**
	Mobility – Road Vehicles: Combustion	**No Standard yet**; CEN (EU)	H2 retrofit – internal combustion engine retrofit (AIS 195 is recently notified in last month)	**Gap in International standards identified**
	Mobility – Road Vehicles: Fuel Cell	**No Standard yet**; No Standardization Body assigned	Missing standards on safety/pressure limits in H2 transportation	**Gap in International standards identified**
	Mobility – Road Vehicles: Fuel Cell	**No Standard yet**; No Standardization Body assigned	Methanol and ammonia norms for utilization as transport fuel	**Gap in International standards identified**
	Mobility – Road Vehicles: Fueling Station	**No Standard yet**; CEN (EU)	H2 refueling system testing and verification methodology	**Gap in International standards identified**
	Mobility – Road Vehicles: Fueling Station	**No Standard yet**; No Standardization Body assigned	Standard for certifying H2 refueling systems (to avoid certification by each H2 car manufacturer)	**Gap in International standards identified**

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)
	Maritime: Vessels	**No Standard yet**; CEN/ CENELAC (EU)	Vessel on-board hydrogen storage (350bar, 500 bar, 700bar, liquid e.g., LOHC, LIHC), including for new ship fuel types	**Gap in International standards identified**
	Maritime: Energy Carrier	**No Standard yet**; No Standardization Body assigned	Safety standards and classification for H2, ammonia, and methanol powered ships. Technical standards related to the storage and handling of H2 carriers (LIHC/LOHC)	**Gap in International standards identified**
	Maritime: Storage	**No Standard yet**; CLC/ TC 31 (EU)	safe integration of onboard H2 storage and hydrogen propulsion systems where hydrogen or its derivatives (e.g., LOHC) are used on-board, including the H2 generation from hydrogen derivatives (e.g., dehydrogenation of liquids such as LOHC).	**Gap in International standards identified**
	Applications: Feedstock	**No Standard yet**; ISO/ CEN (International/ EU)	H2 quality in industry	**Gap in International standards identified**
	Applications: Fuel	**No Standard yet**; No Standardization Body assigned	Standards for using ammonia (or other H2 carriers such as methanol) as fuels for shipping, heavy road transport or aviation are missing	**Gap in International standards identified**

Category 6 (Not a Current Priority for India)

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations
Hydrogen Production	**Sustainability & Origin**	**ISO 13315-2** Environmental management for concrete and concrete structures — Part 2: System boundary and inventory data; ISO (International)	Provides a general framework, principles, and requirements related to the determination of system boundaries and the acquisition of inventory data necessary for conducting a life cycle assessment (LCA) of concrete, precast concrete, and concrete structures. However, environmental management for concrete and concrete structure; definition for calculation of efficiency, key performance indicators (KPI), GHG emissions, certification of origin needs to be addressed	No Indian standard available	No Indian standard available	Not a current priority for India; can be considered at a later stage
Hydrogen Storage & Transport	**Storage: Underground**	**EN 1918-1/-2/-3/-4/-5** Gas infrastructure -	Functional recommendations for design, construction, testing,	No Indian standard available	No Indian standard available	Underground storage of H2 is not the priority for India at

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations
		Underground gas storage; CEN (EU)	commissioning, operation, maintenance, and abandonment of underground gas storage (UGS) facilities in aquifers, oil and gas fields, solution- mined salt caverns and rock caverns up to and including the wellhead, and for surface facilities between the wellhead and the connection to the gas grid			present but under the GCR and SMPV Rules, underground storage is included as a regulated aspect
	Storage: Underground	**EIGA Doc 171/12;** EIGA (EU)	Storage of H2 in Systems Located Underground	Mandated as part of SMPV Rules	Mandated as part of SMPV Rules	
	Storage: Metal Hydride	**ISO 16111: 2018; ISO (International)**	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,	No Indian standard available	No Indian standard available	Metal hydride storage is not the priority for India at present. However, ISO 16111: 2018 is already under development/ consideration by BIS

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations
			design specifications, etc. for storage systems			
	Storage: Metal Hydride	**CGA H-2;** CGA (US)	H2 storage systems in which the H2 is absorbed in reversible metal hydrides and for which the system is designed to permanently contain the solid material so only H2 gas is introduced into or removed from the system. Guidance to regulatory authorities, manufacturers, and users for the classification and labeling of these systems	No Indian standard available	No Indian standard available	Metal hydride storage is not the priority for India at present. But if required this standard can be adopted at a later stage. However, JIS H 7201 is already under development/ consideration by BIS
	Storage: Metal Hydride	**JIS H 7201; JIS H 7202; JIS H 7203;** JSA (Japan)	Method for measurement of pressure-composition-temperature (PCT) relations of H2 absorbing alloys; (de)hydrogenation reaction rates; H2			

Value Chain Stage (L0)	Sub-part of Value Chain (L1: L2)	International Standards Name (Published); Standardization Body (Country)	Standard Description*	Equivalent Indian standard (Description)	Gaps	Recommendations
			absorption/desorption properties of metal hydrides			
	Cross-cutting: Vocabulary	**JIS H 7003;** JSA (Japan)	Glossary of terms used in hydrogen absorbing alloys			
Hydrogen End-use Applications	**Industry: Heat**	**EN 12261, EN 1359, EN 14236, EN 12480, EN 17526, EN 12405-1, ISO 17089;** ISO/ CEN (International/ EU)	Technical Standards for heating applications	No Indian standard available	No Indian standard available	Utilization of green H2 for heating application is not a priority for India

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