Commodities Committee

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White Paper

Energy Transition Commodities: Clean Hydrogen

TIC Council is the global trade association representing the independent third-party Testing, Inspection and Certification (TIC) industry which brings together about 100-member companies and organizations from around the world to speak with one voice. Its members provide services across a wide range of sectors: consumer products, medical devices, petroleum, mining and metals, food, and agriculture among others. Through provision of these services, TIC Council members assure that not only regulatory requirements are met, but also that reliability, economic value, and sustainability are enhanced. TIC Council's members are present in more than 160 countries and the wider TIC sector currently employs more than 1 million people across the globe.

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Abstract

Governments, businesses, and consumers around the world are navigating the complexities of the Energy Transition, surrounded by a flood of new products, technologies, and commodities—all promising to drive a sustainable, green economy. However, amid these numerous offerings and ambitious claims, the challenge remains: how can we ensure that these emerging solutions genuinely contribute to a transparent, reliable, and robust energy transition?

This series of White Papers provides an in-depth analysis of green commodities and their value chains. It explores the challenges faced by economic operators in the commercialization of these products, while also highlighting how independent ESG Verification and Certification services play a crucial role in ensuring quality, transparency, safety, and trust.

This white paper explores **Clean Hydrogen** as a key enabler of global decarbonization efforts, with diverse applications across sectors like steel production, ammonia-based fertilizers, fuel cell electricity generation, synthetic fuels, and industries such as cement, glass, and food.

The paper also examines the hydrogen value chain, covering production methods, environmental impacts, and transportation challenges across various modes such as pipelines, liquefied hydrogen, ammonia, methanol, and solid storage. Additionally, it highlights the importance of hydrogen quantity and quality standards, reviewing the analytical methods used for testing hydrogen and its derivatives.

As clean hydrogen gains momentum, the Testing, Inspection, and Certification (TIC) industry plays a critical role in ensuring the safety, quality, and regulatory compliance of hydrogen projects. From production to transportation, TIC companies provide essential services, including certifying production assets, testing pipelines and transport systems, and verifying the carbon footprint and purity of hydrogen fuels. The involvement of TIC firms helps operators meet evolving global standards, giving stakeholders confidence in the sustainability, safety, and efficiency of hydrogen projects.

1. Introduction / Executive Summary

Given global initiatives to reduce the use of fossil fuels and to cut carbon emissions, hydrogen offers multiple solutions to decarbonising industry, transport and the energy sector. For example, using low carbon hydrogen for steel production, surplus energy storage, transportation and fuel cell-based electricity generation will become key to reaching decarbonisation targets by 2050/2060.

Hydrogen production can be achieved through various methods, either by using fossil fuels, renewable energy sources or nuclear power. Global investment and growth are focused on the production of clean hydrogen, of which there are two main types: (1) green hydrogen produced using carbon-free energy sources, such as solar and wind power, and (2) blue hydrogen produced using natural gas, where the resulting carbon emissions are trapped and securely stored using Carbon Capture and Storage (CCS).

Over 1.400 clean hydrogen projects have been announced globally, equalling investments of US $570 billion and 45 million tonnes per annum of supply announced through 2030.

There are various methods of transporting hydrogen, including in gaseous phase via pipeline, in liquid phase via insulated containers, in the forms of liquefied hydrogen, ammonia or methanol, or stored in a liquid or solid mass. The method of transportation depends on factors such as distance, volume, infrastructure, safety considerations and energy efficiency. In fact, there are potential hazards associated with each of these transportation methods.

To accurately assess ecological impact, the cumulative greenhouse gas (GHG) emissions across the hydrogen life cycle, measured in per kilogram of hydrogen produced (either in mass or energy), is typically used as an indicator. The contribution to climate change greatly depends on the processes used for hydrogen production and methods for transportation.

Various parameters for determining hydrogen quality can be assessed in accordance with international standards ISO 14687, SAE J2719 and EN 17124. The methods used are to be assessed for accuracy, precision, quantification limit, linearity and range with respect to the various applications. However, no internationally accepted method is available yet to quantify hydrogen for the various transportation methods.

Several countries are working on strategies and regulations to support the development of the hydrogen industry, focusing on areas such as production, transportation, storage and utilisation. These initiatives often include financial incentives, research and development programmes as well as targets for increasing the share of hydrogen in the energy mix.

The Testing, Inspection and Certification (TIC) industry supports hydrogen value chains in a variety of ways :

- Certifying production assets and refuelling stations to confirm compliance with technical and safety standards.
- Testing and assessment of material and components of transporting pipelines for suitability; and certifying according to existing standards.
- Monitoring pipelines for leakage, as well as measuring fugitive emissions and calculating carbon footprints of production assets.

- Supervising loading and offloading, where hydrogen or its derivatives are shipped.
- Certifying clean hydrogen quality and/or origins.

TIC companies are uniquely positioned to add value to the hydrogen industry, not only due to our inherent focus on independence and impartiality, but also due to our expertise, worldwide presence and knowledge of local regulations and requirements. Having people on the ground providing physical in-person inspection activity – in addition to paperwork audits – gives us a particular advantage to prevent fraudulent activities and inaccurate claims, provide real-time validations, and thus contribute to a truly responsible and sustainable energy transition.

2. Hydrogen: necessity and applications

a) Overview of Hydrogen's Importance

Hydrogen is the lightest and most abundant molecule in the universe and has great potential in supporting the vital clean energy transition. Currently, hydrogen is predominantly used in industry – producing steel and ammonia as well as in oil refining – but it is also an extremely versatile energy carrier and a clean alternative fuel.

Highlighted below are some of the industries that may benefit the most by using hydrogen as an alternative and sustainable source of energy.

b) Steel manufacturing

Traditionally, the steel industry has been a huge contributor to global CO_2 emissions, due to the primary use of coal in blast furnaces and in basic oxygen converters. The two-step process of turning iron ore into iron, and then iron into steel, releases a large amount of CO_2 into the atmosphere as a by-product. When coal is replaced with sustainable hydrogen in this process, it allows for the complete decarbonisation of steel production – with only water vapour generated as a by-product.

c) Ammonia – Fertiliser, fuel, and energy carrier

Ammonia is produced by combining hydrogen with nitrogen. Around 70% of ammonia being produced is used as an indispensable agricultural fertiliser, but the traditional Haber-Bosch process used for its production has natural gas as a fuel source, and thus contributes to CO_2 emissions. Natural gas can be replaced with renewable energy sources to create a more sustainable product. Separately, the aviation and shipping industries are exploring technologies to use ammonia as a fuel source, massively reducing the carbon intensity of these sectors. Another particularly crucial use of ammonia is for energy storage. Excess power from renewable sources can be stored as hydrogen, which subsequently can be converted to ammonia for easier storage and transportation. The ammonia can be converted back to hydrogen gas as required (known as ammonia cracking) or burned as a fuel source in its own right, thereby producing water and nitrogen as by-products.

d) Electricity generation via fuel cells

Hydrogen can be combined with oxygen in a fuel cell to generate electricity, alongside water and heat. This is an extremely efficient way of generating electricity and is scalable – individual fuel cells can be connected to form stacks, creating fuel cell systems of varying size and power as required for a particular application. Hydrogen fuel cells can be used to power long-haul electric fleet vehicles and warehouse equipment such as forklifts and pallet jacks. In public transportation, hydrogen fuel cell buses and trains are being introduced in parts of Europe, the USA, Japan and South Korea, with Hydrogen Fuel Cell Electric Vehicles (HFCEVs) for personal use also under development. Use of stationary fuel cells for back-up power generation is also crucial for facilities such as hospitals, which need a continuous power supply.

e) Electricity generation via combustion

Hydrogen can be burned in gas turbines or internal combustion engines to generate electricity. This process is similar to how natural gas or other fossil fuels are used in power plants. When hydrogen combusts, it combines with oxygen to form water vapor, producing heat in the process. This heat can then be used to produce steam, which drives turbines connected to generators, producing electricity.

The current limited use is primarily due to the need for significant infrastructure development, cost considerations, and technological advancements. Thus hydrogen is being blended with natural gas as an interim solution for reducing carbon emissions while leveraging existing infrastructure. It serves as a transitional step towards a more extensive hydrogen economy, facilitating the integration of hydrogen into the energy system and supporting the development of hydrogen technologies and markets.

f) Synthetic / E-fuels

In conjunction with Carbon Capture and Utilisation (CCU) technologies, hydrogen created using renewable energy can be combined with captured CO_2 to produce liquid synthetic fuels, such as gasoline/petrol, diesel or even kerosene. Through this application, combustion engines can become carbon-neutral. This offers another promising solution for decarbonising transportation such as shipping and aviation.

g) Cement & glass

Hydrogen can help in the reduction of emissions from the carbon-intensive cement industry in several ways. Sustainable hydrogen can replace coal and natural gas in the production process, and significantly minimise the environmental impact. Hydrogen can also be used to reduce the amount of clinker being required to produce cement. Clinker is a mix of limestone and minerals, heated and transformed in a kiln. CO_2 is released during this conversion process, but by using hydrogen as a reducing agent the emissions can be decreased by up to 50%. In glass manufacturing, hydrogen can be used to lower the energy being required to melt raw materials through batch pre-heating. As a more energy efficient fuel source for melting furnaces, hydrogen also decreases overall emissions from the glass production process.

h) Food industry

Hydrogen is utilized in the food industry in several ways. It is commonly used to hydrogenate oils and fats, to convert liquid vegetable oils into solid or semi-solid fats, such as margarine. Additionally, hydrogen is used for preservation and packaging by being included in modified atmosphere packaging, which helps extend the shelf life of fresh produce, meats, and other perishable items. Hydrogen is also involved in the production of hydrogen peroxide, a bleaching agent, disinfectant, and sterilizer used in the food industry. Furthermore, it is used to produce, via microbial fermentation, various food ingredients and additives like organic acids, alcohols, and other value-added products.

3. Hydrogen production

Hydrogen is rarely found in its natural state on Earth. Instead, hydrogen commonly exists in various compounds. Common hydrogen-containing compounds include water, a wide variety of hydrocarbons, hydrogen sulphide, ammonia and methanol. Hydrogen production can be achieved through various methods, either by using fossil fuels, renewable energy sources or nuclear power[1]. The choice of hydrogen production method depends on factors such as cost, availability of resources, environmental impact, energy requirements, efficiency, scalability, desired purity of the hydrogen produced and the overall energy landscape of a region. Ongoing research and development aim to improve the efficiency and sustainability of hydrogen production from various sources.

The contribution to climate change greatly depends on the exact process being utilised. Hydrogen production processes can be broadly categorised into three main groups, based on the primary energy input being used. Assuming a carbon capture efficiency of 85%, the tables below show the typically available processes. Emission figures are general estimates, because the actual values vary based on the specific process conditions, the efficiency of the technology and the source of the feedstock. Additionally, advancements in technology and the use of renewable energy in hydrogen production are expected to improve the overall efficiency and to reduce the carbon footprint of hydrogen in the future.

There are other types of hydrogen that may become available in the future: naturally occurring hydrogen found in the Earth's crust, and clear hydrogen, which is formed in spent wells by oxidating any leftover hydrocarbons.

Table 1 - Hydrogen Production from Fuels

Process	Abbreviation	Feedstock	Main by-product	Typical GHG emission in CO_2eq per $1kgH_2$	Colour[2]
Steam methane reforming	SMR	Natural gas	Carbon dioxide	9 to 13	Grey
Steam methane reforming + CCS	SMR	Natural gas	Carbon dioxide	1 to 5	Blue
Steam methane reforming using electric heating[3]	eSMR	Natural gas / electric energy	Carbon dioxide	Depends on electricity	Grey / Blue
Steam methane reforming + CCS	SMR	Renewable natural gas	Carbon dioxide	-17 to 6	Not defined
Partial oxidation	POX	Natural gas	Carbon dioxide	9 to 12	Grey

1 United Nations Economic Commission for Europe (UNECE). Technology brief – Hydrogen. Switzerland; 2021.

2 Although hydrogen is often referred to in a whole array of colours, these are not intended to give the ecological impact but just to indicate the process type used. In fact there is no universal consensus on the colour scheme indicating hydrogen production and some of the mentioned colours may change from one source to another.

3 Thomas N. From, Behzad Partoon, Marene Rautenbach, Martin Østberg, Anders Bentien, Kim Aasberg-Petersen, Peter M. Mortensen. Electrified steam methane reforming of biogas for sustainable syngas manufacturing and next-generation of plant design: A pilot plant study. Denmark; 2023.

Process	Abbreviation	Feedstock	Main by-product	Typical GHG emission in CO_2eq per $1kgH_2$	Colour[2]
Partial oxidation + CSS	POX	Natural gas	Carbon dioxide	1 to 3	Blue
Autothermal reforming[4]	ATR	Natural gas	Carbon dioxide	9 to 12	Grey
Autothermal reforming + CSS	ATR	Natural gas	Carbon dioxide	1 to 3	Blue
Gasification[5]	-	Coal / heavy residual oils	Carbon dioxide	20 to 28	Bituminous coal - Black Lignite - Brown Heavy Fuel Oil - Grey
Gasification + CSS	-	Coal / heavy residual oils	Carbon dioxide	3 to 6	Grey
Gasification	-	Biomass	Carbon dioxide	1 to 2	Blue
Gasification + CSS	-	Biomass	Carbon dioxide	-15 to -20	Blue
Pyrolysis[6]	-	Organic waste material	Carbon black	20 to 25	Grey
Water electrolysis[5]	-	Water / grid energy	Oxygen	Depends on electricity energy source	Yellow

Table 2 - Hydrogen production from renewable energy

Process	Feedstock	Main by-product	Typical GHG emission in CO_2eq per $1kgH_2$	Colour[2]	Comments
Water electrolysis	Water / Electric energy	Oxygen	1 to 2	Green	Efficiency depends on type of electrolyser
Thermochemical splitting[4]	Various compounds / Electric energy	Depends on reaction	Depends on reaction	Green	More than 300 proposed cycles
Water thermolysis	Water / Heat	Oxygen	1 to 3	Green	Energy-intensive

4 Mostafa El-Shafie, Shinji Kambara, Yukio Hayakawa. Hydrogen Production Technologies Overview. Journal of Power and Energy Engineering. Japan; 2019.

5 Jose M. Marín Arcos and Diogo M. F. Santos. The Hydrogen Color Spectrum: Techno-Economic Analysis of the Available Technologies for Hydrogen Production. Switzerland; 2023.

6 Olga Bicakova and Pavel Straka. The resources and methods of hydrogen production. Czech Republic; 2010.

Table 3 - Hydrogen production from nuclear energy

Process	Feedstock	Main by-product	Typical GHG emission in CO_2eq per $1kgH_2$	Colour[2]	Comments
Water electrolysis[5]	Water / Electric energy	Oxygen	1 to 2	Pink	Efficiency depends on type of electrolyser
Combined electrolysis and thermochemical water splitting[4]	Various compounds / Electric energy	Depends on reaction	Depends on reaction	Purple	More than 300 proposed cycles

4. Environmental Impact of Hydrogen

Hydrogen is often considered a clean energy carrier when it is produced with low or zero greenhouse gas emissions. However, its ecological impact can vary depending on how it is produced, stored, transported, and used. Following are some positive ecological impacts associated with hydrogen:

- Reduction of GHG emissions during production: When produced using renewable energy sources (e.g., solar, wind, hydro) through water electrolysis, no greenhouse gases are emitted, thus helping to significantly reduce carbon emissions compared to fossil fuels. Producing hydrogen via low-carbon methods, such as natural gas reforming with carbon capture and storage (CCS), can also help lower overall greenhouse gas emissions.

- Air quality improvement: When used in fuel cells, hydrogen produces only water and heat as by-products, emitting no pollutants. This can improve air quality, particularly in urban areas with high levels of vehicle emissions. Hydrogen combustion emits fewer pollutants like nitrogen oxides compared to traditional fossil fuels, provided advanced combustion technologies are used.

- Renewable energy integration: Hydrogen can store excess renewable energy, addressing the intermittency issues of wind and solar power. This stored hydrogen can be converted back to electricity or used in other applications when renewable generation is low. By acting as an energy carrier, hydrogen can help stabilize the grid, enabling a higher penetration of renewable energy sources.

- Decarbonization of hard-to-abate sectors: Hydrogen can replace fossil fuels in industrial processes such as steel manufacturing, which are challenging to decarbonize using electricity alone. Hydrogen fuel cells can power heavy-duty vehicles, ships, and aircraft, offering a low-emission alternative to diesel and aviation fuels.

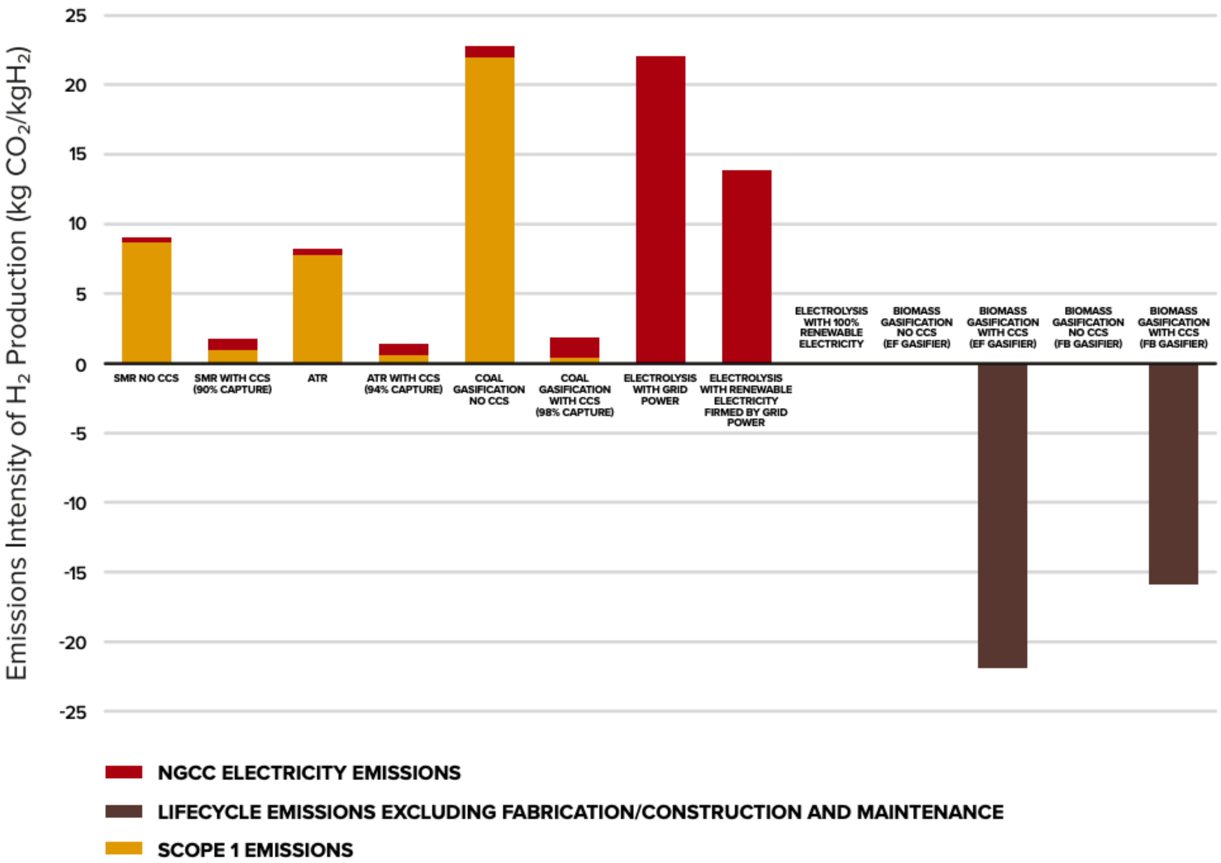
In order to accurately assess the ecological impact, the amount of greenhouse gases per kilogram of hydrogen produced (or energy in MJ contained in the hydrogen produced) needs to be evaluated. A low CO_{2eq} / kg H_2 or CO_{2eq} / MJ value is indicative of hydrogen production methods that contribute less to climate change, aligning with global efforts to reduce carbon emissions and limit global warming.

Greenhouse gas (GHG) emissions for various production routes is given below[7] using both entrained flow (EF) and fluidised bed (FB) gasifiers.

7 Global CCS institute. Blue hydrogen; 2021

Note that by combining Bioenergy with Carbon Capture and Storage (BECCS), the overall process is designed to achieve negative carbon dioxide emissions. This is because the carbon dioxide absorbed by plants during their growth is captured when the biomass is burned to produce energy.

Figure 1 - GHG emissions for various hydrogen production routes assuming the natural gas combined cycle generation carbon intensity used by national grids to be 111gCO2/MJ, EF = Entrained Flow. FB = Fluidised Bed[7]



a) Quantification of GHG emissions

ISO 14064[8] series of international standards provides guidelines and principles for quantifying and reporting greenhouse gas emissions and removals. The ISO 14064 standard consists of three parts:

- *ISO 14064-1: specification with guidance at the organisation level for quantification, monitoring and reporting of greenhouse gas emissions and removals:* This part of the standard provides guidelines for organisations to develop and manage a greenhouse gas inventory. It includes principles for the quantification, monitoring, and reporting of GHG emissions and removals at the organizational level. The aim is to help organisations assess their environmental impact and manage their greenhouse gas emissions in a systematic and transparent manner. Specific

8 International Organization for Standardization (ISO). ISO14064 series. Switzerland; Part 1 issued in 2018 and parts 2 and 3 in 2019.

guidelines on how to use ISO14064-1 are included in ISO/TR 14069:2013(en), "Greenhouse gases — Quantification and reporting of greenhouse gas emissions for organizations — Guidance for the application of ISO 14064-1". TR 14069:2013 builds on the existing International Standards and protocols on corporate GHG inventories and incorporates many of the key concepts and requirements stated in the GHG Protocol by the World Business Council for Sustainable Development/World Resources Institute ("the GHG Protocol").

- *ISO 14064-2: Specification with guidance at the project level for quantification, monitoring, and reporting of greenhouse gas emission reductions or removal enhancements:* Part 2 focuses on projects and provides guidance on quantifying, monitoring, and reporting GHG emission reductions or removal enhancements at the project level. This is particularly relevant for entities involved in specific projects, such as renewable energy projects, afforestation projects and emission reduction initiatives.

- *ISO 14064-3: Specification with guidance for the validation and verification of greenhouse gas statements:* Part 3 addresses the validation and verification process. It outlines the requirements and guidance for organisations and auditors to independently validate and verify the GHG assertions made in accordance with ISO 14064-1 and ISO 14064-2. This helps ensure the credibility and accuracy of reported greenhouse gas information.

ISO14065:2020, General principles and requirements for bodies validating and verifying environmental information, is required by many accreditation entities, such as the American National Standards Institute (ANSI), International Sustainability and Carbon Certification (ISCC), and Entidad Mexicana de Accreditation, AC (EMA, Mexico) for third-party GHG verifications. The 2020 edition replaces the previous edition (ISO 14065:2013). The Scope of the 2020 edition has been expanded to include bodies performing validation, verification and agreed upon procedures in all areas of environmental information (not only greenhouse gas); it has been aligned with the requirements of ISO/IEC 17029; Annex D has been added for additional requirements applicable to green bonds; Annex E has been added for additional requirements applicable to greenhouse gases; Annex F has been added for additional requirements applicable to non-financial disclosure.

ISO 14067 Greenhouse gasses, carbon footprint of products – requirements and guidelines for quantification. This document specifies principles, requirements and guidelines for the quantification and reporting of the carbon footprint of a product (CFP), in a manner consistent with International Standards on life cycle assessment (LCA) (ISO 14040 and ISO 14044). Requirements and guidelines for the quantification of a partial CFP are also specified. Lifecycle carbon footprint calculations are often required in climate-related policies and incentive programmes to measure performance of various energy pathways.

ISO 14060 series provide a framework for organisations to measure, monitor, report and verify their GHG emissions and removals in a consistent and transparent manner. These standards are widely used by businesses, governments and other organisations as a tool to assess and manage their environmental impact, demonstrate commitment to sustainability and engage in carbon management initiatives. They play a crucial role in supporting efforts to combat climate change by promoting standardised and credible reporting of GHG activities at both organisational and project levels.

5. Hydrogen Transportation

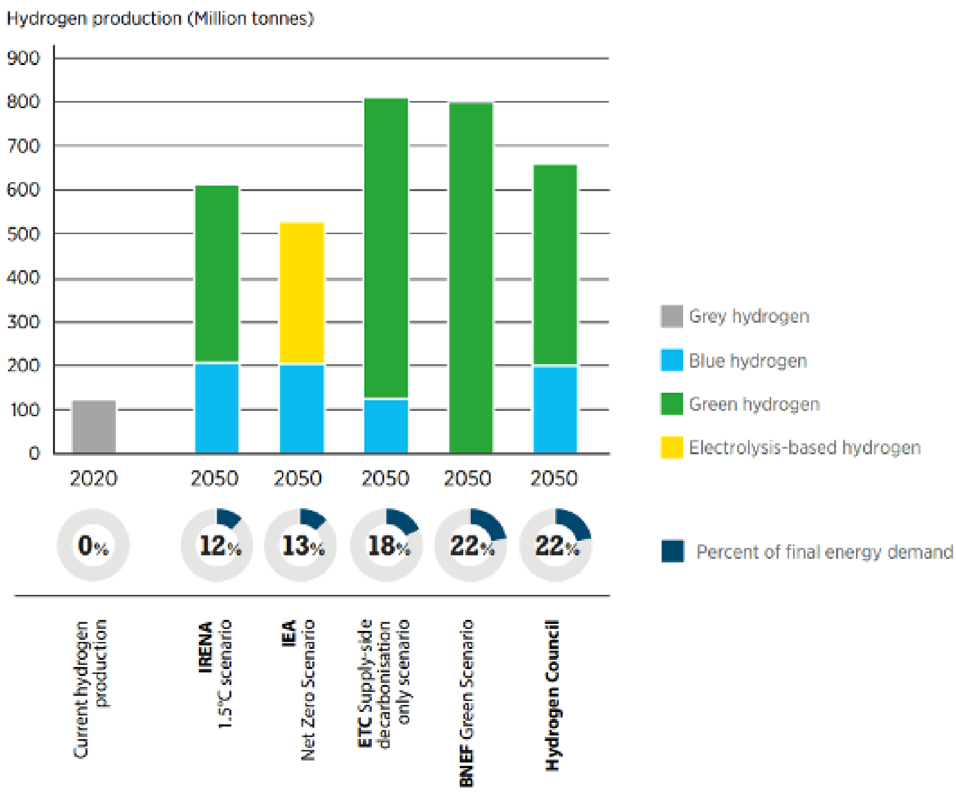
Today the majority of hydrogen is produced and consumed onsite, generally for petroleum refining, ammonia production and methanol production. However, there is growing interest in the use of hydrogen as a clean energy carrier in various sectors, including transportation, power generation and residential applications.

a) Likelihood of hydrogen requiring transportation

Estimates for hydrogen demand vary from 12% to 22% of the total energy demand in 2050, as shown below[9]. In these estimates green and blue hydrogen are prevalent, with grey hydrogen phased out completely.

Towards the middle and second half of this decade, there will be a significant increase in the number of hydrogen projects, which will become bigger and more complex. In the 2030s hydrogen projects will be increasingly driven by private initiatives (rather than the public sector). Beyond 2035, hydrogen projects will gravitate towards near-term commercial business cases. However, establishing a global hydrogen market requires a robust and extensive infrastructure for production, storage, transport and distribution. Developing such infrastructure is capital-intensive and faces challenges related to the need for new pipelines, storage facilities and distribution networks. Also, hydrogen trade involves geopolitical considerations, and establishing international frameworks for hydrogen trade may face challenges related to geopolitics and trade agreements.

Figure 2 - Estimates for global hydrogen demand in 2050[9]



9 International renewable energy agency (IRENA). Geopolitics of the energy transformation : The hydrogen factor. Abu Dhabi; 2022.

b) How can hydrogen be transported?

This will require transporting hydrogen on a large scale, which involves considering various options, each with its own advantages, disadvantages and suitability for specific applications. Here are some common methods for transporting hydrogen:

i. Pipeline

Hydrogen can be transported through dedicated pipelines, similar to natural gas pipelines. This is efficient and cost-effective for large volumes over relatively short distances. Suitable for continuous and high-volume transportation but with a low energy density since the gas density is low. However, it requires a dedicated pipeline infrastructure because even natural gas pipelines need to be modified to be suitable for transporting hydrogen. Additionally, hydrogen embrittlement is a concern, requiring specialised materials.

ii. Liquefied Hydrogen (LH_2)

Hydrogen can be cooled to an extremely low temperature of -253°C to be liquified (LH_2) for transport. This has a much higher energy density and is more suitable for long-distance transport in specially designed cryogenic tanks. However, in order to cool to such low temperatures, it requires an energy-intensive liquefaction process. Insulation and cryogenic storage infrastructure are even more critical than for LNG, and energy losses during liquefaction and regasification have to be closely monitored.

iii. Ammonia (NH_3)

Hydrogen can be converted to ammonia (NH_3) by the Haber-Bosch process[10]. The reaction process is as follows:

Haber-Bosch reaction: $3H_2 + N_2 \rightarrow 2NH_3$

The reaction is typically carried out over iron catalysts at temperatures around 400-600 °C and pressures ranging from 200 to 400 atmospheres. This can be used either directly as ammonia or converted back to hydrogen at the destination. The advantage is that ammonia is already a well-established and globally traded chemical. It is used in the fertilizer industry, in household cleaning products and as a refrigerant. The temperature needed for transportation is approximately -33°C and this requires less energy-intensive liquefaction than LH_2. Existing ammonia infrastructure can be leveraged. However, using ammonia as an energy carrier has environmental risks because it is highly toxic and corrosive.

iv. Methanol (CH_3OH)

Today methanol is used for a wide variety of applications such as chemical feedstock, solvent, fuel, antifreeze, plastic production, acetic acid production, biodiesel production and others. Methanol is mostly produced via low pressure methanol (LPM) which is a catalytic synthesis from natural gas[11]. Following SMR, the hydrogen-rich syngas is then fed into a reactor containing a catalyst, typically a copper-based catalyst, where it undergoes methanol synthesis. This reaction involves combining hydrogen and carbon oxides (carbon monoxide and carbon dioxide) to produce methanol.

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10 K.H.R. Rouwenhorst, P.M. Krzywda, N.E. Benes, G.Mul, L.Lefferts. Ammonia production technologies. Elsevier Ltd, Nederlands; 2021.

11 Daniel Sheldon. Methanol Production – A Technical History. Johnson Matthey Technol. Rev.; UK; 2017.

Methanol synthesis reactions: $CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$

$CO + 2H_2 \rightarrow CH_3OH$

The environmental impact of methanol production can be decreased by capturing the carbon dioxide after SMR and using carbon dioxide obtained from direct air capture.

Methanol is liquid at room temperature, which facilitates transportation. Existing methanol infrastructure can be used since this is already currently in use without needing major investments. However, if methanol is to be converted back to hydrogen, conversion processes at both ends are needed which reduce efficiency because these are energy-intensive conversion steps.

v. Hydrogen tube trailers

Hydrogen is compressed into high-pressure tube trailers for transport[12]. The most common trailers are 200 bar long horizontal metallic tubes with a capacity of 300-500 kg of hydrogen. New trailers using composite cylinders can reach up to 600 bar and a capacity of 1 tonne.

Tube trailers are flexible for medium distances and suitable for areas without extensive pipeline infrastructure. However, the transported capacity is bound by the trailer tubes and so it is limited when compared to continuous delivery by pipelines. Also, the higher the compression and decompression, the higher the energy required.

vi. Hydrogen cylinders

Hydrogen cylinders are used in portable fuel cells for applications such as backup power, remote power supplies, portable generators and in hydrogen refuelling stations. Utilized for small-scale, decentralized hydrogen production as they have a lower capacity compared to tube trailers. Used for local or regional distribution where the hydrogen demand does not justify the use of large tube trailers. They can also be employed in research and pilot projects to test hydrogen applications on a smaller scale before scaling up. They offer flexibility and cost-effectiveness for low-demand applications but require more frequent handling and logistics management.

The typical size of hydrogen cylinders varies widely based on their intended use, ranging from small 1 litre / 200bar cylinders for laboratory use to large 1,000 litre / 700 bar cylinders for industrial and refuelling station applications having a capacity of about 15 g and 39 kg hydrogen respectively.

vii. Liquid organic hydrogen carrier

Liquid Organic Hydrogen Carriers (LOHCs) are chemical compounds that can store and release hydrogen[13]. LOHCs work by chemically binding and releasing hydrogen reversibly. The process involves the hydrogenation of the LOHC to store hydrogen and the dehydrogenation to release hydrogen.

The advantage of LOHCs is that they can store a relatively large amount of hydrogen at ambient conditions, and the release of hydrogen can be triggered when required. Additionally, LOHCs can be handled and transported like conventional liquid fuels, and so existing infrastructure can be used. They are suitable for long-distance transport over water and can be adapted for large volumes.

12 Deborah Houssin, Elena Vyazmina, Sébastien Quesnel, Quentin Nouvelot, Ju Lynne Saw, Sylvaine Pique, Nick Hart, Stephan Montel, Matteo Robino, and Markus Jenne. State of the Art on hydrogen technologies and infrastructures regarding a multi-fuel station environment. MultHyFuel; 2021.

13 Purna Chandra Rao and Minyoung Yoon. Potential Liquid-Organic Hydrogen Carrier (LOHC) Systems: A Review on Recent Progress. Energies, South Korea; 2020.

Common examples of LOHCs include various organic compounds, such as systems composed of methylcyclohexane/toluene, decalin/naphthalene, dibenzyltoluene/perhydro-dibenzyltoluene, perhydro-benzyl toluene/2-benzyltoluene and many others. These compounds are chosen for their ability to reversibly bond with hydrogen and for their stability under typical operating conditions over long-life cycles. Efficiency depends on the LOHC carrier, reaction catalyst, stability of LOHC molecules and biodegradability of LOHC molecules. Another consideration for large scale adoption is that the molecules selected must have an acceptable eco-toxicity profile, low melting point, high boiling point, high volumetric hydrogen storage capacity as well as low production cost.

viii. Solid storage

Solid-state hydrogen storage refers to methods where hydrogen is absorbed, adsorbed or chemically bonded to a solid material[14,15]. These materials are designed to release hydrogen under specific conditions and promise safe and efficient hydrogen storage. Several solid storage options for hydrogen are being explored, such as metal hydrides, chemical hydrides, carbon-based materials and complex hydrides. One major advantage of hydrogen storage in metal hydrides is the ability to store hydrogen in a very energy efficient way, enabling hydrogen storage at rather low pressures without further need for liquefaction or compression.

Each of these solid-state hydrogen storage methods has its advantages and challenges. Factors such as hydrogen storage capacity, release kinetics, thermodynamics and operating conditions are crucial considerations in evaluating the feasibility of these technologies. Research and development efforts are ongoing to improve the performance, efficiency and safety of solid-state hydrogen storage options for various applications, including fuel cell vehicles and stationary energy storage. The main drawback of this storage option remains the comparatively heavy weight and high price.

The below table provides a summary of the various transportation methods for hydrogen and their associated hazards.

Table 4 - Hydrogen transportation methods comparison

Transportation Method	Transportation temperature (˚C)	Production energy % of H_2 LHV consumed	Liters needed per kg of H_2	Associated hazards	Comments
Pipeline	Ambient (15 ˚C)	3-4 at 10bar 10-15 at 700bar	1217 at 20˚C 25.6 at 20˚C	Material Compatibility, Leak Detection	Lowest transportation costs. Low energy consumption but lowest hydrogen density.
Liquefield	-252.95	30 - 35	14.3	Cryogenic Temperatures, Boil-off	Highest transportation costs with highest energy consumption and low hydrogen density.

14 Nejc Klopcic, Ilena Grimmer, Franz Winkler, Markus Sartory, Alexander Trattner. A review on metal hydride materials for hydrogen storage. Journal of energy storage. Austria; 2023.

15 Martin Dornheim. Thermodynamics of Metal Hydrides : Tailoring Reaction Enthalpies of Hydrogen Storage Materials. Institute of Materials Research, Department of Nanotechnology, Helmholtz-Zentrum Geesthacht. Germany; 2011.

Transportation Method	Transportation temperature (˚C)	Production energy % of H_2 LHV consumed	Liters needed per kg of H_2	Associated hazards	Comments
Ammonia	-33.3	15 - 20	8.3	Toxicity, Aquatic Toxicity, Flammability, Corrosivity, Leakage	Medium transportation costs with lowest energy consumption and highest hydrogen density. When combusted NO_x is released. To be green, N_2 must originate from air.
Methanol	Below 65	20	10.0	Flammability, Toxicity, Aquatic Toxicity, Corrosivity, Volatility	Low transportation costs with medium energy consumption and hydrogen density. When combusted CO_2 is released. To be green, CO_2 must originate from air, which drives up costs.
Tube trailers and cylinders	Ambient (15 ˚C)	7-8% at 200bar 9-10% at 600bar	67 at 200 bar 28 at 600 bar	High Pressure, Road collision risks	Facilitates distribution of hydrogen to end-users, such as industrial plants, fuelling stations in absence of pipeline infrastructure.
LOHC (using methylcyclohexane / toluene)	Below 101	30	21.1	Chemical Compatibility, Controlling hydrogenation and dehydrogenation reactions	Low transportation costs with high energy consumption and low hydrogen density. Greatly depends on medium used.
Solid storage (using MgH_2 metal hydride)	Ambient	32	8.4	Temperature and Pressure Control, Hydride Degradation	High volumetric storage density and relatively mild operating conditions but comparatively heavy weight and high price. Contaminations result in high extraction times.

Note that hydrogen has a significantly higher LHV (energy content of a fuel when it is burned and the products of combustion are cooled to the initial temperature) of 120 MJ/kg as compared to both ammonia (of 18.6 MJ/kg) and methanol (of 19.7 MJ/kg). Thus, even though compressed hydrogen in a pipeline at 700 bar needs 25.6 L/kg of hydrogen while ammonia needs 8.3 L/kg of hydrogen and methanol needs 10.0 L/kg of hydrogen, the volumetric energies equate to 4.7 MJ/L, 2.4 MJ/L and 2.0 MJ/L respectively for 1kg of hydrogen transported.

The choice of transport method depends on factors such as distance, volume, infrastructure, safety considerations and energy efficiency. Often, a combination of these methods may be used in an integrated hydrogen supply chain. Ongoing research and development aim to address the challenges associated with large-scale hydrogen transport and improve the safety of these processes[16].

16 Hao Li, Xuewen Cao, Yang Liu, Yanbo Shao, Zilong Nan, Lin Teng, Wenshan Peng, Jiang Bian. Safety of hydrogen storage and transportation: An overview on mechanisms, techniques, and challenges. Elsevier Ltd, China; 2022.

It's important to note that safety measures and regulations are continually evolving as the hydrogen industry develops. Research, technological advancements and adherence to safety standards are critical for minimising risks associated with hydrogen transportation.

6. Hydrogen Quantity and Quality Standards

Hydrogen fuels are classified as three different types: Type 1 refers to gaseous hydrogen, Type 2 refers to liquid hydrogen, and Type 3 refers to slush hydrogen, a mixture of solid hydrogen particles in liquid hydrogen at the triple point that can be used as fuels for spacecraft.

International Organization for Standardization (ISO) 14687:2019(E)[17] further specifies hydrogen in various grades, where the minimum quality characteristics are defined for relevant applications, where:

For Type 1 Gaseous Hydrogen,

- Grades A refers to applications in internal combustion engines for transportation, residential and commercial combustion appliances such as boilers and cookers.
- Grage B refers to applications in power generation and heat generation except for Proton Exchange Membrane (PEM) fuel cells.
- Grade C refers to applications in aircraft and space-vehicle ground support systems except for PEM fuel cells.
- Grade D refers to applications in PEM fuel cells for on-road vehicles. Grade D specifications may also be applied to forklifts and industrial trucks, if agreed upon by suppliers and customers.
- Grade E refers to applications in PEM fuel cells for stationary appliances.

For Type 2 Liquid Hydrogen,

- Grade C refers to applications in aircraft and space-vehicle on-board propulsion and electrical energy requirements, as well as off-road vehicles.
- Grade D refers to applications in PEM fuel cells for on-road vehicles.

For Type 3 Hydrogen Slush,

- No grade specified. Hydrogen slush applies only to aircraft and space-vehicle on-board propulsion.

Compressed Gas Association (CGA) G5.3-2017 has similar specifications for hydrogen grades, as defined based on the quality verification levels (QVLs) and the corresponding uses, where[18]:

For Type 1 Gaseous Hydrogen,

- Grade B refers to general industrial applications.
- Grade D refers to fuel, hydrogenation, and water chemistry applications.

17 International Organization for Standardization (ISO). ISO 14687:2019. Hydrogen fuel quality - Product specification. Switzerland; Published (Edition 1, 2019).

18 American National Standards Institute (ANSI). CGA G-5.3-2017: Commodity Specification for Hydrogen – 7th Edi-tion.

- Grade E refers to hydrogenation, food, and beverage applications.
- Grade F refers to analytical instrumentation, propellant, and fuel cell applications.
- Grade L refers to semiconductor, analytical, specialty and fuel cell applications.

For Type 2 Liquid Hydrogen

Grade A refers to standard industrial, fuel, fuel cell, and propellant applications per MIL-PRF-27201E.

- Grade B refers to high-purity industrial fuel, fuel cell, and applications.
- Grade C refers to semiconductor and fuel cell applications.
- Grade E refers to hydrogenation, food, and beverage applications.
- CGA does not have QVL specifications for Type 3 hydrogen slush.

Despite the similarities in classifications, it should be noted that the ISO and CGA grades may have different specifications for hydrogen fuels used for the same application. Table 5 below compares the specifications for Type 1 Grade D hydrogen fuels under the ISO standard and Type 1 Grade FC under the CGA standard for fuel cell vehicles.

Table 5 - Fuel Quality Specifications for Fuel Cell Road Vehicle Applications

Constituents / Limiting Characteristics	**ISO 14687:2019 Grade D** Unit = mole fractions	**CGA G-5.3 – 2017 Grade FC** Unit = v/v unless otherwise stated
Hydrogen (minimum %)	99.97	99.97
Total impurity limit (maximum)	300 ppm	100 ppm (without Helium) 300 ppm (with Helium)
Individual impurity limits (maximum)		
Water	5 ppm	5 ppm
Total Nonmethane Hydrocarbon	2 ppm (as C1)	2 ppm (as methane)
Methane (CH_4)	10 ppm	-
Oxygen (O_2)	5 ppm	5 ppm
Helium (He)	300 ppm	300 ppm
Nitrogen (N_2)	300 ppm	100 ppm
Argon (Ar)	300 ppm	100 ppm

Constituents / Limiting Characteristics	ISO 14687:2019 Grade D Unit = mole fractions	CGA G-5.3 – 2017 Grade FC Unit = v/v unless otherwise stated
Carbon Dioxide (CO_2)	2 ppm	2 ppm
Carbon Monoxide (CO)	0.2 ppm	0.2 ppm
Total Sulfur Compounds (H_2S, COS, CS_2, mercaptan)	0.004 ppm (as S1)	-*
Sum of (CO, HCHO, HCOOH)	0.2 ppm	-*
Ammonia (NH_3)	0.1 ppm	-*
Halogenated Compounds	0.05 ppm (halogen ion equiv.)	-*
Total PM	1 mg/kg	1 mg/kg

*CGA G5.3-2017 stated that total sulphur, formic acid, ammonia, and total halogenates are not typically analysed but are detrimental to fuel cells. The same limits as those in the ISO 14687:2019(E) standard are cited in Table 4 of the CG A standard but referenced as SAE J2719 specifications.

Typically, hydrogen purity is determined via the following methods:

- Thermal conductivity detector (TCD) that measures the aggregated impurities that have different thermal conductivity as hydrogen. Hydrogen purity is calculated as 100% subtracted by the percentage of total impurities.
- Determining the amount of impurities through a set of analytical methods and subtracting the total aggregated volumetric or molar percentage from 100% to get hydrogen purity.
- Volumetric or manometric gas analyser that extracts hydrogen from collected samples via chemical or physical adsorption and measures quantities of hydrogen using gas laws.

a) Analytical methods for testing impurities in hydrogen fuels

Impurities in hydrogen fuels consist of both inert and reactive contaminants, which could potentially affect the performance of the hydrogen production, storage, transmission and end use systems, some of which are irreversible.

The impurities to be analysed are generally determined by the hydrogen producers and the buyers or the distributors. The ISO 14687:2019(E) Standard Annex B summarised the rationale for the selection of hydrogen impurities to be measured for PEM fuel cell stationary applications[19].

The analytical methods for testing impurities for the fuel cell vehicle applications can be found in Table 2 of ISO 21087: 2019 (E), Sections 6.3 to 6.11 in the CGA G-5.3 – 2017, and Section 2 of the SAE J2719:2020 Standards. Other test methods can be applied, provided they have been fully validated in accordance with pertinent standards.

19 Ongoing hydrogen standard development efforts:
- https://www.iso.org/committee/54560/x/catalogue/p/0/u/1/w/0/d/0
- https://www.astm.org/get-involved/technical-committees/committee-d03/subcommittee-d03

b) Analytical methods for hydrogen-derived fuels

Methanol

Methanol specifications typically include parameters related to purity, impurities content, physical properties and chemical properties. These specifications may vary slightly depending on the intended use of the methanol and the industry standards followed. Some of the most common methanol specifications include :

- Water, because excessive water can affect the performance of methanol in various applications, particularly in fuel blending.
- Acidity, ensuring low acidity in order to avoid corrosion in equipment and compatibility with downstream processes.
- Limits on the content of specific impurities such as ethanol, acetone, formaldehyde, and other volatile organic compounds.
- Purity, with high-purity methanol often required for certain applications such as fuel blending or chemical synthesis.

Methanol specifications used by producers, consumers, traders and regulatory bodies :

- IMPCA (International Methanol Producers and Consumers Association) for various applications such as fuel blending with gasoline, biodiesel production, fuel cell applications, chemical synthesis, solvent applications, production of plastics, adhesives, detergents, and as a coolant or antifreeze.
- ASTM D1152 specifications for industrial applications such as chemical synthesis, solvent extraction, and manufacturing processes.
- ASTM D 5797 for blending methanol with gasoline from 51 to 85% volume as an automotive fuel.
- ISO 6583 for use of methanol in marine applications or similar land based diesel engines or fuel cells.

Ammonia

Currently there are several grades of anhydrous ammonia available in the market, including premium or metallurgical (Met-grade) ammonia at 99.995% purity, refrigeration (R-grade, R-717) ammonia at 99.98% purity, and commercial or agricultural (C-grade) ammonia at 99.5% purity. The C-grade ammonia is typically the cheapest and most readily available. Ammonia standards are developed to address potential leaks and their impact on operational safety and the environment, such as the Occupational Safety and Health Administration (OSHA) 1910.119 for process safety management of highly hazardous chemicals that applies to systems containing 10,000 lbs. of ammonia or greater. ASTM E1066/E1066M-19, "Standard Practice for Ammonia Colorimetric Leak Testing: Significance and Use", is a method used for locating and measuring the size of gas leaks either as a quality-control test or as a field-inspection procedure. It can be used to test critical parts or containers that will hold toxic or explosive gases or liquids or as a quick test for other containers.

Currently, specifications for ammonia are for other uses (mainly fertilizer), but there are no specifications for its use as fuel. There are several parallel efforts on developing ammonia standards for fuels:

- The Ammonia Energy Association (AEA) Fuel Standard Committee has been developing a draft product specification that will facilitate the acceptance of ammonia as a fuel. A draft standard was discussed in a panel discussion in 2020; however, to date it has not been officially released.

- ISO/AWI 23397 is a standard under development. It is intended to define a standardised terminology for ammonia fuel systems for ships and marine technology, in accordance with "Guidelines for ships using ammonia as fuel" developed by the Carriage of Cargoes and Containers (CCC) Sub-Committee of the International Maritime Organization (IMO). This document applies to the use of ammonia as fuel on various ship types but is not applicable to ships carrying ammonia as cargo.

- The IMO CCC Sub-Committee hosted the 9th session in September 2023 to work on interim guidelines for the use of ammonia and hydrogen as fuel, to finalise amendments for the International Gas and other low-flashpoint Fuels (IGF) Code, and to discuss amendments to the International Gas Carrier (IGC) Code for gas carriers and the IMSBC and IMDG Codes on dangerous cargo.

c) Sampling of hydrogen fuels for off-line testing

Sampling is required for off-line testing in the laboratories. ISO 19880-1 (2020) and CGA G-5.3 – 2017 standards have detailed descriptions of the sampling points, sample sizes, sampling procedures for gaseous and liquid hydrogen fuels, as well as safety issues related to sample collection, handling and shipping.

The following rules of thumb are recommended by the standards:

- Sampling points can be anywhere between the hydrogen supplies (i.e., hydrogen containers, dispensers) and applications (i.e., fuel cell vehicles, receiving points at the hydrogen processing, distribution, or end-use facilities).

- Sample size should be sufficient for all impurity testing procedures. If duplicated samples are needed, the sample collection process and conditions should be identical to the original process.

- When withdrawing samples from hydrogen containers or dispensers, the sampling bottles should be properly purged and vacuumed to avoid contamination and the presence of air or other flammable chemicals. The sampling bottles should be properly connected to the hydrogen containers/dispensers without a pressure regulator. Additionally, ensure that all liquid hydrogen is vaporized in the sampling bottles.

- Particular matter can be collected by adding a 0.2-micron PTFE membrane filter disk between the containers/dispensers and the sampling bottles.

- Sampling devices should be properly maintained, calibrated, cleaned (mostly purged) and verified before each use. No water or solvent shall be used during the purging process.

Specialized sampling devices for Particulate Matter are also now available for use as either low pressure (e.g., electrolyser) or high pressure (at HRS stations) sampling of Hydrogen[20].

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20 Thor Anders Aarhaug, Thomas Bacquart, Robert Boyd, Christina Daniels. Review of sampling and analysis of particulate matter in hydrogen fuel. Elsevier, USA; 2023.

d) Hydrogen quantification

There are no internationally recognised standards for hydrogen quantification in all its phases [gas, liquid, solid and supercritical]. TIC members can strive to harmonise a methodology for quantification in order to diminish variances between ports / locations. Quantifying hydrogen can be achieved using various methods, each with its specific applications, advantages, and limitations. The main techniques to quantify hydrogen, include mass flow meters (such as Coriolis mass flow meters), volumetric flow meters (such as ultrasonic flow meters), gravimetric analysis, pressure and temperature sensors, and gas chromatography (GC). Mass flow meters and volumetric flow meters are widely used in industrial applications for real-time measurements, while gravimetric analysis and gas chromatography are more suited for high-precision laboratory work. Pressure and temperature sensors are cost-effective and commonly used in combination with other methods to provide comprehensive data.

e) Standards under development

There is an existing body of knowledge on hydrogen classifications, quantification, quality control and safety. The hydrogen classifications are still valid for a majority of current applications. However, current analytical procedures and limits set for impurity testing are primarily applied to PEM-type fuel cell vehicles only. There is a lack of standards to characterise hydrogen production processes (i.e. water electrolysis, SMR or ATR with carbon capture, biomass gasification, and reforming), hydrogen conversion to ammonia or methanol as fuel products, ammonia cracking and purification to yield clean hydrogen, as well as hydrogen end use as dedicated or blended fuels for power generation, home heating, and transportation. Furthermore, the hydrogen-derived ammonia and methanol fuels can also be used directly for power generation, where fuel specifications and impurity testing procedures are also lacking.

- ASTM D03 and ISO TC 197 are actively updating current standards and developing new standards toward these applications. Examples of some ongoing efforts include[17]:
- ISO/DIS 14687 – Hydrogen fuel quality: Product specification.
- ISO/DIS 22734-1 – Hydrogen generators using water electrolysis, Part 1: General requirements, test protocols and safety requirements.
- ISO/DIS 24078 – Hydrogen in energy systems: Vocabulary.
- ASTM WK88493 – Revision of D8487-23 Standard Specification for Natural Gas, Hydrogen Blends for Use as a Motor Vehicle Fuel.
- ASTM WK84428 – Revision of D7265-12(2018) Standard Specification for Hydrogen Thermophysical Property Tables.

7. What is the TIC industry’s role in hydrogen value chains?

The mission of the Testing, Inspection and Certification (TIC) sector is to offer independent conformity assessment services, either for regulatory purposes or to promote good practice, in order to protect people and the environment. Our activities can include supply chain certifications, industrial site inspections, management system auditing and certification, pre-shipment inspections and many other services. The TIC industry is a major contributor to the global economy and quality of daily life around the world, since it provides a guarantee that products and services are safe, secure, effective, reliable, of good quality and sustainable.

With this mission in mind, the experts working in the TIC industry are uniquely placed to holistically enable the build out of the hydrogen sector. At project conception, we can provide design review services, evaluating the safety, feasibility and environmental impact of a project at the earliest stage. Having this evaluation conducted by an independent third party enhances stakeholder confidence to move the project forward.

The involvement of TIC companies in any value chain engenders trust, and in the hydrogen industry the use of our services will provide operators with a method of assuring authorities, local communities, investors, and all other stakeholders of the viability, safety and sustainability of a hydrogen project. In addition, TIC firms are a valuable source of regulatory insight and can offer technical expertise to assist in navigating an evolving framework of standards, codes and regulations.

TIC companies can help hydrogen operators mitigate risk by providing risk and industrial safety assessments, to ensure staff, equipment and assets are protected from injury, damage and accidents. We can certify production assets, electrolysers and refuelling stations to confirm compliance with technical and safety standards. We can test and assess material and components of transporting pipelines for suitability and certify according to existing standards, and can supervise loading and offloading, where hydrogen or its derivatives are shipped.

We can support a hydrogen project's ongoing success by assisting the operator to continually measure performance. To certify GHG emissions for processes used, operators will need to demonstrate the environmental impact of their assets, supported by independently verified data. TIC firms can calculate carbon footprints of production assets, monitor pipelines for leakage and measure fugitive emissions. To assure the quality of hydrogen produced, we can provide sampling and analytical services.

Producers of sustainable green hydrogen face a unique challenge in demonstrating the environmental, social, and governance (ESG) credentials of their product to environmentally conscious users. To ensure that the hydrogen labelled as 'green' truly meets sustainability standards, it is essential to provide verifiable proof of its low-carbon production process. This involves rigorous assessment of the entire production lifecycle, including the exclusive use of renewable energy sources, tracking the carbon footprint, and ensuring transparency in reporting.

Voluntary certification schemes—and likely future mandatory schemes—play a critical role in this verification process. Testing, Inspection, and Certification (TIC) firms can assess a green hydrogen production asset against stringent ESG criteria. If all requirements are met, they issue a renewable hydrogen label, providing a credible endorsement of the product's sustainability. This certification not only helps producers meet regulatory and market expectations but also enhances their product's appeal to ESG-focused investors and consumers by offering clear and trustworthy proof of its green credentials

The TIC industry is founded on the principles of independence and impartiality. Through our expertise, worldwide presence and knowledge of local regulations and requirements, we are dedicated to supporting a just and responsible energy transition and to preventing greenwashing activities. Only the TIC industry is able to conduct physical onsite inspections, rather than paper-based remote audits, and in this regard, only we can provide true confidence for society in hydrogen products and related services that meet the relevant regulatory requirements and standards for safety, security and sustainability.

TIC companies also advocate for the development of appropriate regulations and standards within the hydrogen industry. TIC companies contribute valuable insights to policymakers and industry stakeholders, helping to shape effective regulatory frameworks that promote safety, sustainability and innovation.

Editor's Note About TIC Council

TIC Council is the global trade association representing the independent third-party Testing, Inspection and Certification (TIC) industry which brings together about 100-member companies and organizations from around the world to speak with one voice. Its members provide services across a wide range of sectors: consumer products, medical devices, petroleum, mining and metals, food, and agriculture among others. Through provision of these services, TIC Council members assure that not only regulatory requirements are met, but also that reliability, economic value, and sustainability are enhanced. TIC Council's members are present in more than 160 countries and the wider TIC sector currently employs more than 1 million people across the globe.

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