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Study

Certification of green and low-carbon hydrogen

An overview of international and national initiatives

adelphi

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An overview of international and national initiatives

Content

Editorial

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Dear Reader,

In light of recent events, most importantly Russia's war of aggression against Ukraine, the world is increasingly looking for alternatives to fossil fuels. Moving away from fossil fuels does not only offer strategic independence from individual providers of such fuels, increasing security, it also offers a solution for another ongoing crisis: climate change. With countries around the world setting themselves targets for net-zero, new energy sources will be needed to decarbonize all sectors of our economies – including some industrial sectors which have been hard to decarbonize so far.

Green and low-carbon hydrogen promises to be the solution to these challenges, which is why countries around the world are turning their attention towards the development of policies and technologies to upscale the usage of hydrogen and its derivatives. In this regard, one must be mindful of the challenges we are still facing regarding this scale-up. Even though production technologies are evolving rapidly, the opportunities and costs for hydrogen production differ widely between different countries. Therefore, international trade will be vital to the large-scale use of hydrogen in some of the world's most advanced economies. This is especially the case if we want to move past what some have labelled as hydrogen being the "champagne" of the energy transition – a scenario in which hydrogen would be so expensive and scarce that it could only be used very selectively.

As important as the establishment of an international market is to decrease and level-out prices across the world, it can only arise with solid foundations for trade, international standards being crucial in this regard. While some standards only need to be agreed on based on technical considerations, aspects which are more political in nature might require significantly more cooperation.

The definition and certification of green and low-carbon hydrogen is central in this political context, as the carbon intensity of hydrogen differs greatly between production technologies. While production through electrolysis using renewable electricity generates almost no emissions, different alternatives such as gas-based hydrogen with CCS emit varying levels of CO2. Considering the net-zero targets and the expected role hydrogen will play in the decarbonization of economies, this emission intensity could significantly determine the ability of hydrogen to deliver on the net-zero goal and is therefore an important quality to be considered in trade. Moving quickly on this issue is vital to enable investment in hydrogen production capacity, especially considering the implementation timelines of such projects.

The importance of hydrogen certification is underlined by the fact that several nations around the world work on definitions and certification systems for hydrogen. The following study will give an overview over the current state of considerations in some of the world's leading economies, trying to identify similarities and differences between approaches.

1 Executive Summary

Green and low-carbon hydrogen are a crucial pillar of decarbonization strategies around the world. Since many industrialized nations do not have the conditions to produce enough hydrogen, global trade will be a necessary enabler for large-scale hydrogen application. To ensure that traded hydrogen will contribute to decarbonization, clear rules and standards as well as certification schemes are required as the foundation for this emerging hydrogen market. This study explored existing as well as emerging regulations and initiatives in this regard around the world.

1.1 International Initiatives

On a global level, IPHE, the International Partnership for Hydrogen and Fuel Cells in the Economy, plays a central role in the development of standards and methodologies to estimate the carbon footprint of hydrogen. Its Hydrogen Production Analysis (H2PA) Task Force has already created a draft methodology, which is the result of an open process joined by a selective group of countries and is seen as a first step towards an international standard. Australia is already working on a guarantee of origin system in line with the mechanisms proposed by IPHE.

Furthermore, the Hydrogen Initiative of the Clean Energy Ministerial (CEM H2I) is cooperating with IPHE and seeks to provide a basis for the utilization and testing of IPHE-developed standards.

1.2 Asia

Leading Asian countries are at the forefront of the advancement of a global hydrogen economy, mostly through technological advancements in hydrogen utilization. Since Japan and Korea both target net zero emissions by 2050 and China by 2060, low-carbon hydrogen (referring to all production methods with comparatively low CO2 emissions, including green hydrogen produced from renewables) is furthermore relevant regarding their climate ambitions.

Public records of meetings of Japan's Hydrogen Policy Subcommittee acknowledge the need for a reduction in CO2 emissions along the hydrogen value chain. The establishment of a clear definition of clean hydrogen as well as the introduction of a certification system have been discussed, but are not being implemented at the moment. At the same time, Aichi Prefecture has already established a regional certification system.

Korea recently became a forerunner regarding the establishment of global hydrogen trade through its Clean Hydrogen Trade Initiative, which is intended to foster international discussions, including clean hydrogen certification. Furthermore, a national certification system for low-carbon hydrogen is currently under development and is planned to launch in 2024. It focuses on blue hydrogen, with a tentative certification threshold of 42gCO2eq/MJ.

China is currently the largest hydrogen producer in the world and is therefore of great importance to the future market. While different government strategies clearly reference low-carbon hydrogen and demonstration projects of green hydrogen production are being launched, there is no mentioning of a national standard or certification system yet. Private initiatives are however discussing the topic and the China Hydrogen Alliance has already proposed a standard.

1.3 The Americas

Both Canada and the United States are in the special position of being expected to become both major users as well as producers of low-carbon hydrogen. Chile in South America is already positioning itself as a leading future exporter.

While low-carbon hydrogen was not referenced in the US' first hydrogen strategy published by the Trump administration, the Biden administration has quickly turned this perspective. After the Infrastructure Bill mandated the development of a Clean Hydrogen Strategy and a Clean Hydrogen Production Standard, drafts of both have been published in September 2022. The strategy clearly underlines the importance of clean hydrogen in the US' climate strategy, while the Standard suggests a clear definition for clean hydrogen, which is supposed to be the foundation of future funding decisions by the US Department of Energy. Additionally, the newly passed Inflation Reduction Act (IRA) is expected to speed up low-carbon, and in particular green hydrogen production through the largest hydrogen subsidies worldwide, in the form of hydrogen production tax credits (PTC). California, the forerunner regarding hydrogen certification within the US, had already developed a monitoring and certification system for renewable hydrogen in the context of its Low Carbon Fuel Standard, introduced in 2007.

The Canadian Hydrogen Strategy from 2020 suggests to introduce technology-neutral thresholds for emissions of low-carbon hydrogen and stresses the importance of designing a relevant methodology together with international partners. In this regard, the Strategy clearly references the EU's CertifHy system as well as CertifHy's threshold. Furthermore, Canada is closely cooperating with the US to develop and align standards.

Chile plays a special role as a prime example of a future exporting country. Its 2020 Hydrogen Strategy points towards the necessity of hydrogen certification and emphasizes that Chile intends to promote the establishment of international certification systems as a foundation for an export market.

1.4 Europe

The European Union's approach is standing out in so far as it explicitly mentions goals for the production of renewable hydrogen, with low-carbon hydrogen using CCS only referenced as a bridge technology for the medium term. Certification and definition of criteria for renewable and low-carbon hydrogen are considered key for boosting demand for and scaling up production under the EU Hydrogen Strategy. A comprehensive European terminology and certification standards have recently been published in February 2023 in the form of two delegated acts by the European Commission. These acts contain a detailed methodology for the certification of renewable hydrogen. In addition, the EU has already launched a voluntary hydrogen certification system, CertifHy, which establishes emission standards and has already been used to certify green and low-carbon hydrogen.

Germany, as Europe's most important actor regarding the hydrogen economy, has decided to focus on green hydrogen and only transitionally to include blue hydrogen to achieve its net zero target. Nonetheless, government funding is predominantly targeted at green hydrogen. . In this regard, the German Ordinance on the implementation of the Renewable Energy Act establishes a clear definition for green hydrogen, with the additional provision that Germany will follow the EU standards as soon as they have been agreed on. German industry has also been among the trailblazers of hydrogen certification, with both TÜV Süd as well as TÜV Rheinland having created green hydrogen standards. These standards are based on German and European regulations and set to connect to CertifHy; but open for projects around the world. First projects have already been certified.

1.5 Conclusion

Most leading hydrogen economies analyzed in this study acknowledge the need for hydrogen certification and stress its importance in the context of hydrogen's role for decarbonization. However, the type of certification, the degree of implementation as well as the level of ambition differs substantially between countries. Thresholds for certification range from 28.2gCO2eq/MJ in the currently discussed EU threshold, ca. 33gCO2eq/MJ for the US Draft Standard, 36.4gCO2eq/MJ for the EU´s CertifHy voluntary scheme to 41gCO2eq/MJ and ca. 42gCO2eq/MJ for the suggestion of the China Hydrogen Alliance and the currently discussed Korean certification threshold.

Individual trailblazers in each region push the implementation of internationally recognizable certification systems and seek to use them as a basis for additional policy measures aimed at supporting a low-carbon hydrogen economy. However, the harmonization of these approaches on the international level remains a challenge, mostly due to the differences in ambition and focus, with countries like Germany or the US either targeting green hydrogen directly or providing substantially higher support for green hydrogen, while others, like Korea, have a clear focus on blue hydrogen produced from natural gas.

For the successful implementation of a global hydrogen economy, a harmonized approach is, however, crucial to give potential exporters a system to rely their investment decisions on, which is why leading hydrogen economies should seek ways to implement globally harmonized, or at least globally applicable, certification solutions.

2 Introduction

Green and low-carbon hydrogen will play a crucial role in the world's future energy system. Its potential uses range from decarbonization of steel and metallurgical industries over transportation and shipping to energy production. The following introduction will provide a short overview over these use cases, the challenge of hydrogen value chains as well as different production forms of hydrogen.

2.1 Hydrogen as an energy carrier

Hydrogen as an energy carrier has the crucial advantage of being very flexible in its use cases. This allows it to be a potential decarbonization option for many sectors.

First of all, hydrogen made from fossil fuels is already used in various industries, e.g. in the chemical industry, and could be replaced by green and low-carbon hydrogen in the future. Hydrogen could furthermore be used as a replacement for natural gas in many use cases, e.g. in industrial applications, heating, as a cooking fuel or for energy production. It could also replace other traditional fossil fuels in many energy-intensive industrial applications and in transportation, where hydrogen cars, trucks, buses and trains have long become technologically feasible.

Green and low-carbon hydrogen can furthermore be used as a basis for hydrogen derivatives, such as ammonia, which is for example used in agriculture, but is also discussed as a potential fuel for shipping. It is also an essential step in the production of so-called e-fuels, artificially created equivalents to traditional fossil fuels used in automotive transportation.

Lastly, green hydrogen could serve as an energy storage solution for renewable energies and therefore help to smooth electricity generation in grids with a high renewable share. In times of low demand and high supply of renewable electricity, hydrogen could be generated and converted back into electricity in case of low supply.

However, the production of every type of hydrogen necessarily leads to conversion losses. This inefficiency calls some of the mentioned use-cases in question and forces policymakers to precisely plan, which sectors are optimally suited to be decarbonized using hydrogen and for which sectors other alternatives, e.g. electrification might be better suited.

2.2 Colors of hydrogen

The terminology around hydrogen is often unclear and different countries and stakeholders use different terms, including clean, low-carbon or green/blue hydrogen, with the first to terms often used in a very general sense, referring to hydrogen produced with comparatively low emissions. In reality, however, it is crucial to take different production technologies and related emission intensities of hydrogen into account, especially if hydrogen is to be used as a decarbonization tool.

So far, almost all global hydrogen production is so-called grey hydrogen, meaning hydrogen produced through the conversion of fossil fuels, such as coal or natural gas without the removal of the CO2 emissions produced. While widely used in industrial application, hydrogen produced in this way tends to be very CO2-intensive due to the previously mentioned conversion losses and holds therefore little to no value when it comes to decarbonization.

A second option is to use fossil fuels, ideally natural gas as it is less emission intensive than coal, to produce hydrogen, but to capture most of the generated CO2 emissions and either sequester or use them in a way in which they are not released into the atmosphere. This leads to so-called blue hydrogen, which is part of many countries' hydrogen strategies. While this does not imply full decarbonization considering current technology, it can contribute to a significant emission reduction.

The third option is to use renewable electricity to generate so-called green hydrogen through electrolysis. If renewable sources are being used, this option does not emit any CO2 during the production process and is therefore seen as the option with the strongest decarbonization potential.

Lastly, there are some additional options, including for example turquoise hydrogen, which uses a chemical process to produce hydrogen from natural gas, during which carbon is generated in solid form, making air capture of CO2 unnecessary. Another option is – depending on the source – yellow or pink hydrogen, produced through electrolysis using nuclear energy.

This study will mostly refer to green hydrogen and low-carbon hydrogen, the latter referring to all production technologies with lowered CO2 emissions, importantly blue hydrogen. In some instances, the term clean hydrogen is used as a catch-all term for both green and low-carbon hydrogen, as this is the terminology chosen by some countries discussed.

2.3 The hydrogen value chain

The current energy and fuel market is global in nature, mostly due to the fact that energy producers and industrialized heavy consumers of energy and fossil fuels are in most cases not the same countries. This has led to a strong international trade in fossil fuels and energy.

The same is likely to happen in the case of hydrogen. Grey and blue hydrogen are dependent on fossil fuel resources, which would potentially give producers of these fossil fuels a comparative advantage in its production. More importantly, however, is the case of green hydrogen. Most of the heavy energy consumers of today – North America, Europe and East Asia – have only limited access to renewable energy, a problem that is exaggerated by conversion losses in the production of hydrogen. Therefore, they will likely need to import green hydrogen from countries with better access to renewable sources, such as solar and wind power – for example from North Africa with excellent conditions for solar energy or the southern part of Latin America with ample wind resources.

2.4 The case for hydrogen certification

One has to assume that current cost differences between grey, blue and green hydrogen will – at least in some sense – persist in the medium run, with hydrogen generally being costlier the less emission its production incurs. Therefore, producers will have an incentive to provide hydrogen with higher emissions. At the same time, however, countries and businesses seeking to use hydrogen for decarbonization will likely favor hydrogen with low emissions – either low-carbon or green hydrogen, depending on their national strategy. According to standard economic theory, a lack of clear and reliable information on the color and exact CO2-footprint of hydrogen could in this case cause a race to the bottom. Without a credible way to guarantee the low carbon emissions associated with their product, producers of green or blue hydrogen would be unable to pass on higher production costs to buyers. This would crowd-out green and blue hydrogen production, causing only grey hydrogen to be provided by the market.

Due to the importance of green and low-carbon hydrogen for decarbonization and the need for international trade, it therefore becomes crucial to enable both buyers and sellers to clearly communicate the CO2 emissions related to traded hydrogen. This necessitates the creation of monitoring and certification systems for hydrogen, which should ideally be globally accepted and uniform to avoid transaction costs and market distortions.

Such hydrogen certification is therefore fundamental to the establishment of a low-carbon and green hydrogen market. Moreover, its timely implementation is crucial, as investments in production capacity must be undertaken timely to ensure sufficient future production capacity. Producers will be unlikely to undertake such investments if they do not have the certainty that they will be able to sell their low-carbon and green hydrogen in the future.

2.5 The focus of this study

Due to the reasons laid out above, which underline the importance of hydrogen certification, this study seeks to provide an overview over current approaches regarding hydrogen certification in the countries considered to be most relevant for the future hydrogen economy. By comparing the different paths countries are taking, the study hopes to foster discussions on the advancement of hydrogen certification both nationally and internationally and to provide examples for mutual learning. This is then distilled into concrete cooperation potentials or potential synergies for bilateral or multilateral collaboration on the topic.

3 International Initiatives

Due to the importance of international trade with hydrogen and its derivatives in the context of the hydrogen economy, global efforts towards certification are already being implemented by different multilateral groups and organizations. Even though national initiatives, which will be covered in more detail in following chapters, are in some cases further developed than these international approaches, they lack the general applicability needed for an efficient global market. Therefore, IPHE and the IEA are crucial forums for the further development of certification and the establishment of a global hydrogen economy.

3.1 IPHE

IPHE, the **International Partnership for Hydrogen and Fuel Cells in the Economy** is an international organization dedicated to the facilitation of "the transition to clean and efficient energy and mobility systems using hydrogen" (IPHE 2022b). The inter-governmental partnership currently has **23 member countries**, including the European Union, and works on a range of different hydrogen-related issues through its working groups and task forces. IPHE views the measurement and tracking of the greenhouse gas footprint of hydrogen as well as an accepted guarantee of origin or certification scheme as a **crucial component for future international trade** (IPHE 2022a).

IPHE also supports the creation of such standards. One of its task forces, the **Hydrogen Production Analysis (H2PA) Task Force**, is "aiming to develop a mutually agreed methodology framework to determine the greenhouse gas emissions associated with hydrogen produced from different pathways" (IPHE 2022a), which seeks to build **the foundation for a future international standard**.

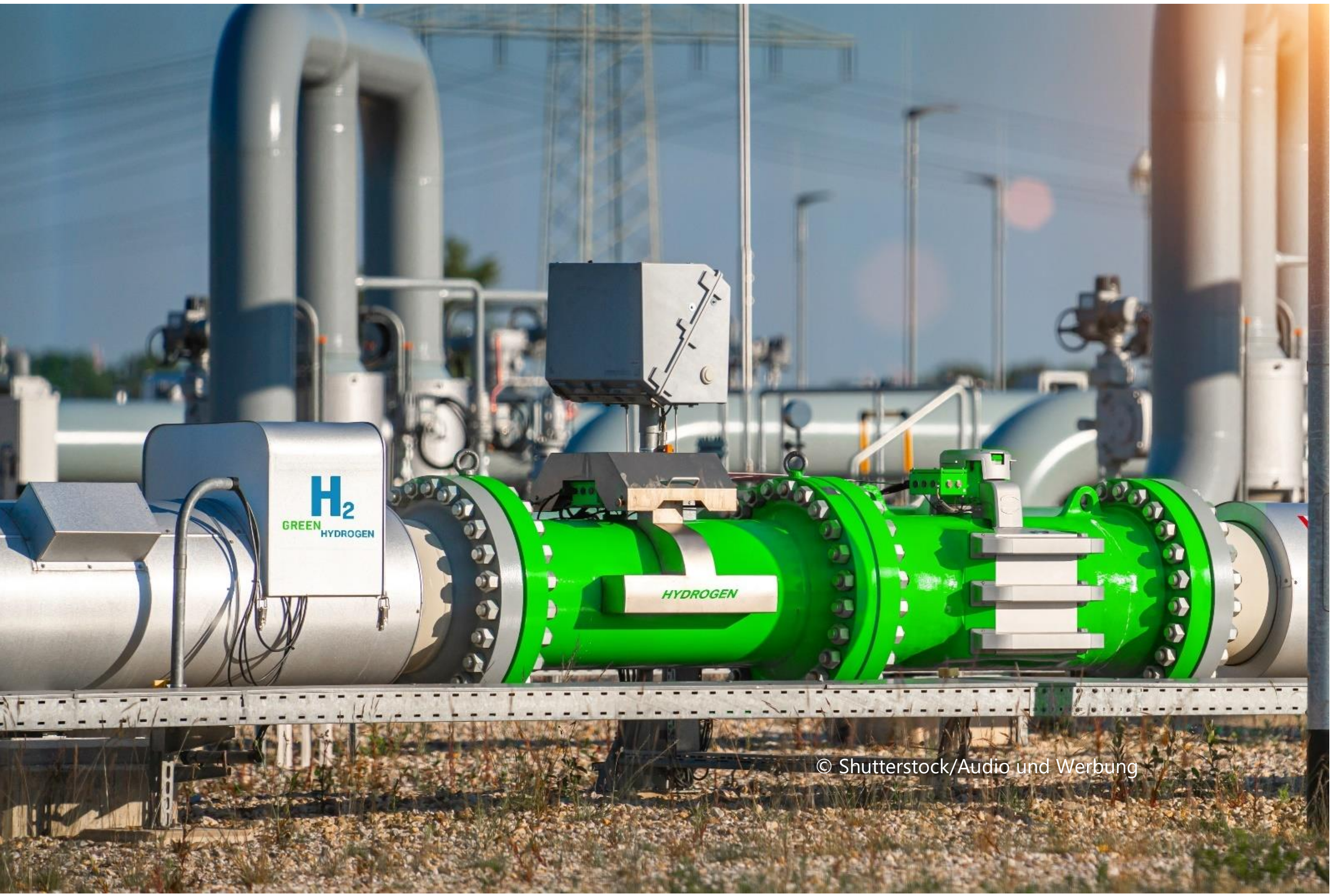
This is already bearing fruit, as Australia is currently working on a guarantee of origin (GO) scheme in line with the mechanisms proposed by IPHE. Moreover, IPHE suggests that the bottom-up creation of a certification system could be **more efficient** than creation via a top-down global system. A bottom-up approach would allow for the emergence of different national initiatives and smaller **bi- or trilateral groups** that could later be consolidated. These groups could, driven by the ambition of individual trailblazers, move forward faster than top-down global approaches and later build the foundation for a global system. Extending this idea, also means that such national or bi-/tri-lateral initiatives could give individual countries more influence on a future global standard, as the experience and expertise of the first movers would likely play a crucial role in its development.

Concerning the details of the methodology proposed by IPHE's H2PA Task Force, a **draft methodology** presented in the fall of 2021 (IPHE 2021) is of particular importance. The document in question is the result of a process open to all IPHE members but "does not necessarily reflect the views of individual IPHE member countries". This is in particular relevant since the members of the core team **designing and directing the paper were exclusively from Europe and Australia**, even though experts from other IPHE countries, including Japan and Korea, also contributed. The paper is furthermore "not a conclusion or direction of the IPHE", but merely intended as the **first step** in a longer process.

The draft methodology is nevertheless noteworthy, as it is the first suggestion by the mentioned Task Force. Its aim is to develop a "methodology and analytical framework to determine the GHG emissions related to a unit of produced hydrogen". The methodology is built on a range of **core principles**, namely the non-exclusion of any potential primary energy source used, flexibility, transparency, comparability as well as practicality. By developing a methodological framework, it partly references existing ISO standards, notably ISO 14040, 14044 and 14067, which were also referenced by IPHE member countries, e.g. in the standards suggested by the China Hydrogen Alliance. While discussing the contents of the proposed methodology is beyond the scope of this overview, it is important to mention that prior analysis has underlined that the methodology "could potentially be a first step towards the creation of an international standard" (Piria et al. 2021) and would **provide a solid basis** regarding many points. Nonetheless, the analysis also points out that the methodology has some shortcomings, e.g. regarding the estimation of fugitive methane emissions or electricity sourced from the grid. This leads to a misalignment with the approaches by more ambitions IPHE members, in particular with the European Hydrogen Strategy and the EU Renewable Energy Directive.

3.2 CEM – IEA

Different national governments cooperate on hydrogen in the framework of the **International Energy Agency's Clean Energy Ministeria**l. The Hydrogen Initiative of the Clean Energy Ministerial (CEM H2I) is a voluntary initiative of several governments which mainly aims to advance hydrogen policy and projects. It is based on non-binding agreements between the individual national ministries (IEA 2022). A special activity on Hydrogen Certification began under the 2021-2022 work program of the CEM H2I. This activity is being implemented together with the IPHE (see above), namely with the aforementioned IPHE Task Force. The idea behind this activity of the CEM H2I is to ultimately provide a basis for **utilization and testing of the methodologies developed by the IPHE Task Force**. Importantly, the EU, which chaired the H2PA Task Force at the time of writing of the work program, will actively and regularly report to the H2I advisory group on the progress made in the Task Force. H2I will then explore relevant activities and opportunities (Clean Energy Ministerial and Hydrogen Initiative 2020). CEM H2I does not work on certification strategies or campaigns beyond this cooperation with IPHE.



4 Regional and national initiatives on hydrogen certification

An internationally standardized methodology would be the most effective approach towards certification in the long run. In the meantime, a range of leading hydrogen economies have understood the need to move faster to securely and timely establish supply chains to power their industries and to reach their net zero targets in time. Understanding and comparing different national approaches offers the opportunity to identify overlaps and potential areas for cooperation. Drawing on the nationally or regionally developed ideas can also benefit the bottom-up development of a global standard as pointed out in Chapter 3.

4.1 Asia

Asia is home to some of the world's most advanced hydrogen economies, in particular China, Japan and the Republic of Korea. In terms of their approach towards hydrogen, they share a focus on hydrogen application across different industries and a crucial role of hydrogen in their strategies towards Net Zero. This also means that especially Japan and Korea are likely to become major importers of hydrogen in the future, which underlines the importance of international trade and certification. Regarding certification, there are, significant differences between different countries, which will be explored in more detail.

4.1.1 China

China, much like the other countries that will be discussed in this report, is also expected to play a major role in the future global hydrogen economy. This is underlined by the size of China's economy and therefore its role as a leading producer and consumer of hydrogen. As of the time of writing, the People's Republic is **the largest grey hydrogen producer in the world** and the country with the **highest installed renewable power generation capacity** (Nakano 2022). China has also been actively supporting the usage of hydrogen, e.g. in the mobility sector, and has started a range of hydrogen-related projects even though the publication of a comprehensive hydrogen strategy is still outstanding at the time of writing (Nakano 2022). These projects notably include demonstration projects for the generation of green hydrogen from wind and solar power (National Development and Reform Commission of the People's Republic of China 2022).

At the same time, however, almost all of the hydrogen produced in China as of now is produced **from fossil sources**, with less than 1% being produced from renewable sources (Song 2022). In light of the developing climate crisis as well as **China's goal to become carbon neutral by 2060**, the generation of green and low-carbon hydrogen as well as their certification is a pressing issue for China. This is indicated by the growing political pressure from the China Hydrogen Alliance, a private organization, which has been calling for 100GW of electrolyzer capacity by 2030 (Nakano 2022).

It is, however, also reflected in official government documents, most notably in the Medium and Long-term Plan for the Development of Hydrogen Energy Industry (2021-2035). In this document, the Chinese government emphasizes that "hydrogen energy is an important part of the future national energy system" and that there shall be a **"focus on developing hydrogen production from renewable energy"**.

It also outlines goals to **actively decarbonize different industries** and to establish a policy environment for the development of the hydrogen energy industry. Despite these formulations and the goal to establish standards for the quality and safety of hydrogen production, standards for green or clean hydrogen are **not explicitly mentioned**. The document only stipulates that China aims to "actively participate in international hydrogen energy standardization activities", without clarifying the underlying intention.

Despite the lack of a national standard or publicly communicated efforts to implement its own national approach towards hydrogen certification beyond the participation in international fora, **private actors have been pursuing initiatives related to hydrogen certification**. Especially worth noting is the 'Standard and Evaluation of Low-Carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen' which was issued in December 2020 by the China Hydrogen Alliance. These guidelines propose specific thresholds for two types of low-carbon hydrogen, so-called "low-carbon" and "clean hydrogen" as well as a more detailed set of standards regarding accounting. In the document, low-carbon hydrogen is defined as hydrogen with greenhouse gas emissions below 14.51 kg CO2e/kgH2. Clean hydrogen is defined as hydrogen below emissions of 4.90kg CO2e/kg (ca. 41gCO2eq/MJ, assuming 120 MJ/kg) (Liu et al. 2021).

4.1.2 Japan

Japan is at the **technological forefront of the development of a global hydrogen economy**, with a particular focus on the use of hydrogen in industry, electricity production and mobility. Importantly, hydrogen will also play a central role in **Japan's transition to net zero by 2050**, as outlined in its 6th Strategic Energy Plan (Agency for Natural Resources and Energy 2021). The importance of low-carbon hydrogen also underlined by the revised version of the Strategic Roadmap for Hydrogen and Fuel Cells from 2019, which mentions **the need for CO2 emission reduction along the whole hydrogen supply chain**. As of now, Japan is pursuing a broad approach, with hydrogen produced with low emissions generally being referred to as clean hydrogen, irrespective of the production technology. Therefore, Japan's approach to clean hydrogen includes hydrogen produced from fossil sources with CCS as well as hydrogen produced through electrolysis using renewable electricity.

Japan is discussing both the **establishment of a precise definition of clean hydrogen** as well as the introduction of a **certification and monitoring system**. Even though no details are known with regards to the current state of these discussions, public records of meetings of Japan's Hydrogen Policy Subcommittee show that the Japanese Ministry of Economy, Trade and Industry (METI) is aware of the need for such a system, in particular in the context of international value chains (Ministry of Economy, Trade and Industry Japan 2022).

An important role is also played by the **Council for a Strategy for Hydrogen and Fuel Cells** (CSHFC) (Wenger and Wagner 2021). The council was founded by METI and consists of a range of industry stakeholders in the hydrogen economy. In a 2017 report, the Council **highlighted the need for low-carbon hydrogen certification**, and a working group also proposed a system of four categories, with the lowest tier being equal to 1.0-3.5 kg-CO_2/Nm3-H2 (ca. 324gCO2eq/MJ) and the highest 0.1-0.4 kg-CO2/Nm3-H2 (ca. 37gCO2eq/MJ). This clearly underlines a demand for a certification system from the side of industry stakeholders.

In addition, the Japan Hydrogen Association has recently published a proposed definition of low-carbon hydrogen reflective of a 70% reduction compared to natural gas steam reforming. This definition suggests a threshold of 3.4 kgCO2eq/kg (ca. 28.3 gCO2eq/MJ) using a well-to-gate approach. The association also targets 3 million tons of clean hydrogen produced by 2030 (Ministry of Economy, Trade and Industry Japan 2/27/2023).

At the same time, **a regional certification system** for low-carbon hydrogen was launched by Aichi Prefecture in April 2018. The system focuses on **direct emissions during the production process**, with hydrogen produced from electrolysis using renewable energy, hydrogen originating from the steam reforming of biogas or sodium hydroxide by-product hydrogen being eligible for the system (Wenger and Wagner 2021).

Apart from this regional approach, the **J-Credit System**, under which third-party certified emission reductions can be traded and used to fulfil emission reduction obligations under a range of different initiatives or serve as voluntary offsets, can also be used for hydrogen projects. Through this system, green electricity used for green hydrogen production can be used to generate credits. METI has also announced that it **plans to add hydrogen usage directly to the J-Credit system** (Energy Conversation Center Japan and Asia Energy Efficiency and Conservation Collaboration Center 2021). Specific details have not been confirmed yet.

On the multilateral level, Japan is a member of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) described above, specifically in the H2PA Taskforce. As initiator of the Hydrogen Energy Ministerial Meeting in 2018, Japan furthermore **advocated for international cooperation on technologies** and the harmonization of regulation, codes and standards in order to speed up cost reductions for hydrogen supply and products (Hydrogen Energy Ministerial Meeting 2021).

4.1.3 Republic of Korea

Korea is also one of the **leading actors when it comes to the realization of a hydrogen economy**, with a particular focus on the usage of hydrogen in the mobility sector. While Korea's focus in the past was primarily on usage rather than on clean production and procurement of hydrogen, this has **significantly changed over the last years**. Already in Korea's 2020 Hydrogen Strategy (Park 2019), water electrolysis is mentioned as a central pillar of hydrogen production and a 70% share of CO2-free hydrogen by 2040 is targeted (Kan 2022), while first imports of clean hydrogen are aimed at for 2030. These are then expected to raise to 23 mio. Mt/year by 2050 (Lee 2021).

In particular to support the imports of hydrogen, the Korean government has introduced the **Clean Hydrogen Trade Initiative in 2021**, through which it intends to discuss and further develop the foundations for global hydrogen trade with like-minded countries. The first of the cooperation areas under the initiative is **clean hydrogen certification**, which includes a standard to calculate life-cycle CO2 emissions as well as verification and mutual recognition of certification (Korea Pavilion 11/1/2021).

In November 2022, the Korean administration announced the new hydrogen economy policy of the Yoon government, elected in February 2022, with a focus on "establishing a clean hydrogen supply chain and nurturing a world-leading hydrogen industry" (Ministry of Trade, Industry and Energy Korea 2022). Alongside building up a clean hydrogen ecosystem domestically and globally, fostering technological innovation in Korea, building the necessary infrastructure, the introduction of a clean hydrogen certification system remains a priority of the Yoon administration. Work on this **national certification system for clean (low carbon) hydrogen** had started under the previous administration in 2021 and is planned to be finalized in 2024 (IPHE 2022c). The system is intended to include different production methods, ranging from green hydrogen production using electrolysis to blue hydrogen production using CCS. The Korean government recently reaffirmed to also consider hydrogen production from nuclear energy (Ha-Nee 2022). A draft of the system, which will take international trends into account and is meant to also be used internationally, is expected for 2023.

While discussions are still ongoing, as of December 2022, a threshold of ca. 5kgCO2eq/kgH2 has been proposed based on the current CO2 intensity of domestic blue hydrogen with 95% sequestration. It is foreseen that this threshold will be gradually lowered. So far, only CCS, not CCU, is considered for the certification of low-carbon hydrogen. The accounting procedure focuses on "well-to-gate", emissions up to and including production, for domestic and "well-to-import port", furthermore including emissions from the transport to Korea via shipping, for imported hydrogen (Lee 12/6/2022).

An amendment of the Hydrogen Act to introduce Clean Hydrogen Energy Portfolio Standards was **passed by the legislature in June 2022** and entered into force on the 12th of November 2022. The Standards will require state utilities to purchase a fixed share of hydrogen as part of their overall fuel procurement (Eun-Joo 2020). This will remove hydrogen energy production from Korea's existing Renewable Portfolio Standards (Song 2022). These require large energy producers to use a certain share of renewable energy or to buy certificates from producers with higher renewable shares. Before the introduction of the new standards, this system also supported hydrogen fuel cells by treating them as renewable energy sources without accounting for the variety of different hydrogen production methods. To support the new Portfolio Standards, a bidding market to supply and purchase hydrogen-generated electricity will also be established in the first half of 2023 (Lee 12/6/2022).

The amendments include a definition of clean hydrogen, the establishment of the aforementioned certification system as well as the requirement for hydrogen suppliers to supply clean hydrogen (Son et al. 2022). Specifically, the new law **defines clean hydrogen as including both CO2-neutral as well as low-CO2 hydrogen according to standards set by presidential decree** (Korean Ministry of Government Legislation 2022). It tasks the Ministry for Trade, Industry and Energy (MOTIE) with setting up a certification system according to the provisions set by the aforementioned decree (Korean Ministry of Government Legislation 2022). It also specifies that the Ministry has the power to certify hydrogen and revoke certifications obtained under illegal circumstances. Furthermore, the law specifies that MOTIE is allowed to **fund and administratively support producers of certified clean hydrogen** and to differentiate this support according to the quality of the certification. The establishment of certification institutions as well as reporting requirements for clean hydrogen producers are also mentioned. Lastly, the amended law also provides the foundation for clean hydrogen requirements as well as for a trading market for electricity produced from hydrogen.

Through the establishment of a legal basis for the future implementation of a clean hydrogen certification system, Korea leads the way in terms of hydrogen certification in Asia. Together with its ambition to cooperate with other nations through the Clean Hydrogen Trade Initiative, it can be assumed that Korea will become a major player in the context of global certification approaches in the future, with a strong focus on blue, not green, hydrogen.

4.2 The Americas

While hydrogen will also play a crucial role for both decarbonization and the achievement of Net Zero goals in the two leading industrialized nations in America, Canada and the United States, the Americas differ from the Asian nations discussed before. Several American nations are expected to become major exporters of green and low-carbon hydrogen due to the abundance of natural resources. This implies that certification is of a two-fold importance for American countries. It matters with respect to the decarbonization of their own economies, but also as a foundation for the establishment of hydrogen exporting industries, like in the case of Chile or Canada. The latter two countries show that exporters are greatly concerned with the establishment of hydrogen certification, as they see it as the very foundation of the future market.

4.2.1 Canada

Canada is expected to play a **major role as a future exporter of hydrogen**, as formulated in its Hydrogen Strategy, which was developed by the government in cooperation with various stakeholders in 2020 (Government of Canada 2020). At the same time, Canada aims to achieve climate neutrality by 2050, which underlines the importance of low-carbon hydrogen production for the Canadian case.

As of now, Canada has **yet to establish a clear definition of low-carbon hydrogen** or targeted CO_2 emission intensities of hydrogen production, while the targeted percentage of emissions reduced through CCUS is still debated (Teichmann et al. 2021). This is especially relevant as Canada foresees a **significant role for blue and grey hydrogen**. For both, the Canadian Hydrogen Strategy sets the ambition that fossil-fuel-based hydrogen production will "predominantly [sequester a share] greater than 90 %" of CO_2 by 2030. The strategy, however, does not provide a clear perspective to zero emissions.

At the same time, Canada is **aware of the need for certification and monitoring**, especially in the context of potential exports. The Canadian Hydrogen Strategy suggests to introduce technology-neutral thresholds for emissions, which can be independently certified. It also emphasizes the **importance of designing a relevant methodology in this regard together with international partners**. The strategy furthermore explicitly refers to the EU's CertifHy system as well as CertifHy's threshold, namely 36.4 gCO_2-eq/MJ. This, however, would not distinguish between different production methods, some of which are significantly more carbon intensive than others.

Similar to the Californian approach, which is discussed in the US chapter, Canada has also decided to implement a **Clean Fuel Standard**, which will obligate primary suppliers of fossil fuels to gradually reduce the lifecycle carbon intensity of sold fuels. The carbon intensity reduction requirement will be gradually increased, starting at 3.5 gCO_2e/MJ and reaching 14 gCO_2e/MJ in 2030 (Government of Canada 2022). As in California, there will be the option to generate tradeable certificates, for example by providing low-carbon hydrogen. The standard will enter into force in July of 2023 (Scherer and Nickel 2022).

Furthermore, Quebec aims to establish itself as **a center for the production of green hydrogen**. The province has developed its own Hydrogen Strategy, in which it stresses the importance of the certification of green hydrogen as well as the harmonization of regulation with the US (Gouvernement du Québec 2022).

There have also been important developments in the private sector, most notably the foundation of CertifHy Canada, which seeks to offer a private-sector solution to the certification of different types of low-carbon hydrogen (CertifHy Canada 2021).

With regards to international cooperation, it is important to mention the Canada/US Regulatory Cooperation Council, through which the two countries **seek to develop and align standards**. Part of these efforts is also the development of a common methodology to determine the carbon intensity of different methods of hydrogen production (Government of Canada 2020).

4.2.2 Chile

Chile is expected to play a role as a major prospective exporter of hydrogen and proves that not only the demand side of a future global market is actively working on visions for the future. Producers of hydrogen might even be more aware of the **need for certification.**

Chile offers abundant natural resources, both wind in the south and sun in the north, to facilitate the production of green hydrogen and its derivatives. In order to take advantage of these resources for the future green hydrogen market, **Chile aimed at establishing itself as a green hydrogen provider early on**. In 2020, the country published its hydrogen strategy, which underlines Chiles advantages for developing a hydrogen economy. The strategy also points towards the **necessity of hydrogen certification** and emphasizes that Chile intends to promote the establishment of international certification systems as a foundation for an export market (Government of Chile 2020).

This **need for a certification system** is also expressed by potential exporting firms in Chile. A recent study (Boyle et al. 2021) underlines that potential exporters need a **clear certification scheme to initiate first projects and undertake the necessary investments**. Only such a clear scheme, either internationally or in bilateral cooperation with an importer, would ensure that their products will have a market once the projects have been completed.

In addition, it was highlighted that the establishment is an important issue, as large hydrogen production projects need years to be implemented. If producers do not have a clear framework to refer to in the very near future, it seems unlikely that there will be the needed supply capacity towards the end of the decade.

Additionally, a report prepared for the Chilean government and the World Bank cites the Chilean Hydrogen Association in saying that the focus should be on **certification rather than labeling**, to ensure verifiability, and that the market – the importers – would **need to set the rules** (Hinicio and Ludwig-Bölkow-Systemtechnik 2021), which is why producers depend on the initiative from the importer's side. The same report also recommends Chile to follow the EU's CertifHy standard in its own approach to certification, which underlines the EU's role as a trailblazer in this regard.

4.2.3 United States

The Biden administration is targeting **climate neutrality by 2050** (Kerry and McCarthy 2021). In this context, **hydrogen is of high relevance**. Currently, the US is the **second largest producer and consumer of (grey) hydrogen in the world** (Wood 2022). 99% of US hydrogen production is currently based on fossil fuels, predominantly natural gas, with only 1% being produced through electrolysis. About 96% of hydrogen consumed in the US serves as a feedstock or reactant in petroleum refineries (57%), ammonia and methanol (38%) and metals production (2%) (Sönnichsen 2022).

The Infrastructure Bill passed by the Congress in early November 2021 mandates the Department of Energy (DoE) to develop a **National Clean Hydrogen Strategy and Roadmap** and a **Clean Hydrogen Standard**, based on a GHG intensity standard for clean hydrogen of max. 2 kg CO2eq per kg of hydrogen at the production site. This definition excludes indirect upstream emissions and downstream transportation emissions (U.S. Congress 2021).

The draft of the Strategy was unveiled in September 2022. It includes a range of provisions regarding the certification of hydrogen, for instance by proposing that best practices should be collected between 2022 and 2025 in order to inform future guarantees of origin and certification schemes. More importantly, the strategy lists the **establishment of internationally accepted standards and certification schemes** across the hydrogen value chain as a priority, with a clear focus to connect already existing initiatives. It furthermore states that these would be **"essential enablers"** (U.S. Department of Energy 2022) of production and trade of hydrogen.

As the new Strategy is only a draft as of now, the most recent fully approved document is a hydrogen strategy formulated under the Trump administration in 2020 (U.S. Department of Energy 2020), which does not mention the establishment of green or low-carbon hydrogen certification, only referring to safety and technical standards. The strategy argues that the production of hydrogen with fossil fuels and CCUS would be the most cost-effective solution going forward, a claim that is questioned by the literature, without specifying any limits on CO_2 emissions. This is most likely driven by the political ideology of the last administration. The forthcoming strategy formulated by the Biden administration includes major changes in this regard and puts a strong emphasis on green and low-carbon hydrogen.

Beyond certification, it is relevant to mention a number of relevant **US' initiatives towards the establishment of clean hydrogen production**, such as the Hydrogen Energy Earthshot initiative (GenH2 2022), which is aimed at reducing the costs of green hydrogen by 80 % until 2030. In the context of this initiative, the DoE mentions its goal to "lower life-cycle greenhouse gas emissions by at least 90% from current levels" for the production of hydrogen (Arjona and Satyapal 2021). Other examples include various initiatives under the **Infrastructure Investment and Jobs Act**, such as the Hydrogen Hubs Implementation Strategy or the Clean Hydrogen Manufacturing Initiative. The former was already announced by the DoE in September 2022, with an overall budget of 7 billion USD, with concept papers being due in November, which underlines the urgency with which the DoE pushes progress in this area.

The newly passed **Inflation Reduction Act (IRA)** from August 2022 is expected to further speed up low-carbon, and in particular green hydrogen production and usage in the USA. It is considered to **include the largest hydrogen subsidies worldwide**, especially through hydrogen production tax credits (PTC). Hydrogen with a minimum reduction of 60 % GHG compared to unabated grey hydrogen (under 4kgCO2eq/kgH2) is eligible for the PTC. The **credit increases the higher the GHG emission reductions**, while only hydrogen under 0.45 kgCO2eq/kgH2, which will likely only hold for green hydrogen, qualifies for the top $3/kg tax credit. Blue hydrogen will also be eligible for receiving the PTC, but only if it has not already received tax credits for carbon capture, in order to further prevent market distortions. Projections assume that with the PTC, **green hydrogen could become already price competitive** in the USA within this decade (Natural Resources Defense Council 2022).

Closely related to the discussions around PTC is the discussion of a definition for "clean hydrogen" as a basis for funding decisions by the DoE. Originally, discussions followed the provisions in the Infrastructure Bill, namely 2 kg of CO_2 per kg of hydrogen. Since the definition in the Infrastructure bill is however limited to emissions at the source, the DoE needed to find a different standard if it wanted to include up- and downstream emissions as well. Following such considerations, the DoE published a **Draft Clean Hydrogen Production Standard** for feedback in September of 2022, which sets an emission intensity target of 4 kg of CO_2 equivalent per kg of hydrogen (ca. 33gCO2eq/MJ, based on 120MJ/kg), thereby assuming 2 kg CO2eq of direct emissions – following the Infrastructure Bill – and 2 kg CO2eq as indirect lifecycle emissions. For now, this value is intended as a guidance for the DoE's funding decisions.

Apart from federal government initiatives, there also exists a "**Roadmap to a US Hydrogen Economy**" (Fuel Cell and Hydrogen Energy Association 2020), formulated by different industry stakeholders through the Fuel Cell & Hydrogen Energy Association (FCHEA). It describes an ideal hydrogen economy development scenario for the US. The roadmap stresses the **importance of certification and "standardization of hydrogen practices to enable broader deployment"**, especially in the long term, as a foundation for an effective clean hydrogen economy beyond 2030. It also points out that **harmonizing definitions of the hydrogen production pathway would be crucial for regulation** in the US as well as for exports. It continues by providing examples for such pathway definitions, specifically naming the EU's definition of green hydrogen as well as the European Certification System CertifHy as examples (see the EU section of this paper). It also mentions Californian standards on minimum renewable content for hydrogen production for publicly funded fueling stations and production facilities.

This points towards the **special case of California**. California was one of the front-runners in the establishment of clear definitions for green hydrogen in the context of the adoption of its Low Carbon Fuel Standard (LCFS) in 2007. This system sets an emission target for the mobility sector, specifically for oil refineries and distributors, and establishes a system of tradeable LCFS certificates. These certificates can be used by entities with emissions exceeding the threshold to offset their emissions and comply with the LCFS. These certificates can be generated by users or distributers of low-carbon fuels, such as clean hydrogen. In order to facilitate this generation of credits, the system established a **certification and monitoring system for renewable hydrogen** used in vehicles or in fuel production. According to the regulation, hydrogen refueling stations need to offer at least a 33 % share of hydrogen from electrolysis, biomethane or thermochemical conversion of biomass (Achtelik 11/16/2009).

4.3 Europe

To reach its ambitious Net Zero targets, nations across Europe will need to import large quantities of green and low-carbon hydrogen from partners across the world. With some of these projects already being initiated, e.g. between Germany and Canada, the issue of hydrogen certification is pressing. This likely also explains why Europe has moved much faster than most other regions on the establishment of hydrogen certification and already has a range of national and EU-wide certification initiatives established. While the situation is somewhat like the one in leading Eastern Asian hydrogen economies, joint policymaking through the European Union means both a stronger need for successful international collaboration as well as a larger global impact of Europe's decisions on hydrogen certification.

4.3.1 European Union

The "European Green Deal" is the climate policy flagship of the European Union. It was passed in 2019 with the objective to achieve **climate neutrality by 2050** within the EU. Clean hydrogen is listed among many other aspects as a key priority contributing to this target (European Commission 2019). The harmonization of safety and environmental standards is of critical importance to support the **EU´s efforts for global leadership in the clean energy transition** and will shape the development of the hydrogen market for all players involved (European Union 2021).

Regulatory clarity and predictability are in this sense crucial for the global hydrogen economy, especially considering the EU's role as one of the **leading hydrogen importers of the future**. A lack thereof could strongly jeopardize the global market ramp-up, as certainty about the exact criteria for green and low-carbon hydrogen required to be eligible for the EU market is a precondition for increased investments in exporting nations (Gherasim 2022; Tovar 2022). EU member states therefore voiced their support early on for a harmonized European certification scheme (Pentalateral Energy Forum 2021).

Following the Green Deal, the EU passed the **"Hydrogen Strategy for a climate-neutral Europe"** in July 2020, setting out pathways of how the production and usage of green hydrogen could contribute to achieve the objectives set out in the Green Deal and decarbonize different industry sectors and transport in the EU. The EU hydrogen strategy (European Commission 2020) foresees a **production of up to 10 million tons of green hydrogen in the EU by 2030**, with the definition that it must be "hydrogen produced through the electrolysis of water (in an electrolyzer, powered by electricity), and with the electricity stemming from renewable sources." The strategy also acknowledges that in the **short- and medium-term low-carbon hydrogen** (using CCS in the production) would be needed. However, **the main focus remains on green hydrogen** and even though "appropriate support would be needed for low-carbon hydrogen, [...] this should not lead to stranded assets" (European Commission 2020).

In response to the Russian invasion of Ukraine the European Commission (EC) passed the **REPowerEU plan** to diversify its energy supply and accelerate the roll-out of renewable energy, cutting the dependency on fossil fuel imports. The plan sets the ambitious goals of producing **domestically 10 million tons of green hydrogen and also import the same amount by 2030** (European Commission 2022a). With these ambitious targets, the EU settles its position to become one of the key players on the global hydrogen market, but will have to import large quantities of green hydrogen (Taylor 2022).

To **push the market** towards the provision of the desired quality and quantity of green hydrogen and its derivatives, a **demand side-supportive framework** was installed by the EU. It is applicable to domestic and imported production to **create certainty for industry and investors for the needed long-term investments** and build-up of a European, but also global green hydrogen supply chain for export nations. The certification and definition of a set of criteria for green and low-carbon hydrogen were considered key actions for "boosting demand for and scaling up production" under the hydrogen strategy, giving security to market players. (European Commission 2022b). Therefore, it was decided to put in place "a comprehensive terminology and European-wide criteria for the certification of renewable and low-carbon hydrogen" (European Commission 2022b).

The central legislative basis for certification of renewable hydrogen is included in the current **Renewable Energy Directive ("RED II")**. The directive was designed to promote and increase the share of renewable energy in the EU´s energy mix up to 32% by 2030. RED II sets the baseline for the definition of **criteria for the production of renewable liquid and gaseous transport fuels of non-biological origin (RFNBO)** used in the transport sector. This **also entails general criteria for green hydrogen and its derivatives** to be counted towards the renewable energy targets and to be considered for green hydrogen support schemes. **RED II** is thus the **starting point for hydrogen certification on the EU-level.**

The **regulatory framework for specific criteria for green hydrogen is determined in two delegated acts (DA) under Art. 27 and 28 of the RED II** (Heinemann et al. 2022; Klessmann et al. 2022). The two DAs were published in February 2023 by the European Commission. They are still pending the approval by the European Parliament and the European Council to enter into effect in June 2023.

The DA on Art. 27 sets out the "**requirements for renewable electricity used to produce these renewable transport fuels so they can be counted as fully renewable**" (European Commission 2023a). The criteria set out in the DA explicitly applies to both domestically produced and imported RFNBOs. One of the core ideas is to assure that the energy used for the production stems from **additional renewable capacities**

specifically dedicated towards RNFBOs. The reasoning behind this approach is to avoid the cannibalization of emission savings with the use of already existing renewable electricity sources and thus a possible increase of emission intensive electricity sourcing in other market segments. The DA itself differentiates between different cases for electrolyzes, sourcing renewable electricity through **a direct connection or an indirect connection** via the grid or through PPAs. It defines different requirements for these cases under which the electricity used can be counted as fully renewable. The carbon intensity of the electricity input is defined as zero as long as the electricity used is labeled as fully renewable under the provisions set out in the DA on Art. 27. This is key for the calculation of life-cycle emissions of renewable hydrogen established by the DA on Art. 28 (Sailer 2021; Scheyl 2022).

For both direct and indirect connections, the central provision is that the supplying power plants must have be max. commissioned 36 months before the electrolyzer. For indirect connections, the **requirements of renewability, additionality, as well as temporal and geographical correlation** must be respected. An exemption was included for electrolyzers being located in a bidding zone with an average emission intensity of 18 gCO2/MJ or lower, under the provisions that the electricity was supplied via at least one PPA and the requirements for temporal and geographical correlation are met. Detailed exemptions also apply for electrolyzers with grid connections via PPAs, located in a bidding zone with an average share of over 90% renewables in the last year or in certain cases of downward re-dispatchment of renewable energy sources. As mentioned above, the **requirement for additionality** entails that the supplying power plants must have been max. commissioned 36 months before the electrolyzer. The addition of capacities is allowed within a further 36 months. Furthermore, the power plant may not receive capital expenditure (CAPEX) or operational expenditure (OPEX) support (exceptions e.g. for grid access or R&D facilities). However, as an **incentive for first movers**, RNFBO producers which have started operation before 2028 are exempt for this criterion until the end of 2038 (Sailer 2021; Friese and Scheyl 2022; European Commission 2023a).

The **requirement for temporal correlation** was included to prove the alignment between the actual production of RNFBO and the previous consumption of renewable electricity. Generally, the RNFBO will have to be produced in the same one-hour period as the renewable electricity or from renewable electricity from a storage asset (charged during the same one-hour period) located behind the same network connection point as the electrolyzer. Until December 31, 2029, one month will be applied. A last option to fulfill the requirement refers to certain circumstances with low energy prices, as it was argued that in this case fossil-based electricity production would not be economically attractive and additional electricity demand from the electrolyzer would stimulate further production of renewable energy. For the last **requirement of geographic correlation**, the power plant and RFNBO production need to be located (or were previously located when operation started) in the same bidding zone, an interconnected bidding zone when the electricity prices on the day ahead market are equal or higher or an interconnected bidding zone in case of an offshore bidding zone (Scheyl 2022; Friese and Scheyl 2022; European Commission 2023a).

Following this, **the DA on Art. 28 of the RED II**, focuses on a "methodology for GHG savings [which] puts forward a **detailed scheme to calculate the life-cycle emissions of renewable hydrogen**" (European Commission 2023b). It determines the amount of GHG emissions savings from RFNBO, including green hydrogen, but also eligible carbon sources and regulations for co-processing. **A life-cycle approach is taken**, covering the entire life cycle of the RFBNO and includes emissions from input, processing, transport and distribution, combustion as well as savings from CCS. The **GHG footprint reduction** from the use of RFNBOs must be **at least 70% compared to fossil fuels**. With the reference value for the fossil fuel comparator of 94gCO2e/MJ included in the **DA on Art. 28, a threshold below 28.2gCO2e/MJ** can be deducted (Friese and Scheyl 2022; Scheyl 2022).

Once the DAs have final approval by the European parliament and European Council, the **implementation of the actual certification system** will follow. The Commission is set to recognize **voluntary schemes**, which can be either national (e.g. in Italy) or privately run (e.g. ISCC, TÜV SÜD) and will **develop actual tangible criteria out of the regulatory framework** for the producers to fulfil. These schemes will then appoint **certification bodies to carry out the necessary audit procedures**. Europe is already leading with regards to the implementation of such schemes, in 2021, 13 schemes have already been positively assessed under RED II by the Commission and could seek official recognition after the publication of the beforementioned delegated acts. (Sailer 2021; Sailer et al. 2022). The **CertifHy scheme already announced to do so and is the most prominent scheme on the EU-level** with a pan-European scope. It has been initiated by the EU-Commission itself to foster the development of certification schemes. It has set the emission threshold for the certification of green hydrogen, before the final publication of the delegated acts, at 36.4 gCO_2-eq/MJ (Heinemann et al. 2022; Piria et al. 2021).

4.3.2 Germany

As many countries in the EU, Germany will also be a **future hydrogen importer**. Green hydrogen will play a **significant role in the decarbonization** of German heavy industry and the attainment of Germany's Net Zero goal. Therefore, the establishment of hydrogen certification as a fundament for hydrogen production and trade is of high importance to the German government.

The importance of hydrogen certification is further strengthened by **Germany's decision to focus exclusively on green hydrogen** to achieve its Net Zero targets. While the German National Hydrogen Strategy from 2020 already pointed out that **only green hydrogen could be**

sustainable in the long run (Bundesregierung 2020), the Ministry for Economic Affairs and Climate Action announced in January of 2022 that all German support programs will be limited to green hydrogen only. This necessitates the rapid establishment of certification schemes to ensure both the targeted domestic green hydrogen production capacity of 10 GW by 2030 (Kurmayer 2022) as well as the ramp up of an international market.

While Germany has put its focus on green hydrogen and only sees green hydrogen as sustainable in the long run, to foster the market ramp up of hydrogen and meet the demand for hydrogen in a transition period, the German government is discussing support for blue hydrogen, especially in relation to the build-up and usage of hydrogen infrastructure. The update to the National Hydrogen Strategy was not yet available at the time of publication of this study (BMWK 1/5/2023).

As a first step towards the ramp-up of domestic green hydrogen production, the German Ordinance on the implementation of the Renewable Energy Act establishes a **clear definition for green hydrogen in §12**. According to the Ordinance, hydrogen produced with electricity from 100 % renewable sources, to be proven through a guarantee of origin, is exempted from the renewable energy levy (Bundesregierung 2021). The Ordinance also includes a provision stating that this definition will be **revised according to EU standards** as soon as they are agreed upon, underlining the importance of EU-wide collaboration on this issue. In the summer of 2022, the German Bundestag furthermore agreed on the so-called Immediate Measures Act, which includes the provision for a legal definition of green hydrogen, which is to be established through an additional ordinance (Zwanziger and Wilden 2022).

While this definition is likely to support the establishment of domestic production capacity, **internationally agreed-on and applicable hydrogen certification will be necessary to establish global hydrogen trade**. The importance of such a certification as well as international cooperation in this regard was already pointed out in Germany's National Hydrogen Strategy (Bundesregierung 2020). Particularly the European context is crucial. Despite Germany being the continent's leading hydrogen economy, a nationally limited hydrogen certification system would be inefficient at addressing the needs of an international market, especially given that the EU is a single trading block. Therefore, Germany is **heavily involved in broader European initiatives on hydrogen certification and definition**, as described earlier.

What makes Germany special in the wider EU context is, however, that the private sector in Germany is among the **trailblazers of hydrogen certification**. Most notably, TÜV SÜD as well as TÜV Rheinland have already established a standard for green hydrogen, which follows German and EU regulations, but is **open for other nations** as well (TÜV SÜD 2022). In this regard, TÜV Rhineland certifies carbon-neutral hydrogen of different production methodologies if the emitted life-cycle carbon emissions are directly compensated and adds a colour label depending on the production itself. There is no clear threshold in terms of emissions before offsetting, but there are different sub-categories depending on the feasibility of carbon emission calculation along the value chain (TÜV Rheinland 2021). TÜV Süd on the other hand, has a dedicated standard of a reduction of at least 70% compared to the RED II reference value (94 gCO2eq/MJ), meaning 28.2 gCO2eq/MJ (TÜV SÜD 2021). Furthermore, the TÜV Süd certification is limited to green hydrogen produced through renewably powered electrolysis as well as steam reforming and pyrolysis using biomass. Its calculations do not include the setup of production facilities or transport, but the latter is included in a separate TÜV Süd certification which is called GreenHydrogen+. In April of 2022, TÜV Rheinland issued the **first ever green hydrogen and ammonia certification** to a planned 300MW electrolyzer facility in Oman (Hydrogen Technology Expo 2022).

For the German private sector certification schemes, a meaningful connection to the future EU certification system as well as the CertifHy pilot is key, which is why the existing certification schemes by TÜV Süd and Rheinland are set to be connected with the CertifHy system. TÜV Süd is directly involved the initiative as one of the project partners (Vanhoudt 2016) and supports the establishment of a EU-wide system through CertifHy. As part of the initiative, a facility in Falkenhagen, Germany, is one of the two green hydrogen pilot projects certified (Vanhoudt 2016)

The importance of the CertifHy project is also mirrored in bilateral initiatives. A cooperation between the German (DENA) and Australian Energy Agencies for example aims at creating a **joint certification system** for hydrogen based on CertifHy (Varma and Boldis 2021).

German industry **largely supports the government's perspective on the importance of hydrogen certification.** Industry representatives see a certification system for hydrogen **as vital for the establishment of a hydrogen economy**. In a "Green Hydrogen Manifesto", which the German Hydrogen and Fuel Cell Association published together with Hydrogen Europe, the need for a comprehensive certification scheme is particularly underlined (Hydrogen Europe et al. 2021). The Association furthermore stresses the need for cooperation, in particular in Europe, to ensure a timely market ramp up of green hydrogen (Deutscher Wasserstoff- und Brennstoffzellen-Verband 2021a), while furthermore welcoming the provisions on requirements for green hydrogen as spelled out in the Renewable Energy Act Ordinance (Deutscher Wasserstoff- und Brennstoffzellen-Verband and performing energy 2021). Some firms would, however, like to see blue hydrogen being included in Germany's funding schemes (Boldis and Graf 2022). This, nevertheless, appears to be limited to individual stakeholders, as most of the debate is instead centred around detailed provisions, such as the need for an exclusively green hydrogen distribution network (Boldis and Graf 2022) or specific conditions on procurement spelled out in the previously mentioned Renewable Energy Act Ordinance (Deutscher Wasserstoff- und Brennstoffzellen-Verband 2021b).

5 Conclusion: Possible further steps and areas to address together.

5.1 Comparison

All countries we analyzed underline the **importance of hydrogen for decarbonization**, while most have acknowledged the **need for hydrogen certification** in some way and stress its importance in different forms. However, the study has also shown that there are **considerable differences between strategies** as well as the level of progress countries have achieved with regards to the implementation of hydrogen certification.

A commonality is that **most countries seek to contribute to international standardization** and certification initiatives, which underlines the importance of a unified global approach. Some experts (Sailer et al. 2022), however, believe that a **global harmonized scheme** is unlikely because forerunners will not reduce their ambitions for such a scheme, while others might be unwilling to become more ambitious. Actively engaging in in existing **formats towards a harmonization** – such as in the context of IPHE – is nevertheless crucial, both to push for more ambition and to jointly advance hydrogen certification as a foundation of future hydrogen trade.

At the same time, however, there are **individual trailblazers** in each region, which have already started to implement certification systems. These trailblazers offer great **opportunities for mutual learning** and can become crystallization points of regional or global considerations regarding hydrogen certification. In addition, the progress the EU has made regarding the establishment of **supranational certification** can serve as a blueprint and inspiration for similar approaches.

It is also worthwhile to note that **private actors have often also stepped forward**, underlining the importance of certification on the one hand, and developing own certification schemes on the other. Especially smaller countries or interested private actors from countries which still have to move towards the implementation of certification could rely on these certification programs as **starting points**, especially when they are aligned with overarching initiatives, e.g. the **EU's CertifHy initiative**.

A range of initiatives, countries and certification systems have also put **certification thresholds for low-carbon hydrogen** forward. To make them comparable, the thresholds have been converted to CO2eq/MJ, assuming an energy density of 120 MJ/kg for hydrogen. Using this conversion, the thresholds range from **ca. 42 gCO2eq/MJ** for the currently discussed **Korean certification** threshold as well as **41 gCO2eq/MJ** for the suggestion of the **China Hydrogen Alliance** over **36.4 gCO2eq/MJ** for the **EU's CertifHy**, ca. **33g CO2eq/MJ for the US Draft Standard, 28.3g CO2eq/MJ for the proposal of the Japan Hydrogen Association** to **28.2gCO2eq/MJ** for the currently discussed **EU threshold** and TÜV Süd's certification. The **lowest thresholds** thus far are the **EU's currently discussed threshold**, which is expected to be 28.2gCO2eq/MJ, the limit for the **highest US tax credit, namely 3.75gCO2eq/MJ**, and the German focus on exclusively green hydrogen. All thresholds are also compared in the graph below.

For the thresholds, the scope of the covered emissions, however, also must be considered. Even though the scope often differs in detail, it is generally differentiated between **well-to-wheel** and **well-to-gate approaches**. The former means that **production emissions, as well as transport and supply up to the end use** are accounted for, while the latter includes only **everything up to – and including – production**. As of January 2023, the Korean Certification System, the US, the proposal of the Japan Hydrogen Association and CertifHy use a well-to-gate, TÜV Süd and the China Hydrogen Alliance a well-to-wheel approach.

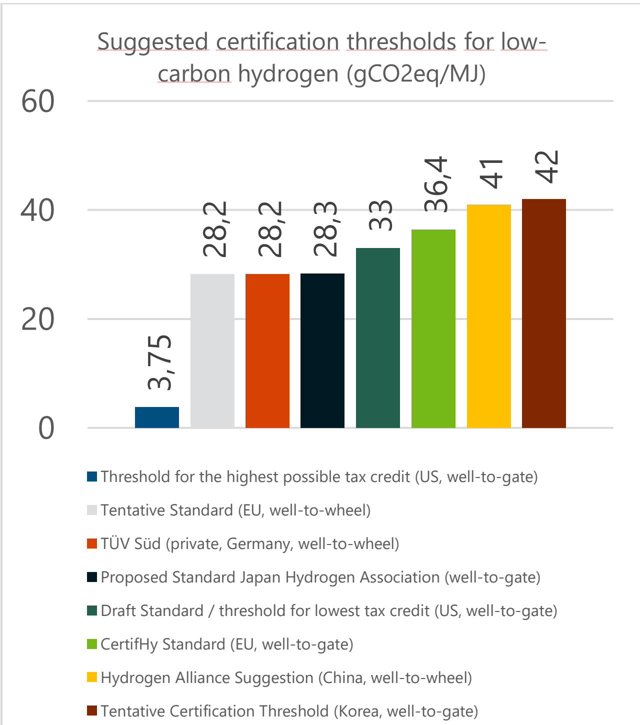


Figure 1: own illustration by authors

5.2 Recommendations and potential for cooperation

The findings of this study highlight a number of potential topics and areas for collaboration. From the perspective of individual countries, the study provides useful starting points for the further advancement of certification initiatives. First of all, it might make sense to further support international efforts towards certification. After much progress has already been made in the context of a generally recognized emission calculation methodology in IPHE, the most important aspect of future cooperation would be **the mutual recognition of national certification systems and bodies** – irrespective of individual national thresholds. If the leading hydrogen economies manage to establish an international standard of certification which enables certifications to be mutually recognized, international trade of hydrogen would be greatly facilitated, while still allowing for a divergence of national thresholds. Additionally, cooperation opportunities also present themselves in the context of monitoring, as this will be crucial to ensure the agreed-on guidelines in a global market.

At the same time, it might be sensible to **reach out to certification trailblazers**, both internationally as well as within the own region or country. Even though the topic is comparatively new, some actors have already made considerable experiences and **learning from them could accelerate and streamline own considerations**. A range of technical details could be the focus of such collaboration initiatives, for example:

- **Development of a methodology** for the calculation of the CO2 footprint of hydrogen.
- Establishment of **monitoring systems**.
- Inclusion of hydrogen standards into **government procurement and funding programs**.
- Development of **certification schemes**.

Additionally, individual countries could use existing private-sector certification schemes or suggested international methodologies for **pilot projects and bilateral cooperation projects** in order to both **validate and test these suggested approaches**. This would also underline the importance of hydrogen certification and could contribute to the advancement of the topic.

Another potential point for future discussions is the **level and future development of low-carbon hydrogen thresholds**. As seen in Figure 1, there is some difference between approaches, and it might be sensible to discuss these in the context of hydrogen's role towards net zero. While they might be indicative of different national decarbonization strategies at the moment, such discussions could also focus on the way forward and in particular the perspective of such thresholds in the medium run and until 2050 under consideration of net zero targets.

Lastly, international initiatives focusing on the advancement of hydrogen certification should continue to seek **building bridges between existing initiatives**, aiming to **ensure future compatibility** between them. Using existing approaches and experiences as a foundation for own suggestions, e.g. on methodologies, could not only facilitate their development. It could also ensure that they will be employed by the **first movers on the low-carbon and green hydrogen market**. It is to assume that these first movers will set the standards for others following later, which necessitates that international solutions are in line with approaches currently being tested and implemented.

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