CREATING A GLOBAL HYDROGEN MARKET

CERTIFICATION TO ENABLE TRADE

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

About RMI

RMI is an independent non-profit organisation, founded in 1982, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policy makers, communities and non-governmental organisations to identify and scale energy system interventions that will cut greenhouse gas emissions by at least 50% by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, DC; and Beijing.

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GLOSSARY

Book-and-claim chain of custody model A chain of custody model that relies on backing each unit of a material/resource with a certificate. Certificates can be bought and traded, and then claimed to account for each unit of material used. Does not rely on physical transfer of resources or materials.

Certification scheme The framework that sets the conditions that must be met to receive final certificates that differentiate hydrogen based on its emissions footprint and other sustainability criteria.

The scheme sets the criteria, or uses criteria from a regulatory framework to define low-carbon hydrogen, as per the certificate label, outlined in a standard.

The scheme should stipulate methods of governance, verification, and tracking (including chain of custody, carbon accounting, credit issuing and retirement).

Certification system The ecosystem or enabling environment required to support scaling of renewable or green hydrogen as a differentiated product. The term includes certification schemes, standards and registries, as well as models to scale adoption (*e.g.* policy, demand aggregation, integration with other metrics and schemes).

Chain of custody The process of sequentially transferring custodial ownership of materials and resources throughout a supply chain.

Ecolabel The product award or label that certifies that a predefined set of requirements (*e.g.* for low-carbon hydrogen or green hydrogen) has been met for an applicable unit of measure.

The label can include carbon footprint data, adherence to environmental, social and governance criteria, and in some cases, geographical and temporal data for the hydrogen produced.

Low-carbon hydrogen Hydrogen produced from any technology pathway that has a carbon intensity below that of the incumbent fossil-based production pathway (known as unabated fossil hydrogen, produced from natural gas or coal). Low-carbon hydrogen typically meets a threshold designated by a certification scheme and may be produced through pathways such as:

- abated fossil hydrogen production, in which hydrogen is produced using natural gas, steam methane reforming and a form of carbon capture and sequestration (commonly known as blue hydrogen)
- pyrolysis of natural gas, in which hydrogen and a solid carbon black product are produced (such hydrogen is commonly known as turquoise hydrogen).

Mandatory market All certification mechanisms that are mandatory and set the bar for all hydrogen producers to follow- including producers wishing to sell in markets where mandatory requirements exist.

Mass balance chain of custody model A chain of custody model that relies on tracing the mass flows between production stages. The mass of the end product must be accounted for by the masses of inputs introduced, throughout the supply chain. The renewable characteristic of materials are detached from the physical flow, and is only kept track of in the bookkeeping.

Quality infrastructure The set of instruments and systems that ensure the quality, performance, safety and tradability of products and goods. These instruments and systems include internationally harmonised technical standards, test methods, calibration, certification and accreditation.

Renewable hydrogen	Hydrogen produced using renewable energy sources. The most established technology in this category is water electrolysis using renewable energy. Renewable hydrogen is commonly known as green hydrogen. Additional environmental, social and governance criteria or grid-connected production criteria (*e.g.* additionality, temporal, or geographical criteria) can be specified by schemes or regulations to further differentiate the product.
Standard	A fundamental set of references, established by consensus, applied to a common and repeated use of rules, conditions, characteristics, scope, methodology, threshold and related management systems. Standards are used to differentiate the types of hydrogen produced. A standard may refer to a methodology developed by another body. Standards are listed in a certification scheme.
Standard (or schemes) holder	The organisation that develops, updates and maintains the standard (or scheme). The organisation could be a private company, a non-governmental organisation or a regulatory body.
Voluntary market	All certification mechanisms that are entirely voluntary and serve to differentiate a hydrogen product from others.

ABBREVIATIONS

CBAM	Carbon Border Adjustment Mechanism
CCS	carbon capture and storage
GATT	General Agreement on Tariffs and Trade
WTO	World Trade Organization
kg	kilogramme
APEC	Asia-Pacific Economic Cooperation
CEN-CENELEC	European Committee for Standardization and the European Committee for Electrotechnical Standardization
CO_2	carbon dioxide
CO_2eq	carbon dioxide equivalent
CoC	chain of custody
EU	European Union
gCO_2eq	gramme of carbon dioxide equivalent
GH_2	Green Hydrogen Organisation
GHG	greenhouse gas
H_2	hydrogen
HBE	(Netherlands) renewable energy unit
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
ISCC	International Sustainability and Carbon Certification
ISO	International Organization for Standardization
$kgCO_2$	kilogramme of carbon dioxide
kgH_2	kilogramme of hydrogen
LCFS	Low Carbon Fuel Standard
MJ	megajoule
MWh	megawatt hour
RED II	Renewable Energy Directive II
RFNBO	renewable fuel of non-biological origin
tCO_2	tonne of carbon dioxide
tH_2	tonne of hydrogen
UNECE	United Nations Economic Commission for Europe

EXECUTIVE SUMMARY

Hydrogen and its derivatives, both low carbon and renewable, are recognised as a key pillar in the energy transition to replace fossil fuels and help decarbonise sectors that cannot be feasibly electrified today: shipping, aviation and some industrial processes such as ammonia and steel production (the "hard-to-decarbonise sectors").

Certification is an essential element of any trade, especially for the development of a new trade in hydrogen. Certificates for hydrogen and its derivatives would contain information on compliance with standards and regulatory requirements, and enable verification through data on sustainability criteria, such as carbon footprint and renewable energy content, thereby allowing differentiation from other less green products.

Certification would also allow compliance with additional environmental, social and governance criteria to be verified and would enable hydrogen consumers to signal demand for greener products by purchasing hydrogen that is certified as low carbon or renewable. Certification is an essential part of developing a global market for hydrogen.

IRENA, together with RMI, conducted an assessment of existing certification systems around the world to look for gaps that, if not filled, will hinder the development of hydrogen trade. The assessment was conducted by identifying the key components of a functioning hydrogen certification system and comparing these components with existing and emerging hydrogen certification mechanisms. Eight voluntary and five mandatory schemes were assessed. This report is a contribution to the work on the G7 Hydrogen Action Pact – specifically on supporting the creation of regulatory frameworks for low-carbon and renewable hydrogen and its derivatives.

None of the existing hydrogen certification systems are suitable for cross-border trade. In addition, there are gaps in standards and in ecolabelling and certification design, resulting in insufficient information in certificates to allow fair comparison across borders. Significant gaps exist in the following: clear information on greenhouse gas emissions produced during hydrogen production and/or transportation; common standards used; ecolabelling; and compliance with environmental, social and governance criteria. Recommendations to close the gaps and avoid hydrogen market fragmentation include the need for countries to adopt:

- a modular approach to certification at different stages along the supply chain, where each part of the supply chain has its own sustainability criteria scope and thresholds;
- a single methodology to calculate the emissions intensity of all hydrogen production pathways, building on other schemes, where possible, to address key emissions sources;
- alignment between accounting methods and policy requirements for additionality, temporal and geographical criteria for hydrogen produced using grid electricity;
- internationally accepted methodologies to manage blending of traded hydrogen in order to link production criteria with market requirements;
- harmonised systems of quality infrastructure for national standards bodies to ensure fairness and accountability of hydrogen certification;
- establish a process to facilitate mutual recognition between certification schemes for hydrogen and derivatives; and
- think beyond hydrogen and ensure continuity for the hydrogen derivatives most likely to be traded, such as ammonia.

INTRODUCTION

Hydrogen is recognised as a key pillar in the energy transition, alongside renewable energy, renewable-based electrification and energy efficiency (IRENA, 2022a). However, the climate benefit of hydrogen depends on the emissions footprint of the method and energy source used to produce it, and this footprint varies widely across pathways.

Low-carbon pathways involve either abated fossil fuels (such as blue or turquoise hydrogen) or electrolysis (such as renewable or green hydrogen). Labelling hydrogen using a colour classification to indicate which technological method was used to produce it has become commonplace; however, this classification does not suffice to quantify and describe the variety of emissions impacts associated with any given type of hydrogen, nor does it meaningfully compare emissions intensity across production methods. Since production and emissions characteristics are undetectable in the hydrogen itself, hydrogen is considered a *fungible* commodity; therefore, such characteristics must be identified during production and transportation.

Capturing sustainability criteria in a product certificate is necessary to establish low-carbon or renewable hydrogen as desirable commodities; for renewable hydrogen, certificates provide a marketable characteristic to hydrogen consumers looking for green products. Through the certification of hydrogen, industries that use hydrogen as a fuel or feedstock (*e.g.* steel or ammonia production) can market their products as having been produced using hydrogen with a specific low- or zero-carbon footprint. This in turn enables consumers to demand the product to be certified, thereby providing signals for long-term investment and giving confidence in a product's low-carbon or green credentials. Certificates will also improve supply chain carbon accounting, which is crucial to the operation of businesses and

industries with potential exposure to carbon credits or carbon taxes. A robust certification mechanism at all stages along the supply chain, building on hydrogen production schemes, can unlock further development in certifying hydrogen derivatives and “green” products.

The establishment of an international hydrogen market will depend on the development and acceptance of certification systems that provide information on the emissions footprint of the hydrogen production value chain. In addition, the spate of new national and regional policies to support renewable hydrogen usage will require that the public bodies to which they apply understand the characteristics of the hydrogen consumed. Policies like industrial and transportation quotas, carbon border adjustment mechanisms, sustainable public procurement, product quotas, carbon contracts for difference, and bilateral auctions will all need a certification scheme.

Many competing hydrogen certification schemes (both voluntary and mandatory) that aim to define low-carbon and renewable hydrogen have emerged around the world to fill this need. Their technical criteria vary in scope, emissions threshold and accounting methodology, meaning that the same label (*e.g.* green hydrogen) might not refer to the same product with the same threshold in different schemes. Furthermore, different schemes could also include additional environmental, social and governance (ESG) criteria, which are not easily comparable with other schemes. Currently, there is *no hydrogen certification scheme suitable for international trade*. Although mechanisms exist to certify hydrogen, the challenge is to have an internationally recognised scheme that avoids the duplication and inefficiencies of having multiple, competing and divergent schemes. To truly differentiate hydrogen, the building blocks of differentiated commodities markets – increasing demand from end consumers and a strong mechanism to scale production – must also be present. Discerning hydrogen relies on pairing standards with a tracking model (chain of custody [CoC]) and the relevant market infrastructure to connect buyers and sellers.

This analysis was conducted by first identifying the critical elements of hydrogen certification, against which existing and emerging certification schemes were assessed. The scope of the study does not include system requirements to track reused carbon dioxide (CO_2) or downstream carbon accounting and links to emission trading schemes; the boundary for low-carbon hydrogen does not consider the impact of the captured CO_2 being used in separate applications, such as carbon capture and use. This report is a contribution of the German G7 Presidency to achieving the aims of the Hydrogen Action Pact, specifically on shaping regulatory frameworks and common standards for hydrogen and its derivatives.

Acknowledgement is made of other reports on this subject, with notable differences in scope:

- *Decarbonising end-use sectors: Green hydrogen certification* (IRENA Coalition for Action, 2022) – this report includes an in-depth look into the components of certifications.
- *Global harmonisation of hydrogen certification* (DENA and World Energy Council, 2022) – this report, completed in early 2022, assessed eight schemes and included an updated list of schemes with details on the components of each.
- *The Breakthrough Agenda report 2022* (IEA *et al.*, 2022) – IRENA was a key author of this report, one of its contributions being the outcomes of the current analysis on hydrogen certification.

METHODOLOGY

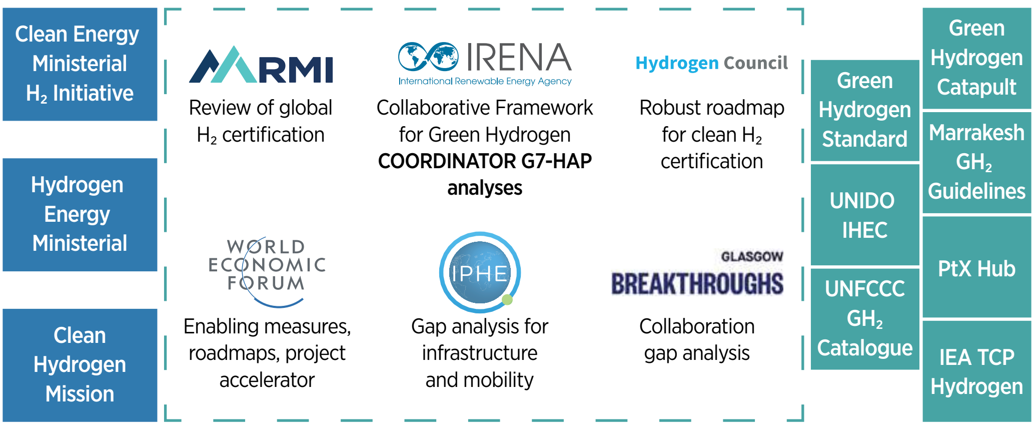
The assessment outlined in this report first established the qualities that a certification would need to achieve to serve the purposes described in the introduction. Existing and emerging hydrogen certification schemes were analysed, as were related regulatory compliance mechanisms, specifically focusing on renewable hydrogen and embedded production standards. Key lessons from similar efforts in biofuel markets were noted, as were distinct challenges and barriers to establishing a successful hydrogen certification system. Based on the analysis of progress and gaps in technical and operational elements in existing standards, key policy recommendations were formed and are presented in this report.

Information was gathered from publicly available data and sourced directly from some of the organisations responsible for each mechanism or scheme.

IRENA collaborates with other key global initiatives, organisations and agencies, in addition to its membership, to ensure a truly global coverage of information and issues. Figure 1 shows the current hydrogen-related network. This specific gap analysis was conducted jointly with RMI, to supplement the report *Accelerating hydrogen deployment in the G7* on the G7 Hydrogen Action Pact.

Gaps in compatibility between the assessed schemes were identified, and solutions were proposed for policy makers to close the gaps.

Figure 1 Overview of IRENA collaborative analyses



Notes: GH2 = Green Hydrogen; IEA = International Energy Agency; IHEC = International Hydrogen Energy Centre; IPHE = International Partnership for Hydrogen and Fuel Cells in the Economy; PtX = Power-to-X; TCP = Technology Collaboration Programme; UNFCCC = United Nations Framework Convention on Climate Change; UNIDO = United Nations Industrial Development Organization; Centre: Core working group for the G7 analyses. Left: Information sharing platforms. Right: Wider collaborative network.

The cost of implementing and administering a certification system – despite being an important aspect of such a system – is not covered in this report. A trusted and reliable system that is intended to be used globally would require an array of quality infrastructure and people, including accredited auditors and other institutions. This would require dedicated resources and funding. In addition, the amount of funding required may be significantly affected by how verification and monitoring is stipulated, such as 100% measurements or a percentage, or elements of self-declaration and spot checks. Due consideration of the cost of certification and the funding will be a key part of the success of an international certification scheme. IRENA has embarked on a project with the Physikalisch-Technische Bundesanstalt (German National Metrology Institute) to develop a roadmap for quality infrastructure to support hydrogen certification, of which cost will be a consideration.

CRITICAL ELEMENTS FOR A HYDROGEN CERTIFICATION SYSTEM

A successful certification system must capture the important technical components (as defined in the standard and certification design; refer to Figure 2) and be embedded in an ecosystem of enabling operational components to ensure scalability. Figure 2 outlines the key operational components for a hydrogen market certification system. Each operational component may be developed and deployed by one or more organisations, though it is typical that the standards and certification design, through to the enforcement and verification, are specified by a single entity: the certification scheme holder.

These components for a hydrogen market can reference and build on existing market mechanisms, such as renewable energy guarantees of origin (for reference in a standard or replicated tracking model) or environmental exchange platforms and registries.

Figure 2 Key operational components for a hydrogen certification system

Standards and certification design	**Governance**	**Enforcement & verification**	**Tracking & business model**
Ecolabel Standards Sustainability criteria: • GHG footprint – scope and threshold • Accounting guidance (data inputs, quality, measurement type, conversions) • Other ESG compliance	Roles and responsibilities of: • Standard & certification owner • Certificate issuing body and registry Data handling protocol Enforcement mechanism and non-compliance clauses	• Audit and verification based on standard criteria • Awards certification based on audit • Quality infrastructure	Chain of custody mode: • Mass balance • Book and claim Digital credit issuing & retirement platform • Registry • Tradability • Credit value Product service • Consumer offering (emissions reductions)

Scale adoption

- Policy and regulation – ambition and integration
- Demand aggregation
- Market engines (normalisation to other metrics)
- Common frameworks (accounting guidance)
- Harmonisation with voluntary corporate standards for emissions accountings (GHG protocol)

Notes: ESG = environmental, social and governance; GHG = greenhouse gas.

CERTIFICATION SCHEME

Standards and certification (including design, governance and enforcement operational elements) ensure that the differentiation between rules and validation processes is transparent for both producers and buyers.

The technical components of a certification scheme are typically embedded in a standard. A standard is an agreed methodology for conducting a process. A standard document is agreed by experts, in national or international settings.

Standards are the result of discussion and co-operation between stakeholders – such as manufacturers, sellers, buyers, customers, trade associations, users and regulators – in a determined process.

In the case of hydrogen, a standard is needed to provide the accounting guidance and criteria to assess renewable or low-carbon credentials. The minimum technical components that should be present in any renewable or low-carbon hydrogen standard are outlined in the following sections.

STANDARDS AND CERTIFICATION DESIGN

Certification scope

The scope of the certification specifies the level at which the differentiated product is assessed (*e.g.* the asset level and what production and transportation pathways it covers).

System boundary

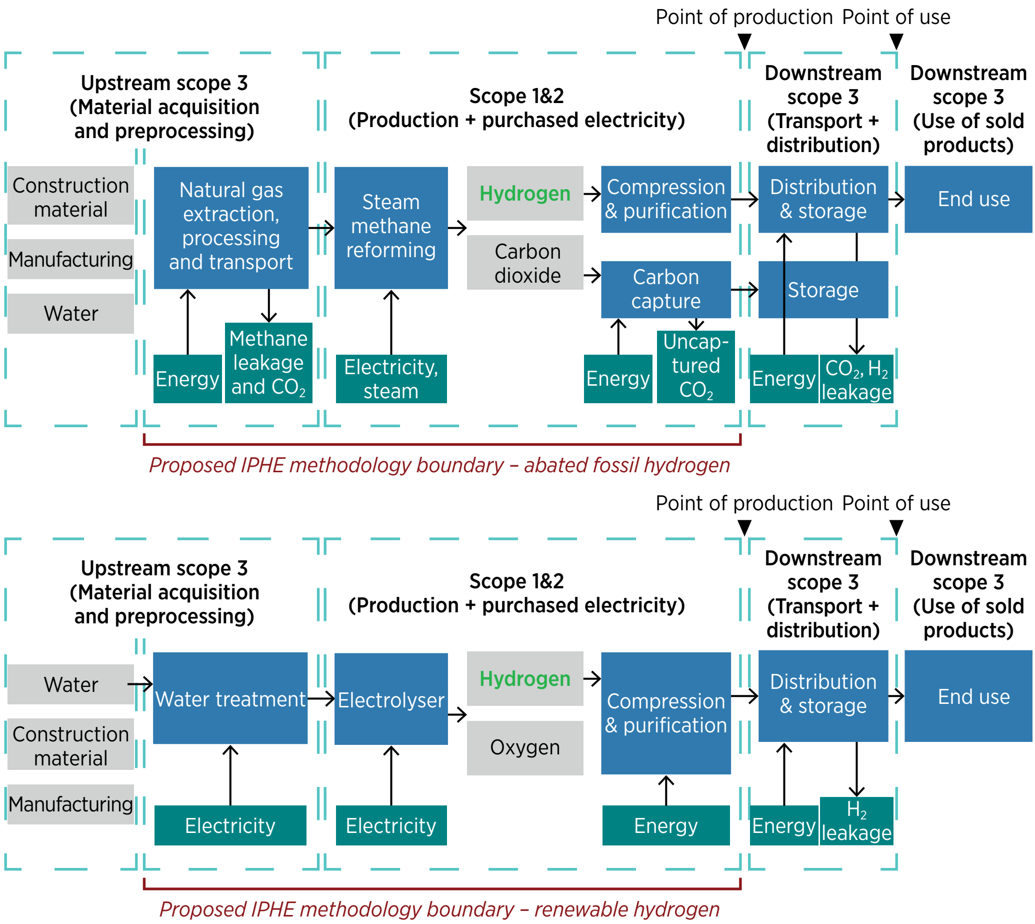
A clear system boundary should be referred to or specified directly in the standard. This boundary should include the main emission sources from the hydrogen production supply chain (*e.g.* electricity for electrolysis for the renewable pathway; upstream fugitive methane and capture unit for the abated fossil pathway).

Figure 3 illustrates supply chains for blue and green hydrogen, based on the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) methodology (IPHE, 2021), which is in the process of being established as an International Organization for Standardization (ISO) standard. System boundaries are typically defined to capture either well-to-gate (up to point of production) or well-to-wheel (up to point of use) pathways. These boundaries serve as the basis for differentiating hydrogen production pathways. As a market develops, conversion of hydrogen to its derivate forms, such as ammonia and methanol, can be incorporated as an add-on either in a production standard or in end-user standards.

The boundary for low-carbon hydrogen need not consider the impact of the captured CO_2 being used in separate applications (carbon capture and use) as the typical storage time of carbon in these products is not sufficient to be considered permanent (more than 100 years). Until guidance is established for determining the emissions impact of carbon stored temporarily in products, such as by calculating avoided emissions compared with incumbent production pathways, certification of low-carbon hydrogen with carbon capture should be limited to sequestration.

Comprehensive schemes should aim to incorporate the transport and distribution sections of the supply chain as the hydrogen market grows, given the leakage potential of hydrogen.

Figure 3 Supply chain and system boundary for blue (top) and green (bottom) hydrogen



Notes: IPHE = International Partnership for Hydrogen and Fuel Cells in the Economy.

Emissions accounting guidance

"Emissions accounting guidance" defines or refers to the methodology used to calculate the greenhouse gas (GHG) footprint across the system boundary for each emissions source. This guidance should define: the scope of relevant GHGs; their global warming potential functional unit according to a trusted and updatable source (*e.g.* the Intergovernmental Panel on Climate Change Assessment Report); the type of data required to perform the calculation (primary or secondary); and where to access these data.

Box 1 International Partnership for Hydrogen and Fuel Cells in the Economy

The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) is a government-to-government partnership consisting of 21 countries and the European Commission whose aim is to share information on hydrogen and fuel cell developments to inform future government policy and foster international collaboration. IPHE countries recognise that governments and industry need to work together to ensure existing and future regulations, codes and standards facilitate the production and use of, as well as investment in, hydrogen, hydrogen technology and infrastructure.

Mutually recognised international accounting standards for different sources of hydrogen along the full supply chain are fundamental to creating a market for low-carbon hydrogen; IPHE's Hydrogen Production Analysis Task Force is working to develop a methodology and analytical framework to determine the greenhouse gas (GHG) emissions related to a unit of produced hydrogen.

The first version of the Task Force's quantification methodology working paper describes the requirements and evaluation methods applied to four hydrogen production pathways: electrolysis; steam methane reforming with carbon capture and storage (CCS); coal gasification with carbon capture and storage; and by-product hydrogen.

The second version includes two new production pathways – hydrogen from biomass and autothermal reforming with CCS – and includes GHG emissions from the conditioning of hydrogen in different carriers: the production and cracking of ammonia as a hydrogen carrier; hydrogen liquefaction; and production and cracking of liquid organic hydrogen carriers. The third version will complete the approach, with consideration of GHG emissions from the transportation of hydrogen and/or hydrogen carriers up to the point of use.

For renewable hydrogen, if a scheme allows grid-connected electrolysers, the validity of the renewable electricity purchasing mechanism should be addressed, including the criteria to evaluate such mechanisms, such as regional constraints and the uniqueness of claims (*e.g.* as outlined in *GHG Protocol: Scope 2 guidance* [Sotos, 2015]).

In renewable hydrogen production, defining renewable electricity criteria for grid-connected electrolysers can ensure material contribution to decarbonisation of the energy system. This can be achieved by defining criteria for additionality and for temporal and geographic correlation.

- Additionality: defined by the GHG Protocol as a project that results in GHG emissions reductions in addition to what would have occurred in the project's absence, meaning that the renewables-based electricity used in electrolysers is produced by new generation capacity. This can be approached by ensuring a direct link, either through a physical connection, or through a commercial power purchase agreement. Both approaches may limit electrolyser operating time to match generation.
- Temporal correlation: specifies the correlation time horizon between the electricity consumed by the electrolyser and the generation profile. A flexible approach to this criterion is recommended (as opposed to strict time matching) in the next few years, to limit first-mover disadvantage.
- Geographic correlation: specifies a geographical correlation between the electrolyser and the additional renewable generation, based on a defined proximity or connection to the same interconnected network.

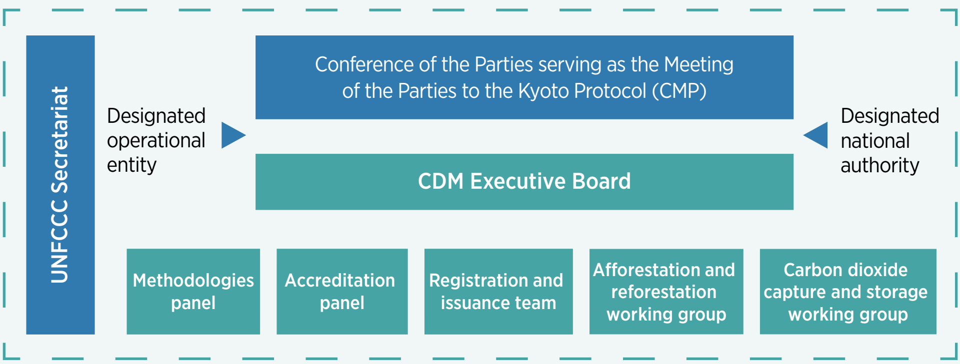
These factors are typically determined at a regulatory level as part of the decarbonisation strategy for a national or regional grid. For example, the European Renewable Energy Directive II (RED II) recently amended its hourly matching temporal requirements in favour of additionality (securing equivalent PPAs). This, in the view of the European Union (EU), would help scale renewable hydrogen in the region and maintain global competitiveness, while achieving grid decarbonisation targets.

Box 2 UNFCCC Clean Development Mechanism

Set up under the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC), the Clean Development Mechanism (CDM) is a carbon market mechanism. It enables entities in developed countries to cooperate with the developing country counterparts to implement cost effective carbon offset projects that were also endorsed by the national authorities as supporting the sustainable development of the Host Party. The projects can register to earn certified emissions reductions (CERs), each equal to 1 tonne of emissions reduction. The project developers can earn and sell CERs, thus providing a financial incentive to reduce emissions. The requirement for *additionality* ensures that the emissions reductions estimated exclude business-as-usual activities by comparing with the baseline (*e.g.* a benchmark) if the project had not gone ahead. As of October 2022, there are 8 205 projects registered with the CDM including 361 programmes of activities, and over 2.32 billion CERs have been issued.

The CDM maintains a list of methodologies for computing the CERs as appropriate for each project type. External auditors (called "designated operational entities") are responsible for verifying the number of CERs to be awarded based on the methodologies. CERs are reflected in the CDM registry and in national registries (through a designated national authority). The Executive Board of the CDM (CDM-EB) has the regulatory oversight over the Mechanism, with support from UNFCCC secretariat. For each individual project, the methodology/ies applied to the project and amount of CERs awarded per issuance request are published on the CDM website.

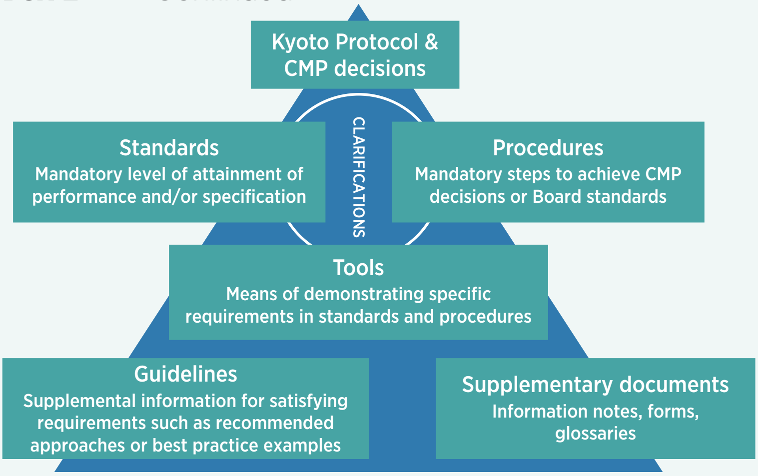
The Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol (CMP) has the ultimate authority over the CDM. Under the guidance of the CMP, the CDM-EB makes operational decisions. CDM-EB has convened several panels of experts to determine the merit of submissions in different areas; the Methodologies Panel assesses and advises the CDM-EB on methodologies.



Source: CDM, n.d.

Central to the idea of an offset mechanism is additionality. For the CDM, additionality requires that a project would not have proceeded with the emissions reduction if not for the financial incentive of the CDM. A project must prove that the registration with CDM is *necessary* to fund the carbon reduction project.

Box 2 Continued



Source: CDM, n.d.

LESSONS LEARNT FROM THE CDM

KEY STRENGTHS	KEY CHALLENGES
Single source for standards and methodologies, which once adopted by the CDM-EB are followed by all projects. Results in uniform decisions and international standards.	Time taken to establish such a global mechanism. For the CDM, it took eight years from concept definition at the Conference of the Parties 3 (COP3) in 1997 to the first CER being issued in October 2005 for two hydroelectric projects in Honduras.
Single registry, control of tracking and CER management.	Demonstrating the additionality to justify the offset. The complexities involved with this are significant and studies show the current methods are not fool proof. Developing reliable methods to demonstrate additionality that are also cost effective and easy to implement is challenging.
Streamlined governance through the supporting panels comprising experts who are selected for their skills, geographical coverage and diversity.	Sourcing the most relevant experts and co-ordinating their availability. This requires effort and time.
Transparency in assessment of methodologies, selection of panel members and overall governance.	A fool-proof assessment of a methodology submission requires effort and time.

Emissions threshold

An emissions threshold, range or value, typically shown in kilogrammes of CO_2 equivalent per kilogramme of hydrogen ($kgCO_2eq/kgH_2$), defines the minimum carbon intensity value to differentiate the product and can be one element used to grant a label (see next section). The threshold value used to define a differentiated product may evolve over time as management practices and climate ambitions increase and as schemes are updated. Depending on the scheme's scope, different thresholds may be assigned to each certification grade, production pathway or label.

Gaining certification and complying with the standard criteria for renewable hydrogen means achieving both the emissions threshold and any other specification in accounting guidance, such as renewable electricity additionality.

The emissions threshold of a voluntary scheme may not be in line with the requirements for a government to provide support or with the requirements of a private company internal policy.

Labelling

If the distinguishing criteria (in $kgCO_2eq/kgH_2$) and other elements, such as water usage, energy source and consumption, specified by the certification scheme are met, a label – such as "low-carbon hydrogen" – can be provided for the product. While the labels of different certification schemes might use the same wording, the standards criteria against which they are evaluated could differ. This may lead to confusion among consumers.

Environmental, social and governance compliance

Green hydrogen should be produced, transported and used in ways that aim to minimise environmental, social and governance consequences, while optimising development opportunities. It is also inherent in the Green Hydrogen Standard (GH2, 2022), which aims to provide certainty and transparency to investors and other stakeholders that the Green Hydrogen Organisation (GH2) label "green hydrogen" means that the hydrogen was produced using renewable electricity that conforms to the highest standards on emissions; to environmental, social and governance criteria; and to the United Nations Sustainable Development Goals. No GH2 certificates have been issued to date. The International PtX Hub has also developed an environmental, economic, social and governenace framework to illustrate the wide range of hydrogen and power-to-x sustainability dimensions and opportunities (PtX Hub, 2022).

Box 3 European Union Biofuels Directive

An example close to the hydrogen sector is the European Union (EU) requirement for biofuels, first introduced in the Biofuels Directive 2003/30/EC. In 2009, the EU Renewable Energy Directive (2009/28/EC) set a 10% renewable energy target in the transportation sector, which further increased the ambition for biofuel use in the EU. These requirements were introduced to reduce the greenhouse gas emissions intensity of fuels used in road transportation (Bourguignon, 2015).

The growing demand for biofuels in Europe (to meet consumption quotas) incentivised foreign biofuel exporters to cultivate more crops – such as palm trees – solely for biofuel production. This indirect land use change could have resulted in deforestation in areas of Southeast Asia and South America, as well as potentially increasing total greenhouse gas emissions (Bourguignon, 2015; Neslen, 2021).

To avoid a similar situation, renewable hydrogen certification and legislation needs to account for the life cycle emissions of the whole supply chain. Proper accounting and enforcement can help mitigate the knock-on effects of such policies, and future policies should aim to avoid such outcomes. The 2018 recast of the Renewable Energy Directive sets limits on biofuels that carry a high risk of indirect land use change, removing these types of fuels from being counted in emissions reduction quotas (European Commission, n.d.a).

GOVERNANCE

Governance of a certification scheme is required to provide transparency and accountability. The governance structure and processes, typically laid out in a programme guide or similar document, should specify the roles and responsibilities of those involved in the scheme and the mechanisms by which compliance, non-compliance and administration of all scheme elements are carried out. The governance of a certification scheme is the responsibility of the scheme holder to stipulate.

ENFORCEMENT AND VERIFICATION

A key operational element of a certification system is verification. This provides assurance to the buyer that the product is aligned to the standard criteria. A scheme should specify the verification process, including the timeline of verification stages, how and with whom the auditing takes place (*e.g.* a pre-approved independent and sector-qualified auditor; a digital mechanism operated by an independent third party), and the data and systems or personnel required for validation.

For successful implementation of national and international renewable hydrogen strategies, it must be ensured that:

- the technology and infrastructure for renewable hydrogen production and transport perform as expected; and
- the trade of renewable hydrogen is facilitated at a global scale while ensuring the sustainability and safety of the production of renewable hydrogen and its derivatives.

These two objectives require a robust quality infrastructure, including standards, testing, metrology, certification and accreditation for the production and trade of renewable hydrogen. The services of quality infrastructure need to be in place to ensure that policy makers' plans and targets on renewable hydrogen are met most efficiently.

Box 4 Digitalising the certification process

Siemens Energy – Clean Energy Certification

The Clean Energy Certification (CEC) from Siemens Energy is a digital service that tracks the environmental impact of energy production by issuing automated, government-approved certificates across the energy sector. The service connects physical assets with a distributed ledger infrastructure layer (blockchain) and covers accreditation schemes for green electricity, green hydrogen, e-fuels and other green energy carriers or energy-intensive goods. The requirements for verification, interoperability, authentication and portability are enabled by a distributed ledger technology.

The CEC contains all relevant information to prove sustainable origin and carbon footprint.

In 2021, the CEC was applied to the Siemens Gamesa at La Plana Hybrid Prototype and Test Facility in Spain. The first industrial-scale implementation of the CEC will be at Haru Oni in Chile, with the aim of producing climate-neutral e-fuel (Siemens Energy, n.d.).

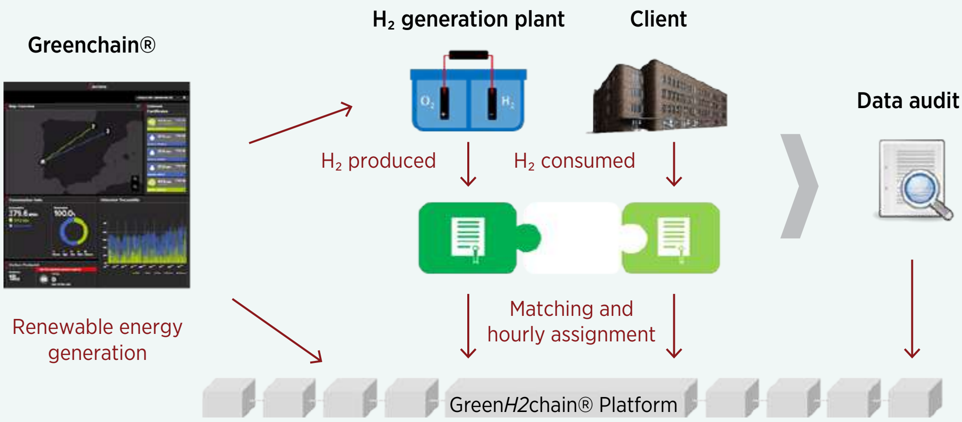
Source: Siemens Energy, 2022.

Acciona Energía Green*H2*chain

Acciona Energía has developed Green*H2*chain, a platform based on blockchain technology that guarantees the renewable origin of green hydrogen. Customers have access to a digital platform to verify and visualise the entire green hydrogen value chain in real time and to quantify, record and monitor the decarbonisation process of their own energy supply. The digital tool is fed with data from multiple sources along the green hydrogen value chain, making correlations and keeping balances among them and maintaining unique identification of every kilowatt hour of green hydrogen. In addition, Green*H2*chain provides all necessary information on hydrogen consumption itself as well as data for calculating the carbon dioxide emissions that consumers avoid by using this type of green energy.

The platform is currently being developed in the Power to Green Hydrogen project as part of a green ecosystem on the island of Mallorca (Spain) and will complement other systems that aim to certify the renewable origin of hydrogen.

Box 4 Continued



Source: Acciona Energía, 2022.

TRACKING AND BUSINESS MODEL

For a buyer to purchase a differentiated commodity and credibly claim the emissions reduction benefits, an administrative record must track the flow of the product through the supply chain. This is referred to as a CoC model. CoC models have varying levels of coupling between the product and the sustainability claim and can use identity preservation, segregation, mass balance[1] or book-and-claim methods (as defined in ISEAL Alliance [2016]). Hydrogen certification schemes whose boundary extends beyond the point of production should specify for each type of supply chain operation (*e.g.* processing, transport) which CoC model should be used.

Renewable hydrogen (and its derivatives) has the potential to be established as a globally traded commodity. Given the complexity involved with this type of supply chain, a book-and-claim CoC model may be useful. Although such a model has the least coupling between the sustainability claim and the product, it allows for a direct financial connection between producers and buyers. This model provides a solution to the logistical challenge of scaling a nascent market, as it provides a pathway for buyers who may not be physically connected to renewable hydrogen production (*e.g.* buyers in Europe purchasing hydrogen from North Africa) to signal demand for this type of product. This model also avoids the GHG emissions related to transportation. A registry component is needed for this model to track these transactions, through certificate generation, trade and retirement. However, for simpler supply chains, a more directly coupled CoC model may be appropriate, such as mass balance. With a mass balance model, there are multiple options for making claims. To ensure integrity and eliminate ambiguity for the offtaker, the preferred claim option should be outlined by the scheme. A recent IRENA Coalition for Action paper provides more detail on the CoC models and tracking of certification systems (IRENA Coalition for Action, 2022).

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1 *If a scheme uses a mass balance model, it should specify whether a batch-, site- or group-level volume reconciliation is used.*

Box 5 Ammonia certification

Ammonia is already a global commodity: out of today's 180 million tonnes of change to global annual supply, around 20 million tonnes are traded across borders. This volume of cross-border trade is likely to expand as existing markets decarbonise, due to renewables-rich regions developing into centres of low-cost production and exporting low-carbon ammonia to centres of consumption. In addition to this shift in existing markets, there is an opportunity for new markets to develop using ammonia to decarbonise other hard-to-decarbonise sectors. All told, by 2050 there could be a market for 688 million tonnes/year of certified ammonia, including 197 million tonnes as a fuel for maritime shipping and 127 million tonnes as a hydrogen carrier (IRENA and AEA, 2022).

While this scale of trade in low-carbon ammonia has the potential to enable global decarbonisation targets to be reached, a multiplicity of regulators is involved, already developing diverse standards for fertilisers, bunker fuels and green hydrogen across distinct regional and international jurisdictions. As the molecule is always the same, an ammonia producer may not know at the initial point of certification which market – region or end use – the product will ultimately serve. Compatibility between certification schemes therefore becomes critical.

First-movers have already successfully traded individual batches of certified ammonia according to various standards but these one-off bilateral trades are so far measured in tens, not millions, of tonnes. To reach scale, an internationally recognised certification system must be developed to quantify and verify the greenhouse gas emissions from ammonia production and enable trade of ammonia as a low-carbon commodity. This project is under development at the Ammonia Energy Association.

Such a system will rely on mutual recognition. Data standards will therefore become critical, enabling information – data and metadata – to be collected and presented in forms that are compatible across different certification schemes. The credibility of the certificate and its chain of custody will be paramount: only with real confidence in its emissions reduction potential will ammonia be widely adopted as a fuel. Without credibility, these new markets may simply not materialise.

As of October 2022, 145 million tonnes of renewable ammonia capacity has already been announced by project developers (Ammonia Energy Association, *forthcoming*). Many of these projects are under construction, and a few are already operational, but – for most of them – the final investment decision will be dependent on confidence in future demand. Supply is not the limiting factor; strong, stable demand signals are necessary for low-carbon ammonia plants to be built.

LANDSCAPE ASSESSMENT OF CERTIFICATION SCHEMES

Certification schemes are evolving rapidly. Information on the list below is as detailed and complete as possible at the time of writing in December 2022. However, schemes may be announced, drafted or updated, or become operational, after this report is published. This report considers schemes as emerging if they are not publicly available for use, have not issued a certificate or are not finalised with the required technical elements in place. Classification is based on IRENA's understanding of each certification scheme or framework and does not imply endorsement of the classification.

The number of initiatives to create a market for hydrogen certification has increased in the last five years, alongside the increasing awareness of the role of low-carbon and renewable hydrogen in decarbonising fossil-based energy and feedstocks in the hard-to-decarbonise sectors. Figure 4 presents the list of schemes and mechanisms that form the new market for hydrogen certification, shown geographically in Figure 5. Mandatory schemes set a benchmark that all hydrogen production in their jurisdiction must follow, while voluntary schemes are optional. Schemes that need to be met to qualify for government incentives are included under the mandatory market. In the EU, voluntary schemes will be used to show compliance with regulatory requirements for demand-side support measures.

Some schemes are wholly born out of industry, while some are based on government initiatives. Of those supported by governments, schemes can be operated by the respective governments or industry. It can also be the case that schemes are government operated, but the standards they produce are not mandatory; or a standard developed by industry is referenced in mandatory requirements in regulation. Moreover, it can be the case that a government mandates a specific requirement, but the choice of selecting a certification scheme is voluntary (*e.g.* EU sustainability criteria for biofuels) (European Commission, n.d.b).

Most mechanisms are designed for a specific country or region. However, the following mechanisms are working towards being recognised internationally: the Green Hydrogen Standard, CertifHy and the Zero Carbon Certification Scheme. For international adoption, it is essential that standards are either issued by a recognised standards holder, recognised in a country's jurisdiction or used by a wide range of hydrogen projects.

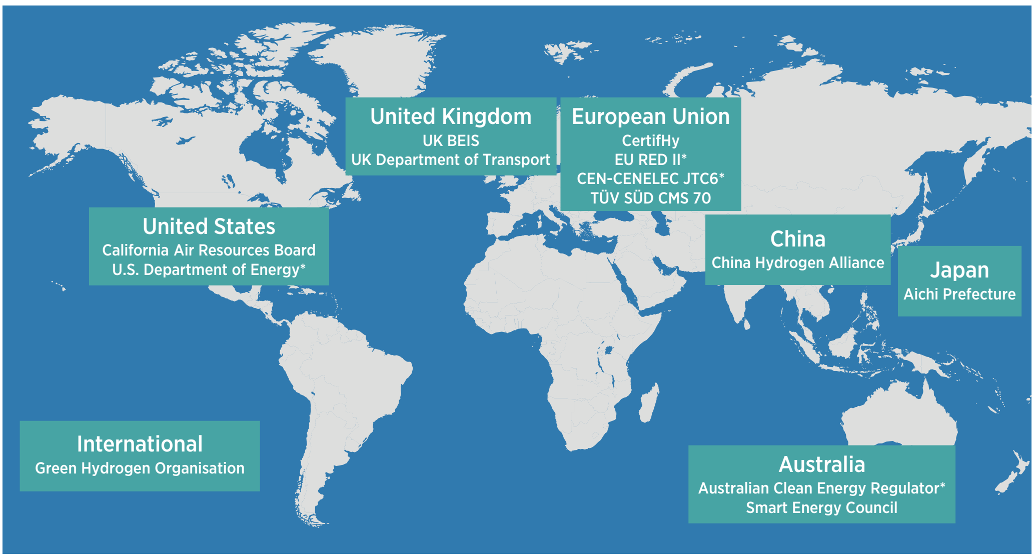
Figure 4 Overview of hydrogen certification

VOLUNTARY MARKET		MANDATORY MARKET
Aichi Prefecture Low Carbon Hydrogen Certification	**China Hydrogen Alliance** Standard and Assessment for Low Carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen Energy	**California Air Resources Board** Low Carbon Fuel Standard
Australian Clean Energy Regulator* Hydrogen Guarantee of Origin	**Green Hydrogen Organisation** Green Hydrogen Standard	**European Commission*** Renewable Energy Directive (RED II)
CertifHy Green and Low-Carbon Hydrogen Certification	**Smart Energy Council** Zero Carbon Certification Scheme	**UK Department for Business, Energy & Industrial Strategy** Low Carbon Hydrogen Standard
CEN-CENELEC* Joint Technical Committee 6	**TÜV SÜD** CMS 70	**UK Department for Transport** Renewable Transport Fuel Obligation
		US Department of Energy** Clean Hydrogen Production Standard

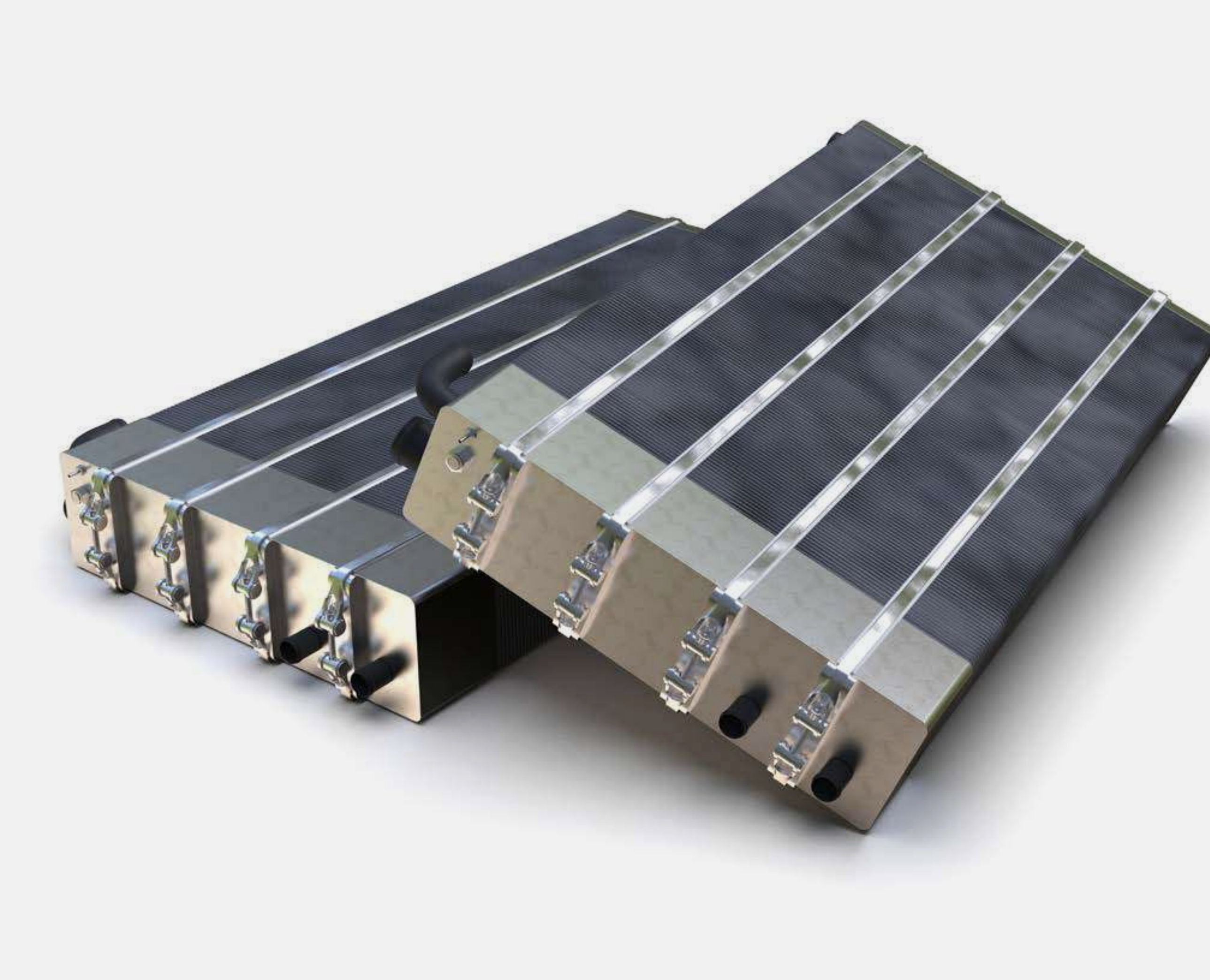
*in development.
**in development for specific program eligibility.

Notes: CEN = European Committee for Standardization; CENELEC = European Committee for Electrotechnical Standardization.

Figure 5 Map of organisations working on hydrogen certification



Notes: * in development. BEIS = Department for Business, Energy and Industrial Strategy; CEN = European Committee for Standardization; CENELEC = European Committee for Electrotechnical Standardization; JTC = Joint Technical Committee; RED II = Renewable Energy Directive II.
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.



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VOLUNTARY MARKET

Although some voluntary schemes and their standards have been developed using the same or similar methodologies, most have fundamental differences that make them incompatible (see Table 1).

Two of the eight voluntary market mechanisms do not stipulate an emissions threshold but limit their scope to assessing the difference in carbon footprint. For voluntary schemes with specified emissions thresholds, the threshold ranges between 1 and 4.9 $kgCO_2eq/kgH_2$ for renewable hydrogen pathways. Another discrepancy is found in boundary setting (see Table 1), where some boundaries are set as emissions to the point of consumption, others are set as emissions to the point of hydrogen production (most commonly when the end user is a nearby factory [as in the case of Japan] or a transport loading point next to the production facility), and others include the footprint of upstream methane emissions. Discrepancies also exist in the validating process for renewable energy use, with different schemes requiring different renewable energy and CoC models. Each mechanism is summarised below.

Table 1 Summary of voluntary market mechanisms with published technical criteria

TITLE	LABEL	EMISSIONS THRESHOLD ($kgCO_2eq/kgH_2$)	BOUNDARY	POWER SUPPLY REQUIREMENT FOR ELECTROLYSIS	HYDROGEN PRODUCTION PATHWAY	CHAIN OF CUSTODY MODEL
Australia **Smart Energy Council** Zero Carbon Certification Scheme	Renewable H_2	No threshold	To point of production	GO required; Solar, wind or hydro	Electrolysis; Biogas SMR	Unclear
China **China Hydrogen Alliance** Standard and Assessment for Low-carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen Energy	Renewable H_2	4.9	To point of production	No GO/additionality specified; Solar, wind or hydro	Electrolysis; Biogas SMR	Not specified
	Clean H_2	4.9	To point of production	No GO/additionality specified; Grid (or unspecified)	Electrolysis; Fossil SMR/ATR with carbon capture	Not specified
	Low-carbon H_2	14.5	To point of production	n/a	Fossil SMR/ATR with carbon capture	Not specified
European Union **CertifHy** Green and Low-Carbon Hydrogen Certification	Green H_2	4.4	Includes upstream methane; To point of production	GO + additionality*; Solar, wind or hydro	Electrolysis; Biogas SMR	B&C
	Low-carbon H_2	4.4	Includes upstream methane; To point of production	GO required; Grid (or unspecified); Nuclear	Electrolysis; Fossil SMR/ATR with carbon capture	B&C
Germany **TÜV SÜD** CMS 70	Green H_2 (non-transport)	2.7	Includes upstream methane; To point of production	GO + additionality; Solar, wind or hydro	Electrolysis; Biogas SMR	B&C
	Green H_2 (transport)	2.8	Includes upstream methane; To point of production; To point of use			Mass
Japan **Aichi Prefecture** Low-Carbon Hydrogen Certification	Low-carbon H_2	No threshold	To point of production; To point of use	GO + additionality; Solar, wind or hydro	Electrolysis; Biogas SMR	B&C
International **Green Hydrogen Organisation** Green Hydrogen Standard	Green H_2	1.0	Includes upstream methane; To point of production	GO required; Solar, wind or hydro	Electrolysis	Not specified

*Aligned with REDII methodology and may be updated once EU delegated act is finalised.

Indicates threshold value

Boundary: Includes upstream methane; To point of production; To point of use

Power supply requirements: GO + additionality; GO required; No GO/additionality specified; Solar, wind or hydro; Nuclear; Grid (or unspecified)

Hydrogen production pathway specified: Electrolysis; Fossil SMR/ATR with carbon capture; Biogas SMR

Notes: ATR = autothermal reforming; B&C = book and claim; GO = guarantee of origin; SMR = steam methane reforming.

Aichi Prefecture Low-Carbon Hydrogen Certification. This certification scheme results from a partnership between the Aichi Prefecture (area) Government, Chita City, Toyota City and local industry to promote a low-carbon hydrogen economy in Aichi Prefecture. The Aichi Prefecture Government oversees the certification of all the produced hydrogen, with industry partners in charge of the supply, transport and consumption of the low-carbon hydrogen. City gas, produced from sewage sludge, is transported via existing gas pipelines and reformed into hydrogen and consumed by fuel cell forklifts in a nearby Toyota factory. In addition, electrolysers on site produce green hydrogen using on-site solar panels to supplement the bio-hydrogen production. The coverage area of certification is the Aichi Prefecture only (Toyota Global, 2018, 2019).

Australia Clean Energy Regulator Hydrogen Guarantee of Origin. A voluntary guarantee of origin scheme is being developed by the Australian Government as part of its national hydrogen strategy. Public and industry consultations over the design of the scheme were held in July 2021, and the scheme is currently undergoing trials. Trials are expected to finish in June 2023, before the scheme is included in legislation. The guarantee of origin is set to apply to hydrogen produced from coal, natural gas and renewable energy and is built on the methodologies established by the IPHE, in collaboration with the Australian Department of Industry, Science, Energy and Resources. The Clean Energy Regulator will be in charge of collecting and analysing information from the producer and consumer (Clean Energy Regulator, 2022; DCCEEW, 2022; DENA and World Energy Council, 2022).

CertifHy. This industry consortium provides certificates for hydrogen produced using both renewable and non-renewable production methods. CertifHy manages the issue and registry of certificates, while a separate auditing body ensures that hydrogen producers follow the requirements of the standards specified. CertifHy certificates are tradable until their expiry or until hydrogen consumption. CertifHy currently operates in Europe but has plans to expand globally, with several other mechanisms adopting the scheme. Currently, the carbon threshold is 4.4 $kgCO_2eq/kgH_2$, but it will be aligned to RED II. CertifHy sets the benchmark for the carbon intensity limit of renewable and non-renewable hydrogen, using nuclear or fossil fuels with CCS, at 60% less than the carbon intensity of steam methane reforming. This percentage is set to increase over time. CertifHy certificates expire one year after issue (CertifHy, n.d.).

CEN-CENELEC Joint Technical Committee 6. The Joint Technical Committee of the European Committee for Standardization and the European Committee for Electrotechnical Standardization, two of Europe's recognised standardisation organisations, is currently drafting a standard on the production, storage, transport, distribution and measurement of hydrogen in energy systems, including renewable and non-renewable sources. This standard fits the context of the overall European strategy for the development of a hydrogen market. The committee is currently working with ISO (ISO/TC 197) on the development of a standard on vocabulary (prEN ISO 24078) (CEN-CENELEC, 2022).

China Hydrogen Alliance Standard and Assessment. This is an industry-led scheme to assess the life cycle emissions for hydrogen. It has three categories for hydrogen: low carbon, clean and renewable. The maximum level of emissions for certification as low-carbon hydrogen is 14.51 $kgCO_2eq/kgH_2$, while clean and renewable hydrogen are capped at 4.9 $kgCO_2eq/kgH_2$. Emissions are calculated at the point of production for all three labels. A third party conducts an on-site audit to verify the submitted documents, and certification

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is conducted annually. Additional audits may be required if the production process changes. Under this scheme, renewable hydrogen must be produced from electrolysis using renewable energy, meeting a 65% reduction from the coal gasification (with CCS) baseline. Clean hydrogen must meet the same 65% reduction but does not have the same renewable energy requirement. Low-carbon hydrogen must meet a 50% reduction from the coal gasification baseline, with no constraints on the technology pathway used to produce hydrogen. Having three labels for hydrogen allows for an intermediary goal to help guide the transition from high-carbon to low-carbon hydrogen production (China Energy Investment Group, 2021).

Green Hydrogen Organisation (GH2) Green Hydrogen Standard. This voluntary industry standard, issued in May 2022, defines green hydrogen as hydrogen produced through the electrolysis of water with 100% or near 100% renewable energy and with close to zero GHG emissions: $\leq 1\ kgCO_2eq/kgH_2$ taken as an average over a 12-month period. The standard builds on the methodology proposed by the IPHE for calculating the GHG emissions, including any emissions from production, water desalination and treatment, and on-site or purchased renewable electricity. It is expected that project operators will report on the emissions associated with the delivery of hydrogen and its derivatives. The standard also encourages project operators to report on embodied emissions. GH2 is developing the quality infrastructure to issue certificates for green hydrogen and, in parallel, is extending the standard to cover hydrogen derivatives, including green ammonia (GH2, 2022).

Smart Energy Council Zero Carbon Certification Scheme. This industry-led certification scheme for green hydrogen includes an assessment of emissions for hydrogen, ammonia and steel production in Australia. It issued its first certificate for a public green hydrogen refuelling station in Canberra in 2022. The Council is also co-operating with the Green Hydrogen Organisation to develop a global standard for green hydrogen (Smart Energy Council, 2020, 2022).

TÜV SÜD CMS 70. This global certification service for green hydrogen is offered by an auditing company for standards based in Germany. The certificate has two boundaries: *point of use* for transport and *point of production* for all other activities. The CoC is different for each boundary, with the former using a mass balance CoC and the latter using a book-and-claim CoC. The certification applies CertifHy thresholds for emissions and will ensure alignment with the EU RED II and its delegated acts (TÜV SÜD, 2022; Velazquez Abad and Dodds, 2020).

Box 6 Green Hydrogen Organisation

Source: Green Hydrogen Organisation, 2022

Since its establishment in 2022, the Green Hydrogen Organisation (GH2) has emphasised the necessity to harmonise global and national green hydrogen standards. GH2 believes that greater convergence in emissions and sustainability standards will lower compliance costs for developers (and customers) while ensuring the growing green hydrogen industry has close to zero emissions and contributes to sustainable development.

GH2 is currently in dialogue with a group of countries about their hydrogen standards, with the vision that the Green Hydrogen Standard will form the basis for further development of their regulatory environment. However, GH2 acknowledges that some governments will continue to promote different definitions and standards based on their own needs and comparative advantages.

To avoid duplication, the standard includes a general principle on "sovereignty and subsidiarity", where demonstrating adherence to credible and comprehensive national requirements shall be deemed sufficient to meet GH2's accreditation and certification requirements.

GH2 is modifying its procedures as national regulations are further refined, based on demand from green hydrogen producers and customers. Where national standards are not defined, the standard provides globally applicable reference points for project developers looking to fast-track project development in accordance with global best practice. GH2 is also currently extending the standard to include the production of green ammonia as a derivative of green hydrogen.

MANDATORY MARKET

To date, at least 60 countries have published or are drafting hydrogen strategies, with several aiming to establish themselves as hydrogen exporter regions (IRENA, 2022a). This number continues to grow as governments aim to demonstrate decarbonisation and energy security policy. A few first-mover regions have set production targets and product quotas to accelerate the hydrogen market (*e.g.* India requiring use of renewable hydrogen in industrial processes; Japan setting mobility and refuelling infrastructure targets). These regions are exploring how they should regulate hydrogen; however, most are waiting for additional industry input before adopting concrete legislative standards.

Most of the strategies include consideration of a certification scheme to quantify hydrogen-related emissions reduction and to identify which hydrogen production method may receive most public support.

The EU, the United Kingdom and the United States are in the process of setting a definition of low-carbon and green hydrogen by specifying an emissions threshold and scope (see Table 2). These regulatory mechanisms should also define:

- how emissions savings will be certified and monitored, especially for imports (this could be done through partnering or referring to voluntary schemes);
- whether the methodology laid out will be adapted for multiple end-use sectors; and
- how end users will be expected to prove compliance with the emissions savings (typically outlined in legislation as a percentage reduction from baseline value) and receive credit for low-carbon fuel use.

Table 2 Summary of mandatory markets with published technical criteria

COUNTRY/ REGION	NATIONAL HYDROGEN STRATEGY	BOUNDARY AND SCOPE (SECTORS)	EMISSIONS THRESHOLD ($kgCO_2eq/kgH_2$)	POWER SUPPLY REQUIREMENT FOR ELECTROLYSIS	HYDROGEN PRODUCTION PATHWAY	REGULATORY MECHANISM	STATUS OF REGULATORY MECHANISM
United Kingdom	**Government of the United Kingdom** UK Hydrogen Strategy	(Energy)	2.4	GO required; Grid (or unspecified); Nuclear; Solar, wind or hydro	Electrolysis; Fossil SMR/ATR with carbon capture; Biogas SMR	**BEIS** Low Carbon Hydrogen Standard	To be implemented in 2022 Certification scheme **to be developed by 2025**
		(Transport)	3.9	GO + additionality; Solar, wind or hydro	Electrolysis	**UK Dept. for Transport** Renewable Transport Fuel Obligation	**Active**
European Union (Proposed)	**European Commission** A hydrogen strategy for a climate-neutral Europe	(Transport, energy)	3.4	GO + additionality*; Solar, wind or hydro	Electrolysis	**European Commission** RED II	**Active** New Delegated Act of RED II **proposed in May 2022**
		Boundary not specified	3.0	GO required; Grid (or unspecified); Nuclear; Solar, wind or hydro	Electrolysis; Fossil SMR/ATR with carbon capture; Biogas SMR	**European Commission** EU Taxonomy	**Active**
United States (Proposed)	**US Department of Energy** National Clean Hydrogen Strategy and Roadmap	(Transport, energy)	4.0	No GO/additionality specified**; Grid (or unspecified); Nuclear; Solar, wind or hydro	Electrolysis; Fossil SMR/ATR with carbon capture; Biogas SMR	**US Department of Energy** H2Hubs draft *(may be adopted by standard for clean H_2 production)*	CHPS not yet finalised H2Hubs criteria requires 2 $kgCO_2/kgH_2$ at point of production to qualify
		(Transport)	No threshold (Certificate issued based on reduction from annual target)	GO required; Grid (or unspecified); Solar, wind or hydro	Electrolysis; Fossil SMR/ATR with carbon capture; Biogas SMR	**California Air Resources Board** Low Carbon Fuel Standard - California only	**Active**

*refers to delegated act criteria, grid connected conditions in delegated act undergoing revision and are subject to change.
**denotes no detail of additionality in draft, but is yet to be finalized.

Indicates threshold value

Includes upstream methane
To point of production
To point of use

Power supply requirements
- GO + additionality
- GO required
- No GO/additionality specified
- Solar, wind or hydro
- Nuclear
- Grid (or unspecified)

Hydrogen production pathway specified
- Electrolysis
- Fossil SMR/ATR with carbon capture
- Biogas SMR

Notes: ATR = autothermal reforming; B&C = book and claim; GO = guarantee of origin; SMR = steam methane reforming.

California Air Resources Board Low Carbon Fuel Standard (LCFS). Introduced in 2011, the LCFS is an incentive scheme for suppliers of fuel (hydrogen, biodiesel and electricity) that qualifies as low carbon. Entities that produce hydrogen for use as fuel (via fuel cells or as a chemical feedstock for another fuel) can earn LCFS credits, which can then be traded in the California LCFS Credit Market. The carbon intensity of the hydrogen is based on the production pathway used, with the California Air Resources Board having set a carbon intensity value for each pathway: 150.94 grammes of carbon dioxide equivalent (gCO_2eq) per megajoule (MJ) for liquid hydrogen produced via steam methane reforming; 10.51 gCO_2eq/MJ for compressed hydrogen produced using wind or solar. The programme continues to be active in the state of California (CARB, 2018a, 2018b).

European Commission Renewable Energy Directive II (RED II, 2022 proposal). RED II sets the target for renewable energy consumption in the EU by 2030. The 2018 target of the directive was for 32% of energy to be sourced from renewable sources. The new proposal (REPowerEU) sets this target at 45% (European Commission, n.d.c). In 2018, RED II introduced a life cycle GHG emissions savings threshold for hydrogen produced using renewable electricity (*i.e.* using renewable fuels of non-biological origin [RFNBOs]) or hydrogen produced from biomass; the threshold is the equivalent of around 3.4 $kgCO_2eq/kgH_2$. This threshold applies for both low-carbon and renewable hydrogen and its derivatives, such as ammonia. Furthermore, the European Commission is working on a draft delegated act on RFNBOs that sets the criteria that have to be met for hydrogen produced via electrolysis to be considered fully renewable (European Commission, n.d.d). Hydrogen produced using grid electricity can qualify as renewable if it is tied to a purchase agreement incentivising new renewable energy generation. Hydrogen produced via renewable energy must source this renewable energy concurrently at set time intervals and report the geographical correlation of the electricity. A second delegated act sets out a methodology for determining the life cycle emissions savings of RFNBOs. Finally, RED II already has a system in place for the certification of renewable fuels that has been used for more than a decade to certify the GHG emissions savings and sustainability criteria for biofuels, including in countries outside the EU. As soon as the detailed criteria and calculation methodology for the life cycle emissions savings of RFNBOs have been finalised, the procedure for certifying renewable hydrogen can proceed through EU Commission recognised schemes (European Commission, 2022).

UK Low Carbon Hydrogen Standard. This standard defines what constitutes low-carbon hydrogen at the point of production. The standard sets a bar of 20 gCO_2eq/MJ of hydrogen, which corresponds to roughly 2.4 $kgCO_2eq/kgH_2$. The standard defines the methodology for calculating emissions and is "neutral" with regard to the production pathways. The standard applies to hydrogen produced in the United Kingdom (BEIS, 2022).

UK Renewable Transport Fuel Obligation. The Fuel Obligation is a credit mechanism for fuel suppliers that supply at least 450 000 litres of renewable fuel per year. The Fuel Obligation covers different types of non-fossil fuels, including hydrogen produced through renewable energy. A supplier can earn Renewable Transport Fuel Certificates by supplying renewable fuel, and these certificates can then be traded in the open market. Only hydrogen produced through renewable energy can earn these certificates (Department for Transport, 2021).

US Department of Energy Clean Hydrogen Production Standard (CHPS) and Bipartisan Infrastructure Law (BIL). Is a proposed standard to define low-carbon hydrogen production in the United States. The standard proposes a target for life cycle emissions of 4 $kgCO_2eq/kgH_2$ well-to-gate to qualify as low-carbon hydrogen and outlines a methodology to account for these emissions. It is not a regulatory standard but may be leveraged to qualify for any subsidies or grants provided by the government, such as the Hydrogen Production Tax Credit under the Inflation Reduction Act. The definition of clean hydrogen as outlined in the BIL/ Infrastructure Investment and Jobs Act, which governs the H2Hubs funding program, requires hydrogen produced with a carbon intensity equal to or less than 2 $kgCO_2eq/kgH_2$ at the site of production. The details and application of CHPS and alignment with BIL definition are currently undergoing a review process (US Department of Energy, 2022).

OTHER INITIATIVES

This list includes organisations and entities that have looked at, or are developing, guarantees of origin, definitions, certifications or standards for hydrogen. This category includes some operational schemes, as well as initiatives that have looked at, or are looking into developing a scheme.

Asia-Pacific Economic Cooperation (APEC) Low-Carbon Hydrogen International Standard. APEC is a key international forum that influences international standardisation and harmonisation, such as through ISO. APEC funded a New Zealand project looking at the feasibility of developing an international low-carbon hydrogen standard. The project reviewed existing hydrogen standards, with the recommendation that APEC member countries *align to an international standard, in lieu of developing their own* (APEC, 2022). The report also suggested that focusing on emissions intensity during production, such as in the IPHE methodology, is more powerful than setting standards to define "arbitrary" production method-based categories of hydrogen. It was recommended that to build trust and the market, consumers must see transparency in the product they are buying.

EU Taxonomy. The taxonomy is a standardised classification system of what are considered sustainable economic activities. It aims to foster transparency, eliminate "greenwashing" and, ultimately, channel capital towards sustainable investments. For hydrogen, Commission Delegated Regulation 2021/2139 (referred to as the EU Taxonomy Climate Delegated Act) defines the substantial contribution of hydrogen production to climate change mitigation objectives if the life cycle GHG emissions savings meet the 73.4% requirement relative to a fossil fuel comparator, analogous to the approach of Directive 2018/2001. (Hydrogen-based synthetic fuels have to reach 70% GHG emissions savings.) The emissions savings threshold to qualify as contributing to climate change mitigation is 3.0 tonnes of carbon dioxide equivalent (tCO_2eq) per 3.0 tH_2. The hydrogen production must also meet a set of "do no significant harm" criteria in relation to five other environmental objectives. This is not yet the EU working definition for blue or green hydrogen; rather, it sets a base standard for what is considered environmentally sustainable hydrogen production (European Commission, 2021).

France Hydrogène. This association comprising French companies, regions and laboratories involved in hydrogen technologies is advising the French government on hydrogen issues, including certification. The French government issued an ordinance on hydrogen in February 2020, defining renewable, low-carbon and fossil hydrogen, and will issue a decree on the thresholds for each label, which should comply with RED II.

France Hydrogène advocates for three labels for hydrogen: fossil, low carbon (including using nuclear electricity) and renewable (requiring 100% renewable electricity). It also advocates streamlining the articulation of the various methods to produce renewable hydrogen; relaxing the additionality principle; applying the same detailed rules to imports of renewable hydrogen and derivatives; attributing correct and consistent average GHG emissions intensity to EU Member States' electricity mixes; introducing an alternative approach to assess the GHG emissions content of grid electricity based on the hourly average carbon content; and streamlining the carbon intensity of renewable electricity and nuclear electricity. It is expected that the decree will require full life cycle calculations of footprint using the ADEME carbon database; therefore, wind, nuclear and solar will not be considered zero carbon (L. Antoni, CEA, personal communication, 29 September 2022).

Gaz Energie. This Switzerland-based industry group of gas supply companies has a target of decarbonising the Swiss gas supply by 2050, using renewable gases such as biogas, synthetic methane and green hydrogen. Hydrogen and synthetic methane need to be produced using renewable electricity in order to be considered a "renewable gas" (Gaz Energie, 2020).

International Sustainability and Carbon Certification (ISCC) Plus. ISCC Plus is a global certification system for sustainable bio-feedstocks. Certification of green hydrogen is covered in the ISCC Plus standard for biofuels, recycled carbon fuels and RFNBOs. Third parties oversee the audits and verify published information, while the ISCC grants the certificates. ISCC Plus follows the thresholds and requirements set by RED II. Additionally, ISCC Plus incorporates land use change, water use and safe working conditions as criteria for its biofuels (DENA and World Energy Council, 2022; ISCC, 2021).

I-REC Standard Foundation: Hydrogen Product Code. I-REC, a non-profit standardisation body based in the Netherlands, currently offers a standard for renewable electricity certificates, I-REC(E), which allows entities to certify their claims of renewable energy use. The I-REC(E) has been issued in over 45 countries worldwide, with certificates totalling 30 million megawatt hours (MWh) issued as of September 2022. I-REC has announced intent to develop a technology-agnostic methodology to track the sustainability criteria for hydrogen production, targeting an alpha version of the standard by Q4 2022 (W. Almazeedi, Avance Labs, personal communication, 30 October 2022).

Republic of Korea Clean Hydrogen Certification System. The Republic of Korea's Ministry of Trade, Industry and Energy has announced plans to develop a clean hydrogen certification system by 2024. The system is expected to account for the carbon footprint instead of the production process. A draft of the certification system is planned to be released in 2023 (Yoon-Seo, 2022).

United Nations Economic Commission for Europe (UNECE). As one of the five regional commissions of the United Nations, UNECE's goal is to promote economic integration throughout Europe, although it also includes membership and participation from other countries. The UNECE is responsible for the United Nations Framework Classification for Resources, an international scheme for the classification and management of energy, mineral and anthropogenic resource projects. The Framework Classification is a numerical coding system that incorporates the project's socio-economic and technical feasibility, as well as the degree of confidence in the estimate of the project. UNECE has recommended that a science-based taxonomy of hydrogen be included in the Framework Classification and proposes that a guarantee of origin scheme be established for hydrogen (UNECE, 2022).

Vertogas. A certification body for green gases (such as biomethane), Vertogas now also provides guarantees of origin for hydrogen in the Netherlands that can be traded on the HyXchange platform or claimed for renewable energy units (HBEs). To be converted to HBEs, the hydrogen needs to be generated using unsubsidised renewable electricity from the Netherlands. HBEs are used to meet mandatory compliance targets. Certificates of imported hydrogen (by foreign entities) need to be exchanged for a Netherlands equivalent, and vice versa. Vertogas works with CertIQ (an electricity certification body) in guaranteeing the origin of electricity sources (Hinicio, 2022).

THE WAY FORWARD

A new global hydrogen market is forming, with public and private actors across the supply chain coming together to form coalitions and agreements to accelerate the hydrogen economy (IRENA, 2021, 2022b) (see Figure 6). To ensure this marketplace achieves the required gigatonne-scale emissions reduction and aids in rapid decarbonisation, a cohesive certification system is required.

Policy makers and the energy sector at large have experience with energy carrier certificates. One example is the electricity guarantees of origin system. A guarantee of origin certifies the origin of renewable electricity from qualified plants and provides consumers with this proof. It is a voluntary certification scheme allowing consumers to choose and document their share of renewable energy consumption.

The European Commission's RED II could be used as a best practice example for hydrogen certification. Indeed, hydrogen used in the transport sector in Europe will have to follow rules similar to those for biofuels. However, in the EU, some uncertainty remains about how the regulatory mechanisms of the directive will apply to imported hydrogen. Further clarity on this point is required and may come as the directive's consultation process is finalised.

The European experience with biofuels shows how, if a market exists, producers will make sure to certify their energy carrier (biofuels, hydrogen, ammonia) to guarantee the carrier's use in that protected market. Moreover, the establishment of the European Carbon Border Adjustment Mechanism will make certificates even more important.

Carbon border mechanisms are import taxes that account for the difference in carbon pricing policies between countries. The objective is to make polluters, even outside the importing jurisdiction, pay the same (or a similar) carbon price as paid by local industry, thereby discouraging carbon leakage through relocation of processes and levelling the playing field between industry, regardless of the local carbon policy. As a border tax, border carbon adjustments should be compliant with the World Trade Organization's General Agreement on Tariffs and Trade. The General Agreement mandates that any taxation of imported goods cannot result in treatment that is less favourable than the treatment of comparable goods produced domestically. However, World Trade Organization case law suggests that a carbon border adjustment mechanism would be allowed if it were based on the carbon content of a product rather than on the goods' country of origin. The adoption of such a policy in Europe or elsewhere will increase the importance of certification schemes since it will be a requirement to know the exact carbon content of each taxed product.

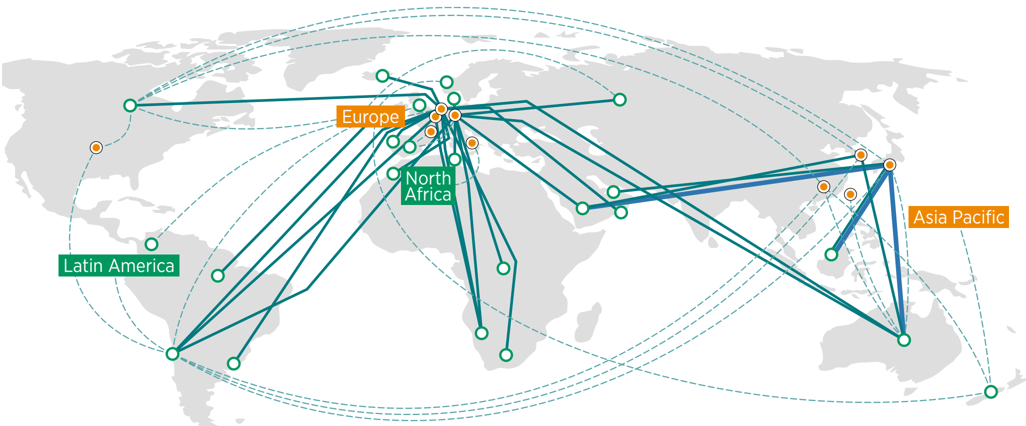
The market for renewable hydrogen and "green" products is likely to include a small number of importing regions, including G7 members, while many Global South countries show cost-competitive potential to produce renewable hydrogen. In practice, this may result in a situation of oligopsony, with a few large buyers setting the rules and regulations for many potential exporters. At the moment, however, leading importing countries are not taking advantage of their position to establish demand for climate-aligned production pathways of hydrogen.

A patchwork of regulation would impede scaling of renewable hydrogen and have negative impacts on the international trade of hydrogen and its derivatives. Potential exporters may look at the few markets and decide which one to focus on, reducing the scalability of their projects. If there is no effort to consolidate and harmonise the technical criteria used to classify hydrogen as low carbon, there may be a formation of markets equal to the number of certification rules in place.

A collaborative framework between importing and exporting countries for assessing and defining technical and ESG elements to differentiate hydrogen is required to ease market participation for producers, which could then replicate their projects across the world. Although defining common rules might seem an inherently technical activity, it will help determine the technologies that dominate a future market and reward those who master them. Standards are created to ensure the quality, safety and interoperability of various goods and services. Divergent standards, however, could fragment a market, stir regulatory competition and erect trade barriers.

Harmonisation of standards and rules can lead to increased visibility over the future of renewable hydrogen. Potential exporters will know the characteristics of hydrogen production to focus on and will have a clear and granular investment signal for the efficient deployment of renewable hydrogen infrastructure (IRENA, 2021, 2022b).

Figure 6 An expanding network of hydrogen trade routes, plans and agreements



Exporter | Exporting region | New routes in place or under development | MoUs in place establishing trade routes | Potential trade route explicitly mentioned in published strategies

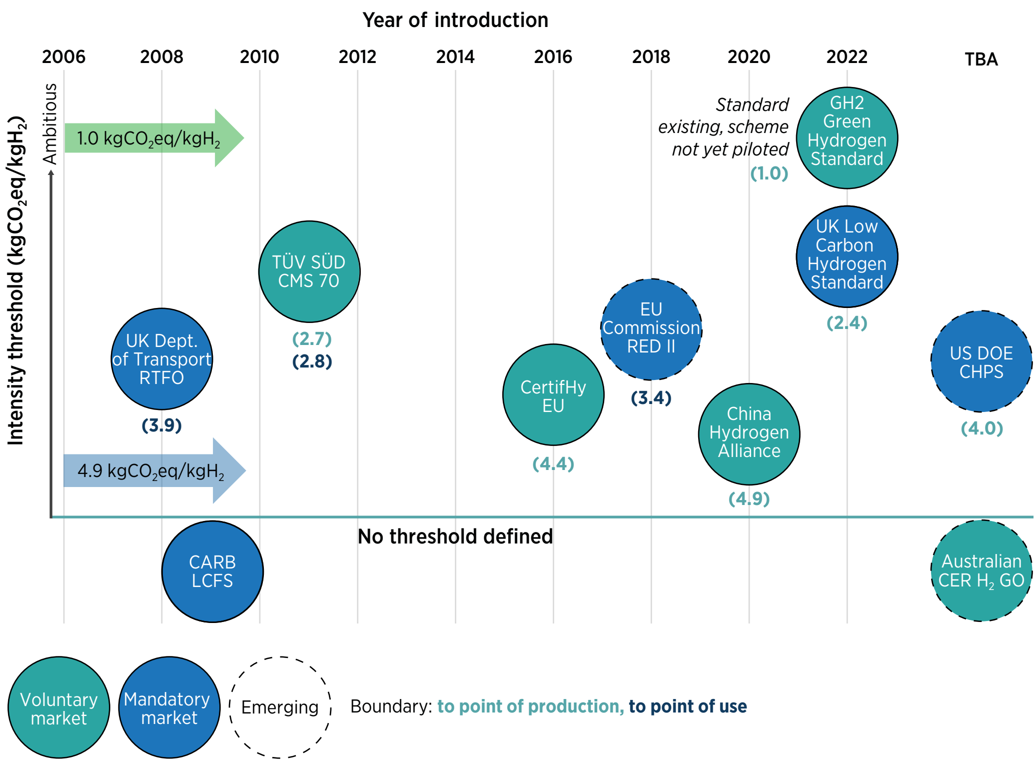
Importer | Importing region

Source: IRENA, 2022b.
Map source: Natural Earth, 2021.
Notes: Information on this figure is based on the information contained in government documents at the time of writing. MoU = memorandum of understanding.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

Current regulations and schemes are not harmonised, either due to differences in boundaries or emissions thresholds (see Figure 7) or to uncertainties regarding additionality and renewable energy requirements.

Figure 7 Timeline of emerging and existing voluntary schemes and regulatory mechanisms



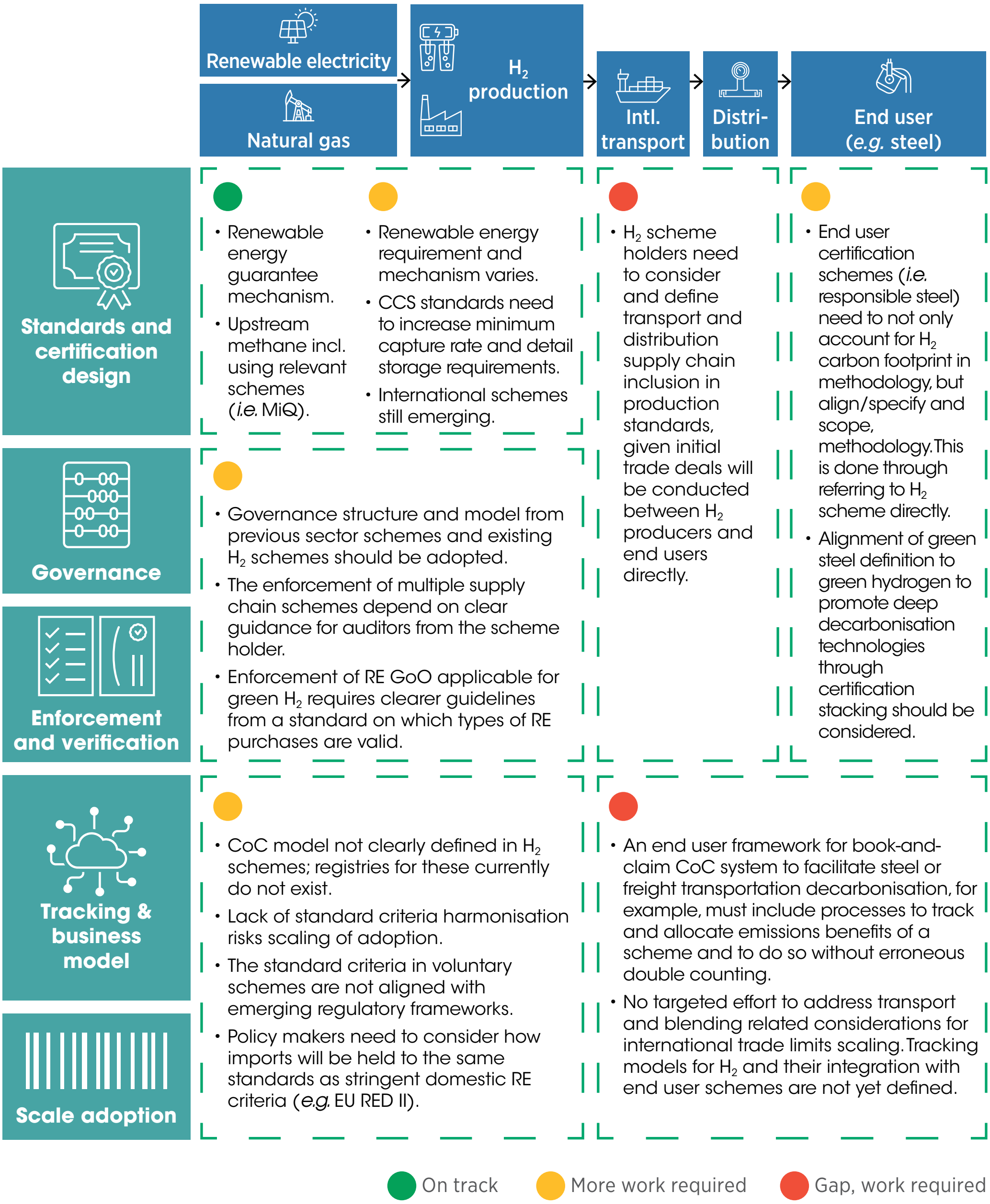
Notes: CARB = California Air Resources Board; CER = Clean Energy Regulator; CHPS = Clean Hydrogen Production Standard; EU = European Union; GH2 = Green Hydrogen Organisation; H2GO = Hydrogen Guarantee of Origin; LCFS = Low Carbon Fuel Standard; RED II = Renewable Energy Directive II; RTFO = Renewable Transport Fuel Obligation; TBA = To be announced; US DOE = US Department of Energy.

Consensus on the criteria for international standards is required to facilitate scaling. This will also clarify for offtake sectors what is in scope and assist in the implementation of their own guidance. First-mover regions can help address considerations related to transport and hydrogen blending in a way that would lay the foundations for cross-border trade.

Furthermore, it is important to recognise that certification schemes are required but are not sufficient to activate a market. Despite the many competing initiatives, there are significant gaps that require attention to enable international trade. Figure 8 illustrates the action areas that still require attention to scale a hydrogen certification system. When considering the supply chain and an end-use market, there is an opportunity for coalitions and policy makers to collaborate and fill in the deployment gaps.

Figure 8 Evaluating the status of a hydrogen certification system

AREAS TO TARGET FUTURE WORK IN H_2 CERTIFICATION SYSTEM



Notes: CoC = chain of custody; CCS = carbon capture and storage; EU = European Union; GoO = guarantee of origin; incl. = including; RE = renewable energy; RED II = Renewable Energy Directive II; req. = required.

More focused collaboration is required to populate these gaps, ensure market activation and provide a clear signal for the development of the hydrogen projects that combine low emissions with sustainable development.

RECOMMENDATIONS

The following recommendations are made in addition to those proposed in IRENA Coalition for Action (2022) for the international harmonisation of certification systems:

For stakeholders:

- To avoid fragmentation of the market, pursue alignment between standards, ecolabelling, certification criteria and maximum carbon thresholds.
- Ensure that certificates contain sufficient information for consumers and policy makers to differentiate between the different forms of hydrogen.
- Incorporate add-on elements that contain information on transport-related emissions up to the point of use.
- Adopt common definitions for allowable grid connection and clearly reference the use of a renewable electricity purchasing mechanism, as well as the criteria to evaluate these mechanisms.
- Reference or develop complementary schemes (for upstream methane and carbon capture performance) to ensure thoroughness of emissions accounting and eliminate duplication. These schemes can further ensure the climate credibility of the hydrogen by stipulating permanent storge of the captured carbon.
- If two certification systems coexist within the same jurisdiction, put in place a double-counting countering mechanism to ensure that multiple certificates are not issued for the same unit of hydrogen.
- Develop transparent and cost-effective hydrogen certificate tracking systems that offer security to certificate holders and that are compatible across borders to avoid administrative burdens and delays to project development.
- Think beyond hydrogen and ensure continuity for the hydrogen derivatives most likely to be traded, such as ammonia.

For policy makers:

- Collaborate under relevant global initiatives for closer international co-operation to establish globally accepted rules and requirements for hydrogen ecolabelling and trade, in line with recommendations made in the IRENA report *Accelerating hydrogen deployment in the G7: Recommendations for the Hydrogen Action Pact and in the Breakthrough Agenda report 2022* (IEA *et al.*, 2022; IRENA, 2022a).
- Adopt a common set of sustainability criteria for hydrogen certification and diplomacy over hydrogen trade rules to signal confidence to investors and industry, including standardised ecolabelling with associated GHG footprint threshold and renewable energy content (see IEA *et al.*, 2022; IRENA, 2022a).
- Initiate public-private dialogue (*e.g.* through the IRENA Collaborative Framework on Green Hydrogen), particularly between import and export regions, to discuss the issues in this report and work towards harmonising trade rules concerning hydrogen.
- Create a CoC framework (*e.g.* through an independent body) to facilitate the exchange and tracking of certificates and avoid double-counting.
- Develop quality infrastructure to support certification by qualifying and educating accreditation bodies, auditors, inspectors and other essential validation services. Such an example is the work being undertaken by IRENA in developing a roadmap for quality infrastructure jointly with the Physikalisch-Technische Bundesanstalt (German National Metrology Institute).

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