H2Global Hydrogen Europe

Standardizing Hydrogen Certification

STANDARDIZING HYDROGEN CERTIFICATION: ENHANCE TRACEABILITY, TRANSPARENCY, AND MARKET ACCESS

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Authors:

Dr. Maximilian Kuhn & Peter Koop
with contributions from Petra Michalke and Dr. Jörg Aign

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Foreword

As the hydrogen era dawns, we are met with enormous potential for a cleaner, more sustainable future. However, this future hinges on our ability to establish universally applicable and rigorous standards for hydrogen certification. The European Union (EU) is ideally positioned to pioneer this initiative, and this paper is a concerted effort towards providing guidance in this pivotal endeavour.

The EU has set the rules for domestic and imported hydrogen in Europe through the Delegated Acts and REDII. At the same time, other regional schemes are developing and there is a need for global harmonisation and mutual recognition. Such criteria, combined with a rigorous verification framework, provide a linchpin for promoting sustainable market development. The implications extend beyond environmental integrity to economic catalysts, which, instil confidence in producers and off-takers by mitigating investment risks and enabling the monetization of a 'green premium', thereby driving robust investment activity.

We stand at a crucial junction in the global energy transition, hoping this paper not only guides policy and decision makers but also contributes to the wider discourse on sustainable energy. The goal is clear - to standardize hydrogen certification assisted by a digital toolbox and, through this, foster a market conducive to the growth and acceptance of hydrogen as a sustainable energy source. The overarching objective is to enable a sustainable future in which the hydrogen economy thrives. This paper delves into these issues, advocating the use of digital tools to boost the traceability and transparency of the hydrogen trade, easing global trade, and accelerating the transition to a hydrogen-based economy.

Jorgo Chatzimarkakis, CEO, Hydrogen Europe: "*Hydrogen's potential is clear. To overcome the initial hurdles, we need a stable regulatory framework, robust markets, and a standardized hydrogen certification process.*"

Markus Exenberger, Executive Director of H2Global Foundation: "*To all who wish to understand the intricacies of the hydrogen economy and its future potential, I highly recommend this enlightening work.*"

Holger Lösch, Deputy Director General of the BDI: "*As a future importer of hydrogen, we must not withdraw to the island of Europe when it comes to the question of the right standards. This is followed by a powerful and self-confident advocacy for the integration of the European standardization system into the international system. A retreat to the island of Europe would entail additional hurdles for the import and certification of hydrogen and hydrogen derivatives from non-EU countries. German industry needs pragmatic and technology-neutral solutions that do not further slowdown the hydrogen ramp-up. This policy brief sets out ways in which we can address these challenges*".

Kirsten Westphal, member of the general executive management board of BDEW: "*Germany and the EU will remain importers of energy. A functioning global market is essential for diversified and affordable supplies of hydrogen and its derivatives in the future. This work presents an internationally interoperable, comprehensive and accessible approach to hydrogen certification. The authors highlight the importance of digital tools for improved traceability, and underscores the EU's crucial role in setting renewable standards. This insightful piece is key to guiding decision-making towards a global and sustainable hydrogen economy.*"

Abstract

This Policy Brief describes the need for, and benefits of globally harmonized standards and certification processes across the hydrogen value chain. The currently starting market ramp-up is based on an increasing need for sustainability. Here, certification is a major tool supporting policies allowing monetizing the sustainability value. However, this is associated with major challenges: lack of globally aligned cross-sector certification standards and lack of integration among existing certification services. Addressing these challenges is a long-term endeavour requiring a step-wise approach to internationally establishing uniform criteria, mutual recognition of certification services, and reliable and trustworthy certificates. Digital certification tools and practices are a major opportunity in this development, automating and simplifying processes while potentially supporting different definitions, certificates, sustainability frameworks and carbon accounting methodologies, which are established or under development worldwide at all regional, global and sectoral levels.

Increasing harmonization will facilitate both project financing and interoperability, and overall liquidity. In general, the speed at which the hydrogen and derivatives markets can ramp up will be accelerated. This is particularly important for Germany set to become a net importer of hydrogen and derivatives in the coming years. We will show in this paper that comprehensive and cross-industry digital operational solutions already exist, which are able to support the variety of regulatory frameworks and customer requirements.

Certification, interoperability, authentication/ transparency, trust and portability across sectors are key requirements for such solutions. The production and use of hydrogen and its derivatives is not an end in itself, but a means to achieve climate neutrality - for Germany by 2045 and in the EU by 2050.

This Policy Brief proposes to use digital twin technologies (e.g., blockchain) to enhance traceability, transparency and interoperability across the hydrogen value chain.

Hydrogen molecules do not have a specific 'fingerprint' that contains information about where they come from, how sustainable they are and how they were produced. Therefore, this core information needs to be carried along the value chain to provide actionable information to customers and regulators (e.g., under the European Renewable Energy Directive, the Carbon Border Adjustment Mechanism, etc.) or landing points/import terminals via certification.

All in all, swift market adoption necessitates trustworthy certification processes, bolstered by automated digital tools. In order to improve traceability and transparency, and thus facilitate global market access, these processes should ideally standardize hydrogen certification.

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I. The Need for Standards and Certification

Standardization may be considered purely technical, dry and boring. It may seem that only geeks are interested in regulations, codes and standards. But in reality, standards are the silent and often forgotten foundations of our technical and digitally driven society[1]. Standardization plays a crucial role in our modern society, serving as the foundation for the development and introduction of new technologies. Hydrogen is no exception. Despite their technical nature, standards are essential for ensuring product reliability, safety, interoperability, sustainability and are facilitating tradability and fungibility of equipment and products. In general, standards promote global trade and economic growth, with estimates suggesting that standardization contributes annually around 30% to economic growth and is worth approximately 1% of the annual gross domestic product. Furthermore, every euro spent on standards yields a 20-fold return on investment[2].

Without adequate standards, products could not meet the necessary safety and quality requirements, especially in the energy industry where safety is paramount. Standards facilitate the interchangeability, replacement, and recyclability of products, making an important contribution to diversified and resilient supply chains as well as to a transition towards a circular economy. Standards act as engines for change and innovation, shaping our daily lives and having an impact on our work and communication. Standards thus make an essential contribution to the transformation to a circular economy.

For consumers, standards provide a guarantee of safety, reliability, and conformity in product use. Standards and certification ensure trust, a crucial element in establishing a liquid hydrogen market with sustainable value chains. Like organic food, consumers need to know they're getting what they pay for, especially since green, climate-neutral hydrogen will cost more than conventional alternatives for the foreseeable future. Firms benefit from standards, as these offer investment security, allowing for the safe production of products that meet the required standards for European and international markets. Moreover, standards provide common reference points for firms along the value chain. This provides the basis for scaling-up production in new markets and for building platforms for innovation. Active participation in standardization is a strategic decision, enabling companies to contribute their own technologies and ideas while also helping to shape safety specifications in areas such as occupational health and safety, environmental protection, consumer protection, and general health protection.

Substantial effort is required for scaling-up the production of hydrogen in order to reach installed electrolysis capacity targets by 2030. These were doubled by the German Federal Government to

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[1] *DIN (2018):* Digitalisierung gelingt nur mit Normen, Positionspapier

[2] *DIN (2000)*: *Gesamtwirtschaftlicher Nutzen der Normung*, 3 Volumes, Berlin: Beuth.

10 gigawatts (GW) from the original 5 GW[3]. The EU's REPowerEU plan[4] targets over 20 million tonnes (Mt) of green hydrogen production per year, half from domestic production and half to be imported by 2030.[5] In its recent background paper, the German National Hydrogen Council estimates a demand of about 56 to 93 terawatt hours (TWh) annually by 2030.[6] A significant amount of this will need to be imported. On the one hand, the expansion and space for renewable energies in Europe is not sufficient, and on the other hand, the basic conditions for electricity / hydrogen production are much better in other regions (up to twice as many full-load hours), which has an impact on production costs.

Achieving these targets is a daunting task because neither exports nor an international market is yet established and operational. Moreover, according to the International Energy Agency (IEA) even though the number of announced hydrogen projects are increasing exponentially, only four per cent are in construction or have reached final investment decision.[7] Among the challenges concerning the ramp-up of climate-neutral hydrogen technologies and the creation of a market, uncertainties about future regulatory frameworks are a significant barrier to investment. The lack of consistent certification and standardization has been identified by many as one barrier.

Currently there is no uniform certification system for hydrogen suitable for cross-border trade, as shown in a new report by the International Renewable Energy Agency (IRENA)[8]. Various voluntary standards, energy labels and certificates are being introduced within specific industrial sectors e.g., International Renewable Energy Certificates (I-REC), Renewable Energy Certificates (REC) in North America and Guarantees of Origin (GoO) for electricity in Europe, green hydrogen certification schemes like TÜV NORD-H2-Label by TÜV NORD, CMS70 by TUEV SUED, CertifHy and Carbon Certification schemes like e.g., ISCC plus. These labels and certificates are decoupled from the physical flow of energy and are not consistent in terms of creating, transferring and devaluing certificates. In the context of establishing a certification scheme, it is of paramount importance to comprehensively define the scheme boundary. This includes a thorough incorporation of all pertinent raw data and a prioritization of the major emission sources embedded within the hydrogen production value chain. Consequently, there is an urgent need for a robust, universally applicable

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[3] Press and Information Office of the Federal Government (2021): Mehr Fortschritt wagen - Bündnis für Freiheit, Gleichheit und Nachhaltigkeit. Coalition agreement between SPD, Bündnis 90/ Die Grünen and FDP.

[4] European Commission (Strasbourg, 8 March 2022): REPowerEU: Joint European Action for more affordable, secure and sustainable energy.

[5] van Hulst, Noé / Westphal, Kirsten (2022): Now is the time to get hydrogen off the ground in Europe.

[6] Wasserstoffrat (2023): Grundlagenpapier: Treibhausgaseinsparungen und der damit verbundene H2-Bedarf in Deutschland, p1.

[7] IEA (April 2023): Towards hydrogen definitions based on their emissions intensity.

[8] IRENA (2023): Creating a global hydrogen market: Certification to enable trade.

set of sustainability criteria. This is due to the critical role such a system will play in providing a consistent, objective assessment of the environmental footprint associated with hydrogen production processes.

II. Hydrogen's Unique Edge: Exploring the Distinct Values

Hydrogen and its derivatives are key enablers for the energy transition in Europe due to their versatility as energy carriers, storage mediums, and facilitators of sector coupling. They enable competitive long-distance transportation of renewable energy, especially from regions with favourable renewable energy conditions, and help integrate intermittent Renewable Energy Sources (RES) via sector coupling, ensuring grid stability by reducing the need for curtailment. Hydrogen also supports decarbonization efforts in hard-to-abate sectors, reduces greenhouse gas emissions, and enhances energy security by decreasing Europe's dependence on imported fossil fuels. By embracing hydrogen technologies, Europe can accelerate its journey towards a low-carbon, sustainable energy future.

In this vein, the development of clear and enforceable sustainability criteria is crucial to ensure the full potential of hydrogen and its derivatives in fostering a sustainable energy future. These criteria should take into account the entire life cycle of hydrogen production and usage, from extraction to end-use, ensuring that CAPEX and OPEX emissions align with environmental, social, and economic sustainability goals. Such a comprehensive approach to sustainability ensures that the hydrogen value chain contributes effectively to societal decarbonization, while minimizing potential negative impacts like excessive water usage or the release of harmful pollutants. This focus on sustainability not only strengthens the argument for the adoption of hydrogen technologies but also helps to recognize its integral role in driving a holistic and sustainable energy transition.

However, some interest groups have been criticizing the hydrogen vector for its energy 'inefficiency' primarily due to the conversion losses that occur during the production, storage, and usage processes. However, this perspective is very limited when evaluating the role of these energy carriers in the context of achieving full societal decarbonization.

First, hydrogen and derivatives provide an essential complement to RES in sectors where molecules are needed (e.g., chemical industry) and direct electrification is challenging, such as heavy industry and long-haul transportation (e.g., shipping and aviation). By enabling the decarbonization of these hard-to-abate sectors, hydrogen and e-fuels contribute to a more comprehensive and holistic decarbonization strategy.

Second, hydrogen and its derivatives can act as energy storage and energy carriers of RES. Renewable energy sources, such as solar and wind, can be integrated with energy carriers, such as hydrogen, to improve the overall efficiency of the system. Hydrogen enables the storage and transport of excess electricity from renewable energy sources, reducing the need for curtailment. Retrofitting existing infrastructure to distribute, store and deliver hydrogen can be cost effective compared to building new electrical systems, especially over long distances. In a low-carbon energy system, industries that use hydrogen extensively, such as refining and chemical production, can continue to do so.

Therefore, pure energy efficiency concerns should never outweigh other important issues like resource efficiency, land use and systemic issues. Hydrogen optimizes the use of resources, reduces the burden on the electricity grid and facilitates linking the sectors. These broader system-level benefits are overlooked when hydrogen's energy efficiency is assessed solely in terms of conversion losses. Hydrogen's versatility is an enabler of sector integration and a facilitator of a more efficient energy transition. The individual conversion losses are often outweighed by the societal benefits of hydrogen in facilitating decarbonization across sectors.

In light of these factors, the perceived energy inefficiency of hydrogen should be reassessed in the broader context of achieving societal decarbonization. Hydrogen is essential to a comprehensive clean energy transition because of its unique capabilities. Distinct values of hydrogen and its derivatives can be identified, each of which represents a set of contributions that hydrogen provides to the energy system as a whole, also from a cross-sectoral point of view:

- **Arbitrage value** - Hydrogen enables the separation of ‘cheap’ and ‘expensive’ hours of electricity pricing.
- **Insurance value** - Hydrogen storage ensures that enough hydrogen is available for end uses with constant demand (industrial use cases) and uncertain demand (e.g., H_2 turbines, H_2 heating technologies, stationary fuel cells). Storing hydrogen also provides a certain independence and security of supply like the different oil and gas storages and reserves that exist already today.
- **System value** - Hydrogen avoids over-investment in other infrastructure elements across the energy sector by enabling sector coupling for "transport" beyond the electricity grid.
- **Kick-start value** - Hydrogen's storage capability helps to optimise the scale of investment in renewable energy capacity to meet transition targets, thereby facilitating the emergence of a hydrogen ecosystem.
- **Environmental value** - As an energy vector, hydrogen helps to avoid critical resource management (CRM) and electrical redispatch. This reduces grid stress and avoids RES curtailment. As its use does not generate any emissions, Hydrogen avoids having disseminated (tailpipe) emissions that are impossible to capture.

In conclusion, it is crucial to reassess the energy efficiency discussion in the broader context of societal decarbonization. Hydrogen's unique capabilities position it as an essential player in achieving societal decarbonization. Its multifaceted contributions, ranging from arbitrage to environmental impact, underscore its importance in enabling a sustainable, low-carbon future. Moving forward, we delve into the realm of International Hydrogen Standards and their role in establishing a unified certification pathway.

III. International Hydrogen Standards: The Pathway to Unified Certification

Hydrogen standards are critical for the development of a hydrogen-based energy system [9]. Standards ensure compatibility, safety, and provide guidelines for hydrogen systems. Additional regulations and legislation can further ensure that these standards are met, providing an additional layer of safety. Understanding these rules is critical for successful renewable hydrogen development and global trade. To initiate exports and imports to Europe or between any other region, a universal recognition and uniform standards for hydrogen and its derivatives products need to be established in the international market. This represents a daunting task. We will try to elaborate how this could be done via implementing a digital product passport for hydrogen.

Product quality, the carbon footprint and origin of the Hydrogen and its derivatives needs to be defined, as well as social and environmental/sustainability requirements. Certification schemes should consider the comprehensive system within a Life Cycle Impact Assessment (LCIA) taking all impact categories into account. ISO 14040 provides guidance for developing impact categories based on the goal and scope of the LCA study, that shall follow the Do-No-Significant-Harm (DNSH) principle, taking into account the most commonly used impact categories:

[9] Recent publications on certification of hydrogen:

- IEA (2023): Towards hydrogen definitions based on their emissions intensity.
- G7 (2022): Energy and Environment Ministers' Communiqué, G7 Climate.
- German Energy Agency (dena) / World Energy Council (2022): Global Harmonisation Of Hydrogen Certification.
- German Energy Agency (dena) (2023): Establishing a National Hydrogen Standard, An aid to decide between developing an own national hydrogen standard or adopting an international hydrogen standard at the national level.
- German Energy Agency / World Energy Council (2022): Global Harmonisation of Hydrogen Certification, Berlin
- German National Hydrogen Council (2021): Hydrogen Action Plan Germany 2021 – 2025
- Hinicio / Ludwig Bölkow Systemtechnik (2021): Recommendations for a Green Hydrogen Certification Scheme in Chile that is compatible with national and international carbon markets.
- Oeko-Institut (2021): Sustainability dimensions of imported hydrogen, Working Paper 8/2021.
- IRENA Coalition for Action (2022): Decarbonising end-use sectors: Green hydrogen certification, International Renewable Energy Agency.
- IRENA (2022): Green hydrogen for industry: A guide to policy making.

- Global warming potential (GWP)
- Acidification potential (AP)
- Eutrophication potential (EP)
- Ozone depletion potential (ODP)
- Human toxicity potential (HTP)
- Ecotoxicity potential (ETP)
- Resource depletion potential (RDP)
- Land use and biodiversity
- Water consumption and scarcity
- Waste generation and disposal

In conclusion, besides other impact categories standardizing the methodologies to determine the carbon footprint of hydrogen is crucial for developing a sustainable energy system.

This task is part of the ISO TC 197/SC 1/WG 1 currently developing ISO/WD 19870 on "*Methodology for determining the greenhouse gas emissions associated with the production, conditioning and transport of hydrogen*", which will be further discussed below. To ensure transparency for buyers and facilitate cross-border trade of clean hydrogen, a certification system is necessary. Defining the system boundary and calculating (greenhouse gas) emissions, are essential components of such a certification system.

IV. Germany's Pioneering Role in Shaping Hydrogen Standards

In the coming decade, greenhouse gas accounting and sustainability certification will play a significant role in shaping the future energy system. They are set to become foundational pillars of national economies. This is evident as European Commission President Ursula von der Leyen recently announced ambitious targets, aiming for a 55% reduction in greenhouse gas emissions by 2030 and striving for climate neutrality by mid-century.

To achieve the above, certification is crucial for the hydrogen economy, trade of derivatives, and product safety, facilitating the transition to a circular economy. The "German Strategy Forum for Standardization,"[10] established by the Federal Ministry for Economic Affairs and Climate Protection (BMWK), identifies strategic standardization topics for the German economy and future competitiveness, including certification. Headed by Parliamentary State Secretary Dr. Franziska Brantner, this high-ranking body aims to strengthen German participation in European and international standardization bodies. One of its four ad-hoc working groups thus also focuses on hydrogen. Its tasks include advising the BMWK on standardization issues, such as expert training and funding, while also mirroring the European "High Level Forum on Standardization".

[10] BMWK (2023): „Deutsches Strategieforum für Standardisierung" soll Deutschlands Rolle in der globalen Normung stärken, Pressemitteilung.

This initiative is supported by the "Standardization Roadmap for Hydrogen Technologies"[11]. A joint initiative of the German Institute for Standardization (DIN), the German Commission for Electrical, Electronic & Information Technologies in DIN and VDE (DKE), the German Technical and Scientific Association for Gas and Water (DVGW), the German Association for Standardization and Railway Engineering (NWB), the German Association of the Automotive Industry (VDA), the Association of German Engineers (VDI) and the German Engineering Federation (VDMA), funded by the German Federal Ministry for Economic Affairs and Climate Action. It aims to actively support the market launch of hydrogen together with experts from all areas of the hydrogen value chain and to establish a corresponding quality infrastructure[12].

German organizations DIN and DVGW play key roles in national and international standardization, developing hydrogen-related standards. Around 20 standard committees at DIN are involved in developing standards in the field of hydrogen, acting on national, European and international level. DVGW, the regulatory authority for hydrogen networks in Germany (according to Section 49 of the EnWG[13]) has created databases like VerifHy[14] for verifying hydrogen suitability in gas networks, products, and components. They also identify areas for action within the regulatory framework and adapt existing rules and standards for gas infrastructures and applications to accommodate higher hydrogen contents and 100% hydrogen-ready systems.

In order to address the challenges of establishing a global hydrogen market, international cooperation is essential. This cooperation involves various aspects, including technology research and development, the enhancement of certificate and sustainability criteria, and the development of standard market protocols. It is crucial to have transparency in sustainable activities and production, which necessitates robust certification systems to track energy in the future energy system.

One key aspect is ensuring the interoperability of certification schemes worldwide to enable a global hydrogen market. Additionally, the development of tracking systems for hydrogen identification and its properties is significant, as hydrogen prices will depend on its CO_2 intensity and downstream CO_2 saving potential. These tracking systems should be able to integrate into centralized trading platforms that connect to national or European trading systems.

Examining the current state of hydrogen imports into the EU requires an assessment of import characteristics in relation to prevailing regulations and the identification of potential solutions to

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[11] See: DVGW: Normungsroadmap Wasserstofftechnologien, https://www.dvgw.de/themen/energiewende/wasserstoff-und-energiewende/normungsroadmap-wasserstofftechnologien

[12] For interested parties willing to participate in the process, see https://din.one/display/NRMWST

[13] Gesetz über die Elektrizitäts- und Gasversorgung (Energiewirtschaftsgesetz - EnWG) § 49 Anforderungen an Energieanlagen; Verordnungsermächtigung

[14] See: VerifHy, https://www.verifhy.de/

existing challenges. This exploration includes considering the role of the German industry in shaping the energy landscape. To facilitate data sharing and exchange, the establishment of a universal set of standards is crucial. Such a framework not only strengthens EU competitiveness and resilience but also reduces adaptation costs and strengthens value chains.

Internationally, the German Energy Agency collaborates with organizations like the World Energy Council and H2Global to harmonize standards. The EU, along with regions like the UAE, prioritizes renewable energy tracking. In fact, the EU has launched the REDII directive, which focuses on the transport sector and on renewable fuels of non-biological origin (RFNBO).

By fostering international cooperation, enhancing certification systems, and promoting standardized tracking and trading platforms, we can lay a solid foundation for a global hydrogen market. This collaborative approach will support the growth and integration of hydrogen as a key player in the future energy system.

V. Background: Hydrogen Characteristics and Methodology

a. The Role of 'Guarantees of Origin' for Hydrogen

Similar to electricity, the EU hydrogen market will be supported by a system of Guarantees of Origin (GoOs) to facilitate a market-based approach that allows users to choose production methods with specific attributes that characterize the production and quality of hydrogen. For hydrogen imports to participate in EU markets, it would be essential to assess the characteristics of hydrogen entering the EU and to issue GoOs. This will require an assessment of the characteristics of hydrogen at the point of entry into the EU and a process for issuing GoOs.

The Carbon Border Adjustment Mechanism (CBAM)[15] establishes a system that puts a financial value on the embedded greenhouse gas emissions of specific materials when they are imported to Europe. Specifically, the inclusion of hydrogen and of certain hydrogen carriers, such as Ammonia, within CBAM[16] while excluding others like methanol and e-kerosene raises concerns regarding the creation of a fair level playing field. To ensure equitable trade conditions, it is imperative to provide undistorted trade conditions for all forms of hydrogen and its carriers.

[15] European Commission (2021): Proposal for a Regulation of the European Parliament and of the Council establishing a carbon border adjustment mechanism.

[16] The Carbon Border Adjustment Mechanism (CBAM) employs a unique approach in determining "embedded emissions," which does not align with other standards/ methodologies, such as Renewable Energy Directive II (RED II). Furthermore, the emissions calculation for hydrogen and ammonia under CBAM follows different structures. For more details, refer to the final CBAM regulation published in the Official Journal (OJ) on May 16, 2023.

To create a sustainable market for hydrogen technologies, it is important to establish clean, affordable, safe and reliable supply chains, with the adoption of transparent standards and protocols that support efficient international hydrogen trade. This involves international standards to facilitate the removal of legal barriers and support the development of a common way to determine the attributes of hydrogen in order to use these attributes to check compliance with whatever definition of clean/ sustainable hydrogen may apply in a given geography.

This requires a mutually recognized international framework that is robust and avoids mis- or double-counting of environmental impacts. The framework will provide a mutually agreed approach to "guarantees" or "certificates" of origin covering greenhouse gas inputs and other criteria used in the production, conditioning and transport of hydrogen.

b. What are Guarantees of Origin and Proofs of Sustainability?

A Guarantee of Origin (GoO)[17] is a certificate that counts quantities of product produced with specific attributes in order to be able to assign them to a specific user while being transported and distributed via a common infrastructure. Commonly, GoOs provide information on attributes related to the production of a certain amount of electricity, gas, or heating and cooling. It is a voluntary instrument used to characterize and verify the origin of energy and allows carrying further sustainability information. GoOs provide information such as the type of energy carrier, distribution channel (grid connection), type of support scheme (where applicable), the carrying medium, aggregation stage, temperature range, maximum supply pressure and, network identity along with the type, location, and amount of energy produced, and can be used to support claims of using renewable energy in marketing and communication materials. They also serve as a tool to promote the development of renewable energy sources by providing financial incentives for their production and use.

One limitation of the Guarantees of Origin method is that it primarily focuses on tracking the origin and attributes of renewable energy generation without providing comprehensive information about the entire life cycle emissions associated with a specific energy product or technology. GoOs mainly certify the renewable source, but they do not capture the emissions generated during other stages of production, distribution, and end-use. Therefore, GoOs[18] alone may not provide a complete picture of the environmental impact or carbon footprint of an energy product.

[17] Art. 19 RED II serves as the legal basis in Europe for Guarantees of Origin (GoO)

[18] Refer to standard EN 16325, presently being updated to encompass renewable gases (including hydrogen) and heating/cooling: it designates carbon footprint as an optional data field, with a primary emphasis on origin.

To assess the life cycle emissions over the full value chain from well-to-wheel, Proofs of Sustainability (PoS)[19] should be considered, which allow carrying the greenhouse gas intensity forward along the entire supply chain.

c. Complexity in Determining the Environmental Characteristics of (Imported) Hydrogen

At present, there is considerable uncertainty about the demand for hydrogen, an inadequate infrastructure for the delivery of hydrogen to customers and, most importantly, a lack of clarity in the regulatory framework and certification schemes. In this context, the IEA states that "*The scale-up of low-emission hydrogen production requires clear policy frameworks, including agreed standards for environmental criteria and policies to incentivize end users to commit to long-term purchases and manage offtake risk. Standards and certification for guaranteeing that hydrogen-based commodities meet environmental criteria, either voluntary, set by regulatory obligations or linked to government and market incentives, have become a priority for project developers to gain investors' confidence*".[20]

However, due to different pathways for hydrogen production, producing hydrogen molecules that are identical but with varying greenhouse gas intensities presents a significant challenge. Additionally, hydrogen-based products and fuels can be made from a mixture of fossil and low-carbon or green feedstocks, making it difficult to distinguish between them. Clean hydrogen could be used as a feedstock for emission reductions in the production of "downstream" products such as ammonia, electricity or steel, or even serve as the basis for E-fuels, such as SAF. As with hydrogen itself, the emissions associated with these products need to be monitored, documented and verified. Furthermore, certain products made from hydrogen can also be used to produce hydrogen again, making accounting standards for different hydrogen sources along the supply chain vital for creating a market for low-carbon hydrogen.

These standards need to be internationally agreed upon to establish a mutually recognized framework that prevents mislabelling or double counting of environmental impacts. This will very likely take years if not decades to achieve. However, we will show a methodology that uses existing data

[19] "Proofs of Sustainability" (PoS) are defined in Implementing Regulation (EU) 2022/996 complementing RED II: Art. 2 „(23)'proof of sustainability' means a declaration by an economic operator, made on the basis of a certificate issued by a certification body within the framework of a voluntary scheme certifying the compliance of a specific quantity of feedstock or fuels with the sustainability and greenhouse gas emissions savings criteria set out in Articles 25(2) and 29 of Directive (EU) 2018/2001;"

[20] IEA (2023): Towards hydrogen definitions based on their emissions intensity.

on the lowest granular level to define a common ground that also can help to accelerate the global standardization process.

d. The "Methodology for Determining the Greenhouse Gas Emissions Associated with the Production, Conditioning and Transport of Hydrogen" ISO/WD 19870

One of the limitations stemming out of the lack of a uniform certification system, is that the methodology for calculating greenhouse gas emissions in not uniformly defined. There is ongoing work within ISO TC 197/SC 1/WG 1 to develop ISO/WD 19870 on "*Methodology for determining the greenhouse gas emissions associated with the production, conditioning and transport of hydrogen*"[21]. This work is using a document developed by the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)[22] as seed document[23] which the International Organization for Standardization (ISO)[24] is developing into a specific standard to further detail the requirement set by ISO 14067 to the determination of greenhouse gas emissions associated with hydrogen production, conditioning and transport.

A first draft of the corresponding technical specification should be issued by the end of this year. The work has been initiated based on a methodology proposed by IPHE[25]. Critics[26] argue that the draft methodology may underestimate emissions due to its reliance on inventory data and lack of real-time monitoring. Currently, there is no universally agreed framework for determining the greenhouse gas intensity of hydrogen production. As mentioned before, the methodology presented in this paper can accelerate the process to come to such a universally agreed framework.

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[21] ISO, ISO/CD TS 19870, Methodology for Determining the Greenhouse Gas Emissions Associated with the Production, Conditioning and Transport of Hydrogen to Consumption Gate

[22] IPHE (2021): Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen, IPHE Working Paper Ver1 Oct 2021.

[23] ibid

[24] ISO, ISO/CD TS 19870, Methodology for Determining the Greenhouse Gas Emissions Associated with the Production, Conditioning and Transport of Hydrogen to Consumption Gate, https://www.iso.org/standard/65628.html

[25] IPHE (2021): Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen, IPHE Working Paper Ver1 Oct 2021.

[26] Oeko-Institut (2021): Critical Review of the IPHE Working Paper "Methodology for Determining the GHG emissions associated with the Production of hydrogen".

VI. Digitization as the Source Code for Accurate Accounting

This chapter looks at the (digital) tools to support market development, following the arguments in the previous chapters that highlighted the need for a harmonized approach and universally agreed methodologies and calculation methods. It is argued that hydrogen standardization needs to be accompanied by digitalization tools.

Digitization serves as a central catalyst for the advancement of hydrogen standardization, offering multiple benefits to facilitate the emergence of a robust hydrogen economy. Digitization enhances data accuracy and accountability, thereby fostering a safe, efficient and environmentally responsible hydrogen system using data based digital tools such as tokens and blockchain technology. In addition, the CO_{2e} impact of digital structures/processes must also be considered in an overall assessment. Increased accountability through digitization prevents data manipulation, increases stakeholder trust and promotes security.

A major benefit of digitization is its ability to enable automation. The resulting scalability speeds up the hydrogen certification process, making it more cost-effective, more timely and better able to meet the growing demand for certified hydrogen.

Digital twins, acting as virtual simulations of real-world assets, have become a key instrument in the digitization process. They can replicate the performance and behaviour of physical systems, offering insights for proactive issue resolution. Additionally, they enhance communication and collaboration among stakeholders involved in hydrogen standardization, promoting accessible information exchange and aligning standard development with stakeholder needs. These virtual replicas facilitate and expedite the development of hydrogen technologies by providing a risk-free virtual environment for design testing and simulations, but also for regulatory compliance checks for the produced hydrogen before real assets have been built.

To conclude, digitization and automation can serve as key drivers for hydrogen standardization. By improving accuracy, accountability, automation, scalability, security and collaboration, digitization supports the successful establishment of the hydrogen economy and transition to a sustainable energy future. It plays a crucial role in ensuring that hydrogen systems remain safe, efficient and reliable, and in monitoring the environmental impact of producing and using hydrogen.

We are very aware that not everything can be fully automated, and that digitization will not replace audits. The inspection of production sites and measurement equipment, the review of processes and procedures is the basis that data which is entered or uploaded into the digital tools is correct.

VII. Assessing CO_{2e} Emissions and Other Relevant Data Points for the Production of Hydrogen Products

The growing importance of carbon footprint and not only 'colour coding' in the context of climate change mitigation and adherence to the Paris Agreement has led to significant investments in hydrogen value chains. Key performance indicators (KPIs) related to CO_2 equivalent emissions (CO_{2e}) of hydrogen products (H_2, NH_3, and others) are essential for large off-takers to calculate their carbon footprint and establish pricing strategies. To accurately calculate CO_{2e} emissions throughout the hydrogen value chain, it is crucial to ensure precision, transparency, security, technical inter-operability and independency.

- **Precision**: Ensure accurate underlying data[27], which allows for aggregation and flexibility in response to regulatory changes.
- **Transparency**: Clearly present each calculation step to facilitate auditing and enable data-driven decision-making by end customers.
- **Security**: Implement safeguards to prevent unauthorized alterations of information.
- **Technical inter-operability**: Ensure the use of open technical standards of data exchange.
- **Independency:** Ensure a technical solution that is free from any bias or influence, providing equal access and opportunities for all participants to avoid any conflict of interest and to increase market access, trust and scalability.

Along the value chain, there will be many different stakeholders handling hydrogen and its derivatives.

Therefore, despite the European Union's efforts to establish the Union Database[28] for Europe and the European Economic Area, it is unlikely that a single digital platform will serve all global stakeholders. Therefore, any digitization shall adhere to international digital standards for data exchange, such as the Partnership for Carbon Transparency provides an international standard for data exchange for GHG emissions.

The consideration of the before-mentioned design parameters was also a prerequisite in the formation of the collaborative networks (SAP, TÜV NORD or the German Energy Agency, Siemens Energy, TÜV SÜD), that bring together the needed expertise from different angles.

[27] An inherent limitation of blockchain technology is the potential of erroneous or misleading data being incorporated into the blockchain. Owing to the unalterable nature of blockchain data, any inaccuracies introduced cannot be corrected later. This creates an illusion of precision which might not necessarily be an accurate reflection if the initial data input was flawed. Thus, it's imperative to retain traditional on-site audits as a fundamental aspect of the certification process. This step ensures the data's veracity prior to its integration into the blockchain system.

[28] RED II Art. 84 and Art. 28

While the H2Global Foundation remains technology neutral to various approaches, those two collaborative networks have developed concrete solutions, that are described in the following.

a. Introducing the Green token approach by SAP and TÜV NORD

SAP contributes with its experience in developing and implementing industrial IT applications across various sectors. To ensure the compliance with certification requirements or regulatory schemes from the beginning, TÜV NORD further supports the efforts of SAP with its expertise on safety, IT-security and regulatory compliance with existing and prospective certification requirements.

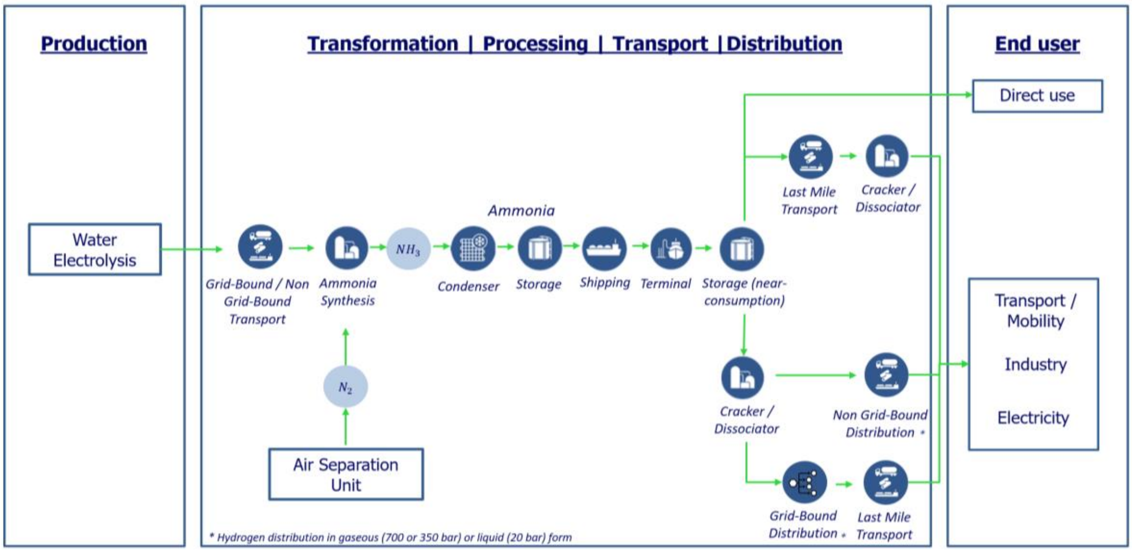

Figure 1: Green Ammonia Supply Chain; Source: H2Global

The value chain of green ammonia (NH_3), depicted in Figure 1 has been used as a case study. Ammonia is an important molecule needed for fertilizer production and it is also one of the promising long-distance hydrogen transportation options. Detailed analyses of various aspects of the hydrogen, ammonia, and methanol value chains like roles and responsibilities have been conducted through interviews with H2Global trustees.

However, the previous analyses did not include the essential digital layers needed for an efficient value chain. To address this, the H2Global Foundation and SAP hold workshops to explain and visualize how these digital layers have to look like in detail.

Integral to this value chain are multiple digital layers developed for CO_{2e} emissions calculation, mass balancing, and accounting for renewable electricity access just to mention a few.

The CO_{2e} emissions of the entire ammonia value chain are calculated, taking into account mass balancing complexities due to mixing different hydrogen products.

Electrolyzer operators sign Power Purchase Agreements (PPAs) with renewable energy providers to access green electricity. For hydrogen production, both green electricity supply and electrolyzer consumption are measured at regular intervals (e.g., every 15 minutes). An energy data management system (e.g., SAP's Cloud for Energy[29]) calculates the difference between renewable electricity input and (grid) consumption, creating a new time series. Any grid-drawn electricity not covered by PPAs is multiplied by the CO_{2e} emissions per kWh for the specific grid segment during the same interval. This information, provided by transmission grid operators, research institutes, or companies, results in a time series detailing CO_{2e} emissions for electricity not supported by PPAs.

Simultaneously, hydrogen production is measured in the same interval as electricity consumption. Dividing the CO_{2e} time series by the hydrogen mass time series produces a new time series showing CO_{2e} emissions per mass of hydrogen. This data is transferred to a system (e.g., SAP's Green Token[30]) that creates digital twins, called tokens, for each hydrogen mass unit (e.g., per gram), indicating the associated CO_{2e} emissions with each hydrogen unit.

For desalination cases, CO_{2e} emissions related to water production are included. While fossil fuel value chains are also significant, their data availability is currently limited. Lifecycle emissions of renewable power plants can be included or excluded from calculations as per regulatory requirements.

Beyond CO_{2e}, it's crucial to have the ability to capture diverse data points for political, physical, and ESG factors to comply with certification, regulatory and subsidy schemes. Examples of such data points can include additionality (date of the creation of the RES), certificates of origin, method of production, physical reality checks (geo-location of the supply and consumption meter, bidding zone, voltage levels), and ESG criteria like gender equality, no use of drinking water in dry regions, investments into the local communities, no relocation of people for the project, professional treatment of the wastewater of the desalination facility etc.

[29] See: SAP Cloud for Energy, sapstore.com

[30] See: GreenToken by SAP, https://www.green-token.io/

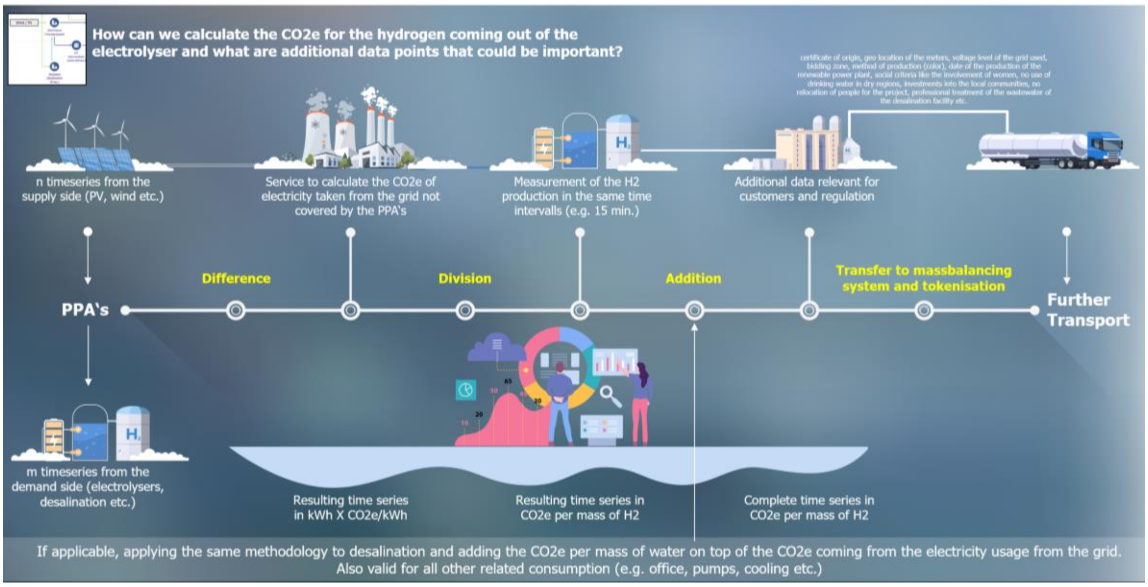

Figure 2: CO2e Calculation of the Mass of Produced Hydrogen; Source: SAP & H2Global

The aim of including all these data points and more in each token is to communicate all relevant information throughout the hydrogen value chain to meet the requirements of not only regulations such as REDII and RFNBO, but also CBAM, supply chain legislation and other corporate sustainability reporting requirements, in addition to current and future certification or regulatory schemes.

Real-time emission and inventory accounting can ensure reliable data, boost trust, avoid greenwashing, and reduce transaction costs through digital tools and technologies.

To address trust issues that may arise between supply and demand stakeholders, a visualization provided by SAP[31] can be employed to enhance understanding and foster confidence in the data being shared and processed throughout the value chain.

[31] See: GreenToken by SAP, https://www.green-token.io/

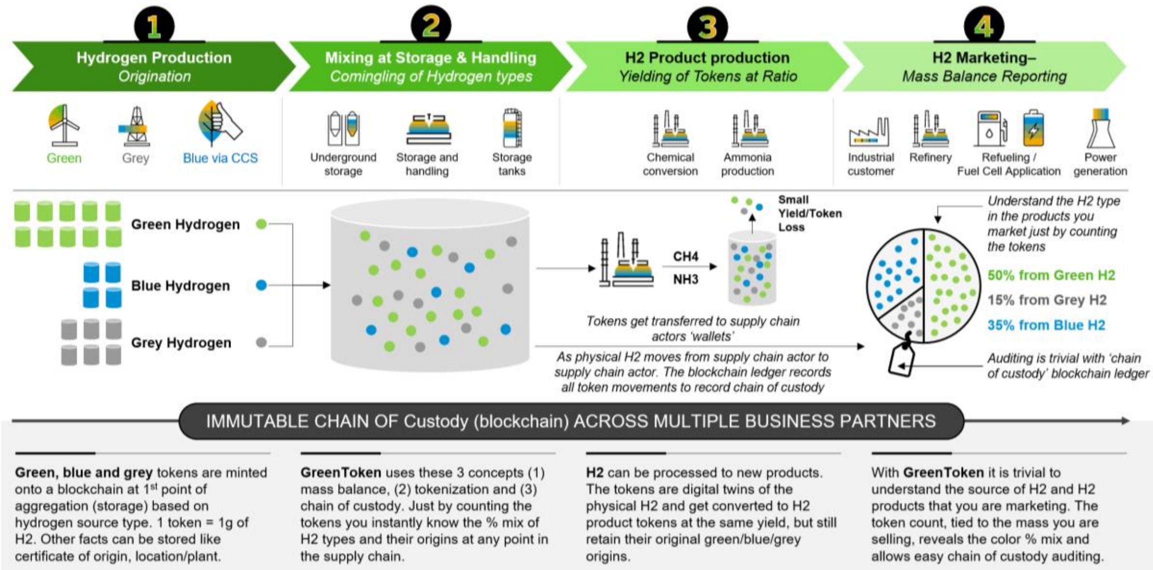

Figure 3: GreenToken – Tracking Hydrogen by Source; Source: SAP

SAP's GreenToken is a system for tracking and tracing all relevant information attached to hydrogen or derivatives through the entire value chain in an auditable way. This system is based on three key concepts: mass balance, tokenization, and chain of custody.

Each token, representing a particular mass or energy content of hydrogen, carries multiple pieces of information (e.g., 60 different attributes), enabling a granular understanding of the hydrogen products' qualities at any point in the supply chain. Resulting in billions of unique tokens when transporting large amounts of H_2, NH_3, or CH_4. Token data is transferred between private blockchain wallets, representing physical locations like production tanks, ensuring auditability and security.

Tokens allow differentiation between hydrogen products with varying environmental impact or different ESG data points. For instance, electrolysis-derived hydrogen with low CO_{2e} emissions can achieve financial benefits in certain countries. The system also allows for a tailored approach to meet customer requirements, assigning specific percentages of green, blue, or grey tokens to different customers just to use the simplified picture above.

In an example, a green ammonia shipment from Australia mixes with grey ammonia in a Rotterdam tank. Using GreenToken, the exact amount and specific qualities of green ammonia can be determined. Despite physical mixing, tokens allow digital distinction between the green and grey ammonia, promoting transparency and environmental consciousness.

To ensure interoperability and lower entry barriers for new value chain partners, digitization should adhere to international data exchange standards. This does not compromise data security, which is maintained by the blockchain. This standardization facilitates easy integration into other companies' systems, promoting inclusivity in the digital value chain.

b. Assessing CO_{2e} Emissions Across Transportation Modes and Ammonia Production/ Cracking

The calculation of CO_{2e} emissions for hydrogen transport modes is crucial for understanding environmental impacts. Key considerations include fuel type, distance travelled, load capacity, utilization rate, and emission factors. These allow calculation of CO_{2e} emissions per transport mode (pipeline, ship, train, road), forming a comprehensive understanding of the hydrogen value chain's environmental footprint.

Figure 4: CO2e Calculation of Transport; Source: SAP & H2Global

In case of missing data or if data cannot be measured right now, already existing databases can help determine emissions.

The Haber-Bosch process is the primary method used in ammonia production, operating at high pressures and temperatures between 400 and 500°C. As these processes typically run 24/7, calculating CO_{2e} emissions is simplified. To measure emissions, the fossil fuel input and resulting CO_{2e} emissions are determined, along with electricity-related emissions using the previously described methodology. These emissions are then combined with the portion of corporate emissions allocated to the ammonia plant and the CO_{2e} emissions associated with the utilized hydrogen. This calculation is then allocated to the produced ammonia. The SAP solution that is used for the calculation of CO_{2e} emissions on product level is Sustainability Footprint Management[32].

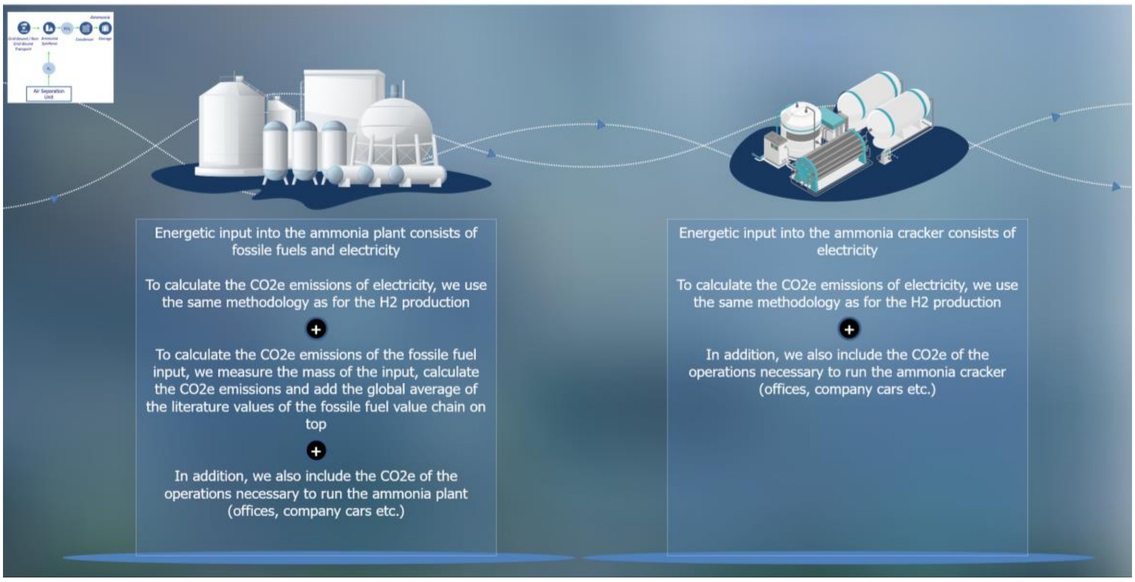

Figure 5: CO2e Emissions from Ammonia Production and Cracking; Source: SAP & H2Global

Ammonia crackers, although in early stages, primarily use electricity as an energy input, allowing the established electricity emission measurement methodology to be utilized. A portion of corporate emissions is allocated to the ammonia cracker, divided by the hydrogen production, resulting in CO_{2e} emissions per hydrogen unit.

With these methodologies, it is feasible to calculate CO_{2e} emissions for the entire ammonia value chain, from renewable energy production to final transport to the end customer. Therefore, the end customers get their most pressing question answered: How much CO_{2e} are on top of the purchased mass of hydrogen or derivatives? This information is needed to be able to calculate the product footprint of the products produced by these companies (e.g., fertilizer, chemicals etc.).

Governments and regulators get full flexibility in steering the market as the suggested approach can serve any regulatory scheme or certification and can also be used as data input for regulatory databases like the before mentioned Union Database. All relevant data is captured, calculated and transported through the entire value chain. When a certificate or regulatory scheme must be provided, a simple analysis of the relevant data points and visualization according to the predetermined rules does the job.

[32] See: SAP Sustainability Footprint Management I Carbon Accounting Software, https://www.sap.com/products/scm/sustainability-footprint-management.html

Automated certification solutions – a clear demand not only from producers Automation of the certification process can be achieved by working closely with certification bodies, helping to increase trust between supply and demand. Following the principle of a trusted third party and, by this means, to ensure full independency of the intended solution, SAP and TÜV NORD are advancing the development of an independent and holistic digital tracking and certification system for hydrogen products. The joint efforts of SAP and TÜV NORD consider the examination and confirmation of the traceability solution for its intended purpose (e.g., conformity of data processing). This also includes the overall validation of the platform to ensure its functionality, safety, security as well as compliance with relevant certification schemes.

Particular emphasis of the mutual activities of SAP and TÜV NORD is hereby on the validation and integrity of data uploaded into the IT system (e.g., measurement systems), quality assurance of the data foundation for all subsequent processes as well as the establishment of a unified assessment basis for relevant and selectable standards and accreditation requirements. The benefits of such an independent industrial solution and the contributions of the relevant stakeholders are summarized in the following Figure 6.

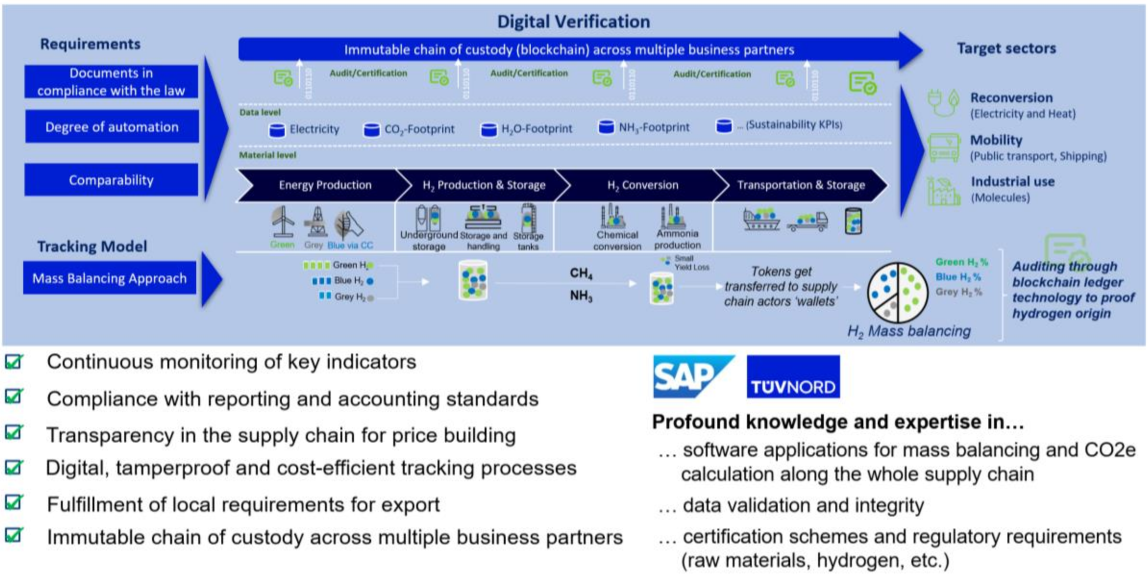

Figure 6: Tracking and Certification of Hydrogen Supply Chain; Source: SAP & TÜV NORD

When it comes to certification processes, automation has its limits. Manual tasks such as hardware inspection and review of processes and procedures cannot be fully replaced. However, by fostering close collaboration between certification bodies and software vendors, a significant portion of the process can be digitized, surpassing previous capabilities.

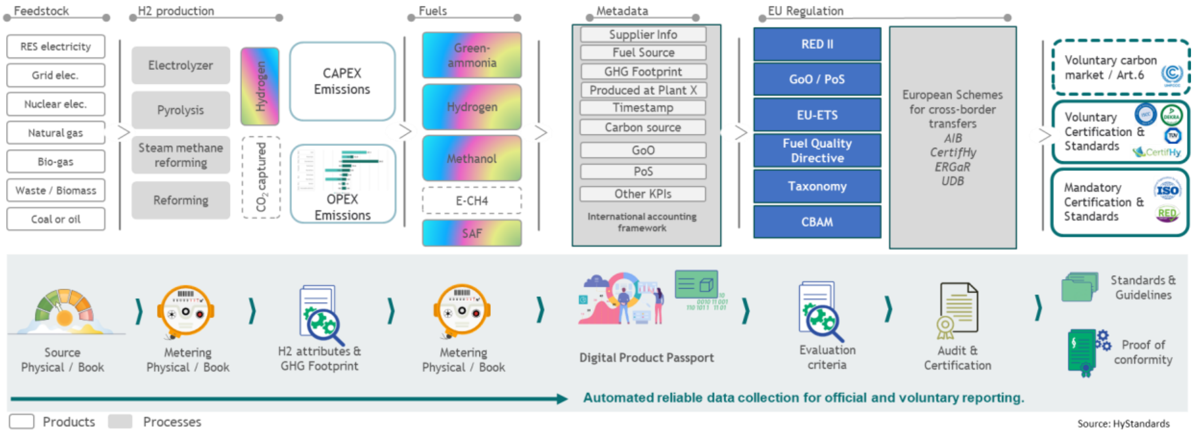

Figure 7: Digital Product Passport Approach; Source: HyStandards

Our shared vision includes continuous monitoring of data inputs and processes, enabling certification bodies to apply a digital stamp on top of the analysis of relevant data specific to a certification or regulatory scheme. This digitization effort has the potential to minimize paperwork and reduce the burden of manual effort. As a result, the number of required audits can be drastically reduced, ultimately saving valuable time and financial resources for companies involved in the hydrogen value chain.

In the depicted schematic, a holistic process encompassing diverse feedstocks and technologies is employed to generate hydrogen in varying "colours" denoting different carbon intensities. The measurement of carbon intensity hinges upon the selected methodology, incorporating either capital expenditures (CAPEX) or operational expenditures (OPEX) emissions, or both. Following this, the produced hydrogen can undergo conversion into a range of fuels and carriers, inheriting the carbon intensity from the preceding upstream processes. To streamline compliance with distinct regulatory mandates, the aggregation metadata, encompassing diverse Key KPIs, is achieved through consolidation within unified documents/ analytics.

By consolidating all relevant data points, compliance with multiple regulations becomes more manageable and transparent. German companies are already at the forefront of these efforts.

It is worth noting that this approach is in line with the evolving demands of regulators, highlighting the importance of data provision as a basic requirement. One possible outcome of this evolution could be the establishment of a digital product passport for hydrogen. This would serve as a comprehensive and standardized information resource. Such a passport would facilitate compliance with regulatory frameworks by allowing for transparent tracking of key data.

Recognizing that multiple companies share similar perspectives, we extended an invitation to Siemens Energy to shed light on their approach in this regard. By exploring their insights, we aim to further enrich the understanding of different strategies and perspectives within the industry.

c. Introducing the Clean Energy Certification as a Service: An Open Ecosystem by Siemens Energy, TÜV Süd and DENA

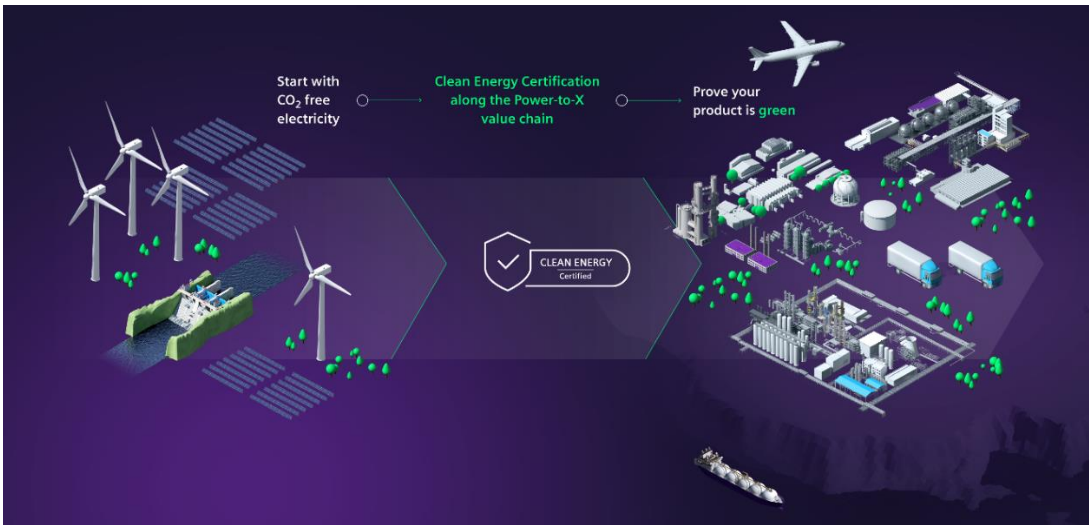

Figure 8: Clean Energy Certification by Siemens Energy; Source: Siemens Energy

Siemens Energy understands the critical importance of tracking and validating the environmental impact of energy production in our pursuit of a sustainable energy future. To address this need, it has developed the Clean Energy Certification as a service (CEC)[33] together with its partners TÜV SÜD, an international acknowledged accredited certification body, and the governmental owned German Energy Agency dena. This digital service revolutionizes the way how to monitor and certify the sustainability of energy sources, ensuring transparency and accountability in the energy sector.

The CEC system offers a comprehensive solution for monitoring and evaluating the environmental impact of energy production through automated and tamper-proofed certification as a service within an open ecosystem. It operates across sectors and the entire energy value chain, connecting physical assets with a distributed ledger infrastructure layer, commonly known as blockchain. By leveraging this advanced technology, the CEC system covers accreditation schemes for a wide range of renewable sourced energy carriers and energy-intensive goods, including green electricity, green hydrogen, e-fuels, and low carbon energy carriers. One of the key strengths of the CEC system is its ability to provide robust verification, interoperability, authentication, and portability through the distributed ledger technology. This ensures the integrity and reliability of the certification process, enhancing trust and transparency throughout the energy sector. The CEC system contains all the necessary information to prove the sustainable origin or the reduced carbon

[33] See Siemens Energy: Clean Energy Certificates, https://www.siemens-energy.com/global/en/priorities/future-technologies/clean-energy-certificates.html

footprint of energy sources. By issuing certificates, stakeholders can easily demonstrate compliance with sustainability goals and showcase their commitment to environmental stewardship. This approach promotes a sustainable supply chain and accelerates the transition to GHG reduced or carbon neutral energy sources.

The CEC satisfies market needs for Power-to-X customers and enables compliance with future governmental requirements such as the EU Renewable Energy Directive II (EU RED II) and the Carbon Border Adjustment Mechanism (CBAM).

The CEC system offers a portfolio of certification schemes within the field of unregulated and regulated sectors and will also be open for a variety of certification bodies the producer may select according to his business needs.

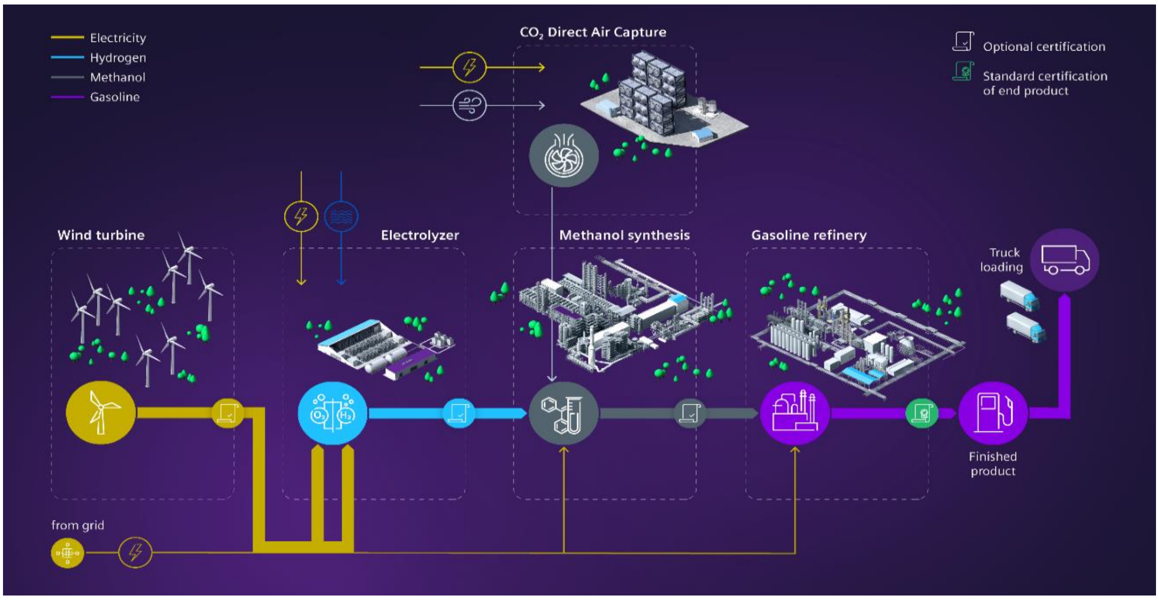

Figure 9: Clean Energy Certification Approach; Source: Siemens Energy

Recognizing that a sustainable energy future requires collaboration and partnership, Siemens Energy is actively establishing this CEC system as an open ecosystem for the verification and certification of renewable energies, products, and goods reaching out and being open to connect to complementary service providers from various sectors, e.g., banking or fuel tracing.

In 2023 Siemens Energy applied the Clean Energy Certification service at Nobian's chlor-alkali electrolysis plant in Germany[34]. Nobian has been providing green hydrogen since 2021 and as the first certified chlor-alkali electrolysis plant, they understand the demand for an automated, transparent and fully traceable certification process along the whole value chain.

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[34] Blockchain solution pilot for certification of green hydrogen (nobian.com)

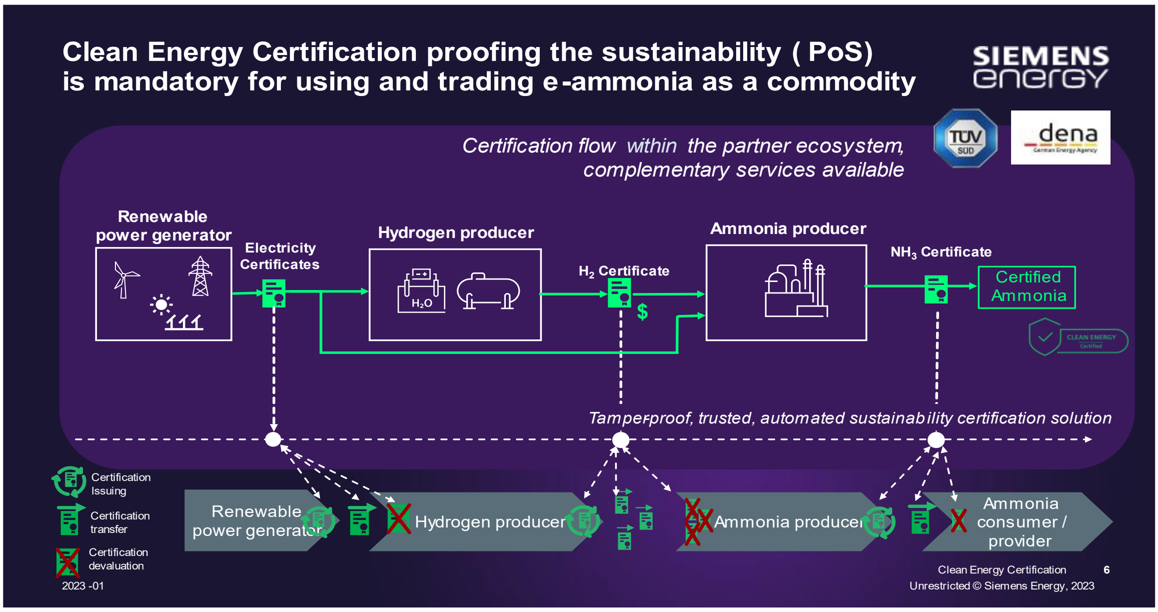

Figure 10: Clean Energy Certification for Ammonia; Source: Siemens Energy

The advantages of the Clean Energy Certificates are far-reaching, including meeting regulatory requirements, achieving higher market prices for products produced with clean energy, gaining customs and tax reductions, securing project financing through proof of sustainability, and enabling clean energy trading on stock exchanges and other marketplaces. The Clean Energy Certificates unlock new business potential within the cross-sector energy market, enabling stakeholders to align with sustainability goals and contribute to a greener future.

d. Summary Streamlining Integrity: Chain of Custody

This chapter discussed the importance of calculating CO_2 equivalent emissions throughout the hydrogen value chain, which is essential for large off-takers to calculate their carbon footprint and establish pricing strategies. To achieve precision, transparency, and security, the H2Global Foundation and other stakeholders have evaluated digital capabilities and available methodologies, using the green ammonia value chain as a case study. Key points include:

- The precision of the underlying data is critical to accurately calculate CO_{2e} emissions throughout the hydrogen value chain.
- Transparency is necessary to present each calculation step clearly and enable data-driven decision-making.
- Security is essential to prevent unauthorized alterations of information.
- Digital layers have been identified to facilitate the value chain's functionality, including calculating CO_{2e} emissions, addressing mass balancing issues, and accounting for renewable electricity access.

- Digital tokens representing specific quantities of hydrogen are used for the transport of the CO_{2e} emissions and other needed ESG data through the hydrogen value chain and support the seamless integration with processes.
- Technical inter-operability: Ensure the use of open technical standards of data exchange (such as the Partnership of Carbon Transparency is providing for GHG emissions).
- Calculating CO_{2e} emissions for transportation modes such as pipelines, ships, trains, and trucks is crucial for understanding the hydrogen value chain's environmental impact.
- With these components, it is possible to calculate the CO_{2e} emissions for the entire ammonia value chain, from renewable energy production to final transport to the end customer.
- Automating certification processes can be achieved by working closely with auditors to optimize various processes along the value chain, helping to resolve trust issues between supply and demand.
- By means of real-time emission and inventory accounting, stakeholders can base their products on reliable and integer data that cannot be altered via applying blockchain technologies.
- The aim is to communicate all relevant information throughout the hydrogen value chain to meet the requirements of regulations, certifications, and corporate sustainability reporting requirements.

Overall, the chapter provided a comprehensive overview of the digital capabilities to accurately measure CO_{2e} emissions throughout the hydrogen value chain, highlighting the importance of precision, transparency, and security in achieving a sustainable and environmentally conscious supply chain.

VIII. Digital Product Passport: Unifying Hydrogen Certification & Trade Globally

Numerous voluntary certification schemes and regulations exist, making it infeasible to hard code specific certifications for (low carbon) hydrogen, ammonia, or methanol production and transportation due to their inconsistency and potential legal changes over time. A more efficient approach is to identify the relevant data points for all certifications and regulations and carry these through the value chain on top of a token. Furthermore, by using international acknowledged technical standards for sharing data on GHG emissions (Partnership on Carbon Transparency), we ensure that companies worldwide can easily integrate their GHG emission into the value chain. This will add trust and accountability to the GHG reductions achieved via hydrogen and derivatives and thereby serve the digital product passport (DPP) as well as the public.

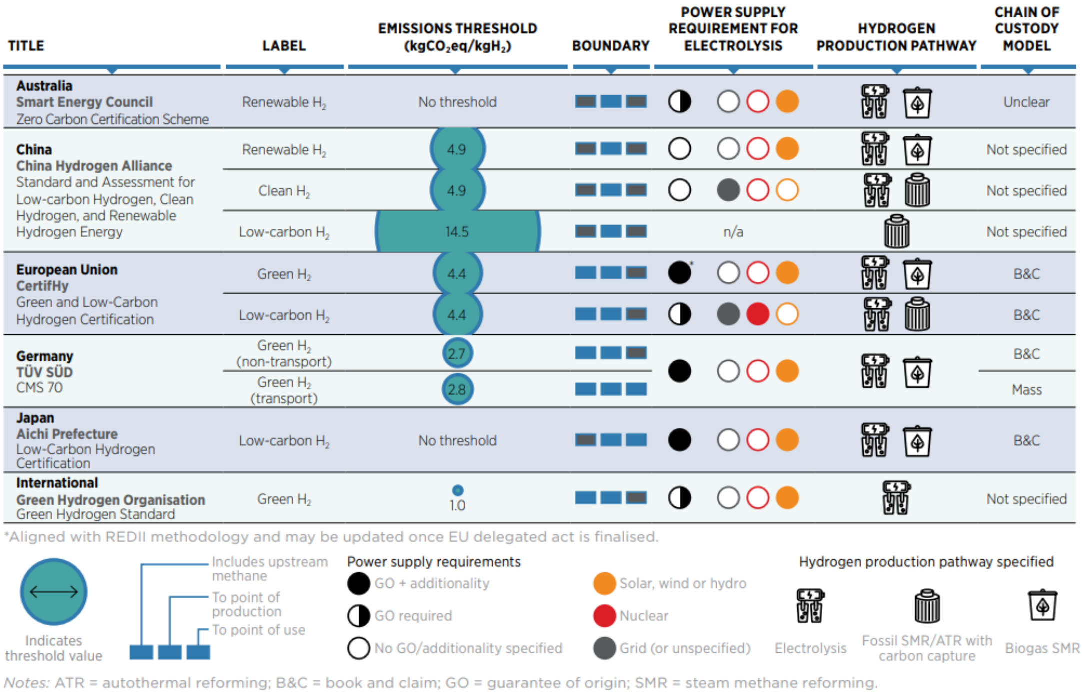

Figure 11: Summary of voluntary market mechanisms; Source: IRENA[35]

The concept of "Digital Product Passports" can be applied to the case of hydrogen and its derivatives. A DPP is a structured collection of product-related data and attributes across a product's lifecycle. DPPs share information for every product across the entire Value Chain. Relevant data is analysed and provided to authorities when needed, for instance, when a ship loaded with low-carbon ammonia enters the EU. This data informs whether regulations are adhered to and helps decide on subsidies, tax discounts, or penalties. Additionally, it provides end customers with continuous information for their CO_{2e} emissions calculation.

Implementing a DPP across the hydrogen and Power-to-X value chain can resolve existing limitations, enabling global transparency, automated certification, interoperability, trust, and industrial decarbonization. DPPs offer a resilient, automated certification platform. They manage data points related to Guarantees of Origin and Proof of Sustainability, as well as other KPIs, thereby streamlining certification and trading of hydrogen and other energy carriers. For instance, upon a ship's arrival, necessary data points are considered and analysed, determining cargo portions that meet the criteria.

Certification bodies can provide automated certificates of compliance based on these requirements, allowing products to enter markets. Collaborating with an audit company familiar with relevant certifications ensures the software company remains updated without needing in-depth

[35] IRENA / RMI (2023): Creating a global hydrogen market: Certification to enable trade.

certification knowledge. This partnership could lead to fully automated issued certificates, similar to a passport stamp.

Below is an exemplary DPP for hydrogen as being developed by Point Twelve in collaboration with Hydrogen Europe, focusing on technology-enabled continuous certification across energy carriers value chains[36].

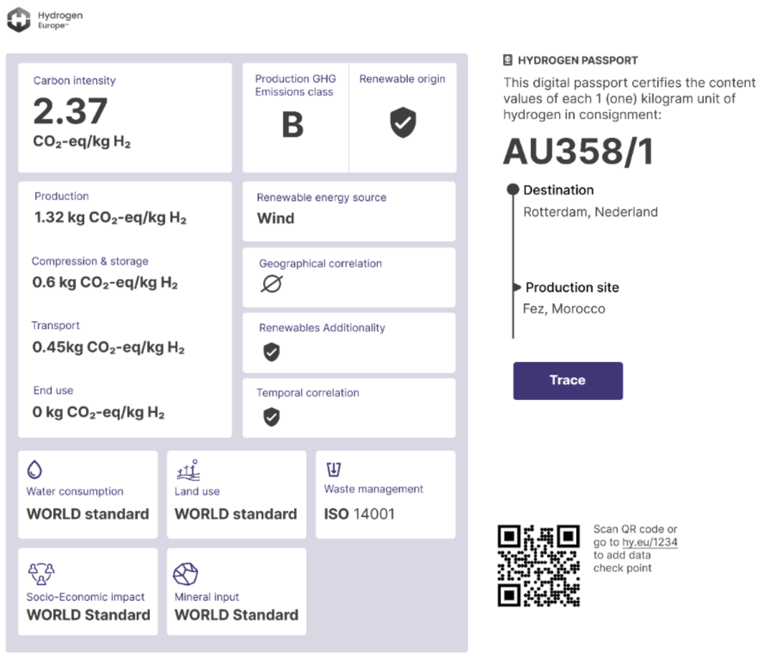

Figure 12: Exemplary DPP for Hydrogen; Source: Hydrogen Europe

Potential benefits of a DPP system include:

1. Increased transparency: A DPP system offers clear, verifiable information on the origin and carbon impact of imported hydrogen.
2. Regulatory compliance: A DPP system allows regulators to ensure imported hydrogen adheres to the same standards as domestic production.
3. Fair competition: DPP levels the playing field between imported and domestic hydrogen by allowing informed purchase decisions.
4. Improved data collection: Tracking carbon impact provides regulators and policymakers with vital data for future policy making and low-carbon production incentives.

[36] For further information see: https://point-twelve.energy/

This approach benefits non-EU countries from North America or MENA region by reducing dependency on European Commission's approval for GoO trading, as DPP could offer a universally recognized certification system. It also allows better integration with other countries' trading schemes, like the EECS-compatible schemes developed by Energy Community contracting parties. Lastly, a DPP offers agility to accommodate future regulatory changes and advancements in the hydrogen and broader energy market, promoting global energy trade efficiency.

In summary, a hydrogen DPP enhances traceability, transparency, market confidence, compliance, competitive advantage, collaboration, green hydrogen adoption, trust, scalability, and future-proofing. By using blockchain technology, the DPP offers a secure, transparent, and scalable system that fosters investments, innovation, and growth in the hydrogen sector, contributing to sustainability and global climate goals.

IX. Recommendations

Standards play a fundamental role in driving economic growth, global trade and the transition to a circular economy, while ensuring product safety, reliability and sustainability.

In this context, a harmonized global certification system is crucial, especially in the rapidly evolving hydrogen industry. This requires innovative legislation, governance, and the use of digitization tools. While perfect and globally harmonized legislation and regulation is of course the ideal, we do not need to wait for it. With the approach proposed in the paper, every company working in the hydrogen value chain can start right away and be flexible: Here, companies in Germany and Europe are already offering existing solutions that can be implemented on a global scale.

For regulators and certifiers:

It is recommended that regulators and certifiers familiarize themselves with the existing solution portfolio and architectures in order to effectively support the diverse landscape of voluntary certifications, legislation and mandatory certification. A comprehensive understanding of the current technical capabilities and flexibility of these solutions will enable experts and decision makers to make informed decisions regarding future legislation and regulation. This proactive approach will lead to the development of robust and adaptable frameworks that meet the evolving needs of the hydrogen sector and promote effective collaboration between industry stakeholders and regulators.

For companies:

Once companies have made the Final Investment Decision for a hydrogen project, they should begin to consider the digital layers needed to connect the various players in the value chain.

Calculate CO_{2e} emissions and identify other ESG data points and KPIs that end users are asking for, including voluntary certifications and regulatory requirements.

By using the same digital tools that will be used in the actual transport of hydrogen through the value chain, you can gain valuable clarity during the planning process. This early adoption of digital tools will also allow you to familiarize yourself with the functionality of these tools before they are needed in the production environment. Importantly, it also builds trust between the supply and demand sides, as the configuration of these tools provides an opportunity to understand the process in depth at an early stage.

Given that most hydrogen projects in the planning stage are expected to come on stream between 2025 and 2030, it is crucial to start implementing these tools as early as possible. By being an early adopter, you can avoid potential capacity constraints that may arise if everyone needs the same tools at the same time. Aim to be at the forefront of not only hardware, but also software solutions for hydrogen production and management. Taking this proactive approach will position your company to succeed in the evolving hydrogen market.

X. Annex: List of Terms and Definitions

Term	Definition
Audits	Systematic, independent examination of an organization's records, activities, or performance to verify compliance with regulatory standards, and identify potential areas for improvement.
Automated System	Systems which operate or control a process with minimal or reduced direct human intervention.
Blockchain	A decentralized, digital ledger where transactions are recorded chronologically and publicly. It provides a secure and transparent method for tracking the ownership and transfer of assets.
Book and Claim	An approach where renewable energy is added to the grid, and its environmental benefits are sold separately as certificates. The consumer purchases these certificates to claim use of renewable energy.
CAPEX	Capital Expenditure, i.e., funds used by a company to acquire, upgrade, and maintain physical assets.
Carbon Border Adjustment Mechanism (CBAM)	A tax on carbon emissions attributed to imported goods that have not been carbon-taxed at source.
Certification	The process of providing a formal attestation that a product, service, or system meets specific standards or requirements.
Certification Bodies	Organizations that assess the compliance of a product, service or system with standards and provide certification upon successful evaluation.
Certification Scheme	A system that certifies that a product, service, or system complies with specific standards or criteria.
Codes	Set of rules or guidelines designed to regulate behaviour or activities in a particular context, often in relation to professional standards or legal regulations.
CO_{2e}	Carbon dioxide equivalent, a measure used to compare the emissions from various greenhouse gases based upon their global warming potential.
Digital Product Passports (DPP)	Digital tools providing a range of information about a product's characteristics and lifecycle data, aiming to increase transparency and circularity in the value chain.
Digital Twins	Virtual replicas of physical systems, providing a real-time, dynamic simulation of their performance and behaviour for optimization and problem resolution.
Do-No-Significant-Harm (DNSH)	Principle from the EU taxonomy for sustainable activities, stating that an activity qualifies as environmentally sustainable only if it does not significantly harm any of the environmental objectives set out in the taxonomy.
E-fuels	Synthetic fuels produced by the conversion of electrical energy into chemical energy, often produced using renewable energy sources.

Energy Carrier	A substance or system that contains energy which can be converted to useful work. For example, hydrogen, which can carry/store energy until it is converted into other forms such as electricity.
Energy Labels	Information labels displaying energy efficiency or consumption for products or systems, aiding consumers in making environmentally conscious decisions.
ESG	Environmental, Social, and Governance, three key factors in measuring the sustainability and ethical impact of an investment in a business or company.
Final Investment Decision (FID)	A decision by the board of directors that officially sanctions and allows for the commitment of funds to a project or investment.
GreenToken	A type of digital token associated with the blockchain technology, which represents a certain quantity of green or renewable energy.
Greenhouse Gases	Gases in Earth's atmosphere that trap heat, contributing to the greenhouse effect and global warming. Including: carbon dioxide, methane, and nitrous oxide.
Guarantees of Origin (GoOs)	Certificates issued to prove that a certain unit of produced energy is generated from renewable resources.
Hydrogen	An energy carrier which can be used to store, transport, and deliver energy produced from different sources.
Interoperability	The ability of different information technology systems, software applications, and devices to communicate, exchange data, and use the information that has been exchanged.
International Organization for Standardization (ISO)	An international standard-setting body composed of representatives from various national standards organizations.
International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)	An international partnership to facilitate and accelerate the transition to clean and efficient energy and mobility systems using hydrogen and fuel cell technologies across applications and sectors.
Key Performance Indicators (KPIs)	Metrics used to evaluate factors that are crucial to the success of an organization.
Life Cycle Impact Assessment	A method used to evaluate the environmental impacts caused throughout a product's life cycle from raw material acquisition through production, use, and disposal.
Life Cycle Assessments (LCAs)	Systematic analysis of the environmental aspects and potential impacts associated with a product, service, or process over its entire life cycle.
Mass Balance System	A system of accounting that tracks the input and output of materials within a production process to ensure everything is accounted for.
Methodologies	A set of methods, procedures, and rules used by those who work in a discipline or engage in an inquiry; a set of principles and procedures to pursue knowledge and truth.
MRV (Measurement, Reporting, and Verification)	A process used to monitor and verify the results or progress of a project or scheme against predetermined goals or standards.
OPEX	Operating Expenditure, i.e., the ongoing costs for running a product, business, or system.

Power Purchase Agreements (PPAs)	Legal contracts between electricity generators and buyers (often utilities or large corporations) where the buyer purchases the generator's energy for a specified period at a predetermined price.
Power-to-X	Technological processes where electrical power is converted into other forms of energy, substances, such as hydrogen, often to facilitate storage or transportation.
Proofs of Sustainability (PoS)	Documents or certificates demonstrating that a product, service, or system adheres to sustainability principles or standards.
REDII	The Revised Renewable Energy Directive, an EU directive setting an ambitious target for the EU to achieve at least a 32% renewable energy share by 2030.
Regulation	A rule or directive made and maintained by an authority, designed to control or govern conduct.
Renewable Fuels of Non-Biological Origin (RFNBO)	Fuels that are produced from renewable energy sources other than biomass.
SAF	Sustainable Aviation Fuel, a type of jet fuel made from sustainable, renewable resources and designed to reduce emissions compared to conventional jet fuels.
Sector Coupling	The integration of energy consuming sectors with the power producing sector to increase the share of renewable energy, optimize energy use, and reduce greenhouse gas emissions.
Standards	Defined benchmarks or specifications established by consensus to ensure that materials, products, processes, and services are fit for their intended purpose.
System Efficiency	The ratio of useful output energy to the total input energy, used to measure how efficiently a system converts energy from one form to another.
Traceability	The ability to verify the history, location, or application of an item by means of documented recorded identification.
Voluntary Standards	Standards that are not mandated by law but can be adopted by industries or organizations to meet specific objectives or criteria.
Value Chain	The full range of activities required to bring a product or service from conception, through different phases of production, delivery to final consumers, and final disposal after use.

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Department – Analysis and Research
Trostbrücke 1
20457 Hamburg

Authors:

Dr. Maximilian Kuhn
Hydrogen Europe
Advisor

Peter Koop
SAP SE

Global Lead for Energy Transition and Hydrogen

With contributions from:

Petra Michalke

Siemens Energy
Innovation Expert

Dr. Jörg Aign
TÜV NORD EnSys GmbH & Co. KG
Manging Director

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