REPORT

Global Harmonisation of Hydrogen Certification

Overview of global regulations and standards for renewable hydrogen

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Executive Summary

This report analyses whether a **uniform global certification system for renewable hydrogen** is feasible. For this purpose, **eleven hydrogen regulations/standards** are assessed with regard to their commonalities, differences, and potential for harmonisation (ISCC PLUS, CertifHy, dena Biogasregister, TÜV Süd CMS 70, China Hydrogen Alliance's Standard, the Certification Scheme of the Japanese Prefecture Aichi, the Australian Zero Carbon Certification Scheme, the funding programme H2Global, the Californian Low Carbon Fuel Standard, the EU Renewable Energy Directive (RED) II and the UK Renewable Transport Fuel Obligation) (Table 1).

Certification of renewable hydrogen and its derivatives serves several purposes. It is an essential tool to demonstrate compliance with criteria set in the respective regulatory framework. Once this step is taken, consumers and companies can credit renewable hydrogen towards private-sector obligations – such as in the fuels sector – or even benefit from voluntary commitments. In addition, the willingness to pay higher prices for renewable hydrogen depends on the regulatory framework for which certification is a requirement.

The most harmonised sustainability requirements of all eleven hydrogen standards/regulations evaluated are the use of **renewable electricity inputs**, **mass balancing** as the tracking model, as well as the **eligibility of all carbon sources**, provided that they are **not deliberately produced** for the production of hydrogen and its derivatives.

The assessment concludes that a global certification system will be challenging, as it is unlikely that certain markets, e.g. the European Union (EU), would give up their ambitious criteria (e.g. the renewable electricity criteria according to Art. 27 RED II in the EU) for the sake of a globally harmonised system.

Therefore, the report offers a thought experiment, which proposes a plant concept that is recognised by all eleven hydrogen regulations/standards assessed:

- **Direct connection** between the renewable power source and the electrolyser
- **GHG reduction of 70%** compared to a fossil baseline
- Carbon source: **Atmospheric (DAC)**

Furthermore, the chain of custody must be traced by mass balancing, a tracking model where the physical delivery of an energy carrier goes hand in hand with the certificate.

However, since this plant concept is linked to relatively high production costs, the study also presents further plant concepts which are suitable for different hydrogen standards and regulations (Table 11).

The EU is primarily perceived as a potentially large consumer of renewable hydrogen. This can already be seen from the requirements of the Fit-for-55 package, which sets significant incentives for the use of Renewable Fuels of Non-Biological Origin (RFNBOs) in the transport sector and the industry. With its regulatory conditions and the associated support instruments for market take-up, the EU has created an incentive for producers of renewable hydrogen around the world. For this reason, clear documentation and certification requirements regarding RFNBOs are needed to demonstrate compliance with sustainability requirements. At the same time, requirements must not be too complex or strict, risking the market ramp-up of RFNBOs. If the regulatory conditions prove to be too strict, there is a risk that large producers of hydrogen and RFNBOs will opt for other certification or sales markets altogether and the EU market becomes less attractive in the long-term. This development would be contrary to the EU's ambition to strengthen leadership for technical standards, regulations and definitions on hydrogen, as defined in the EU's hydrogen strategy.

Table 1: Harmonisation options of sustainability criteria in different regulations/standards for hydrogen/ RFNBOs (1/2)

Sustainability criteria for hydrogen/RFNBOs	Schemes							Funding Programme	Regulations		
Regulation/standard	**ISCC PLUS**	**CertifHy**	**dena Biogas-register**	**TÜV Süd CMS 70**	**China Hydrogen Alliance's Standard**[1]	**Certification Scheme (Japan)**[2,3]	**Zero Carbon Certification Scheme**	**H2Global**	**LCFS**	**RED II**	**RTFO**
Market	**EU**	**EU**	**DE**	**DE**	**CN**	**JP**	**AU**	**DE**	**US/CA**	**EU**	**UK**
Purpose	v	v	r	v	n/a	v	v	r	r	r	r
Renewable electricity	+	+	+	+	+	+	+	+	+	+	+
Tracking models	MB	B&C	MB	MB; B&C	n/a	B&C	MB	MB	B&C[4]	MB	MB
GHG emissions	Well-to-Wheel	Well-to-Gate	According to demand	Well-to-Wheel	Well-to-Wheel	Well-to-Gate	Well-to-Gate	Well-to-Wheel	Well-to-Wheel	Well-to-Wheel	Well-to-Wheel[5]
Eligible carbon sources	+	tbu	+	Out of Scope	Out of Scope	n/a	+	tbu	+	Pending Delegated Act	+
Land use	+	-	-	-	-	-	-	+	+	-	-[6]

[1] FuelCellChina (2020)
[2] The scheme operates on a regional level in the Aichi Prefecture (Adelphi, 2019).
[3] Personal communication with MITSUBISHI Japan, 24.09.2021.
[4] BEIS (2021)
[5] BEIS (2021) discusses cradle-to-gate
[6] It is currently discussed to implement emissions resulting from iLUC in the methodology to calculate GHG emissions for RFNBOS within the UK low carbon hydrogen standard (BEIS, 2021).

Table 1: Harmonisation options of sustainability criteria in different regulations/standards for hydrogen/ RFNBOs (2/2)

Sustainability criteria for hydrogen/RFNBOs	Schemes							Funding Pro-gramme	Regulations		
Regulation/ standard	ISCC PLUS	CertifHy	dena Biogas-register	TÜV Süd CMS 70	China Hy-drogen Al-liance's Standard[7]	Certifica-tion Scheme (Japan)[8 9]	Zero Car-bon Certi-fication Scheme	H2Global	LCFS	RED II	RTFO
Market	EU	EU	DE	DE	CN	JP	AU	EU	US/CA	EU	UK
Water Consumption	+/-	-	-	-	-	-	+/-	+/-	+/-	+/-	-
Social Impact	+	-	-	-	-	-	-	+	+	-	-

Map legend	
+	Criteria is covered
-	Criteria is not covered
+/-	The topic is mentioned, but no actual criteria is implemented
n/a	No information available, if the respective criteria is covered in the standard/regulation
tbu	to be updated
v	voluntary
r	is based on the national framework in order to get state ben-efits granted

[7] FuelCellChina (2020)
[8] The scheme operates on a regional level in the Aichi Prefecture (Adelphi, 2019)
[9] Personal communication with MITSUBISHI Japan, 24.09.2021

1 Why harmonise standards for Renewable Hydrogen?

Hydrogen as an alternative energy carrier is increasingly gaining momentum. With more diverse areas of application and reducing costs, the demand for hydrogen is growing worldwide. The European Union (EU) in particular, but also countries such as Japan or South Korea, will probably not be able to meet their future demand through domestic production and will therefore have to rely on imports. In order to complete the transition towards a climate-neutral energy system, proof of the sustainable production of hydrogen is just as important as its eligibility for national targets in the area of renewable energies and emission reduction for many countries. Establishing proof that the hydrogen was produced sustainably is key in this context. Certification can serve this purpose.

Certification mirrors the existing legislative framework, which, in the EU, only foresees state aid for renewable hydrogen. Therefore, the focus of this paper is the certification renewable – or *green* – hydrogen, which is defined as hydrogen produced from renewable electricity sources such as wind, solar, hydro, geothermal and ocean energy. The analysis does not include other productions methods – or colours – of hydrogen, like so-called grey, blue or turquoise hydrogen.[10] Biobased hydrogen was also not considered, since current hydrogen standards/regulations do not cover it.

This paper provides an overview of the certification of hydrogen and its derivatives for the transport sector and the industry as the two main target sectors for hydrogen identified by the EU's hydrogen strategy in 2020. The focus lies on renewable hydrogen produced from electrolysis as well as hydrocarbons, which are synthesised from hydrogen and carbon dioxide. Examples for hydrocarbons include synthetic methane, methanol, ethanol, di-methyl ether, petrol, kerosene and diesel. Green ammonia and green metals play a major role for the industry sector.

Despite the novelty of the topic, several hydrogen standards already exist. In Germany, TÜV Süd already has a voluntary hydrogen standard in place for the transport sector and the industry (CMS 70). ISCC is an established global Voluntary Scheme (→ **Glossary**) recognised by the European Commission (EC) and has already voiced its aim to expand its portfolio towards hydrogen. It also seeks to be recognised by the EC, once the Delegated Act based on Art. 27 (3) RED II provides more clarity on the renewable electricity criteria for the production of Renewable Fuels of Non-Biological Origin (RFNBOs) for the transport sector. However, under ISCC PLUS renewable hydrogen can already get certified. ISCC PLUS is a voluntary market-based scheme for bio-based and recycled raw materials for all markets and sectors not regulated as transportation fuels under the European Renewable Energy Directive (EU RED) or Fuel Quality Directive (FQD). The CMS 70 has been developed by TÜV Süd itself, whereas certification schemes like The Roundtable of Biomaterials (RSB) or ISCC are multi-stakeholder initiatives linking different stakeholder groups. The Voluntary Schemes are not separately listed in this report but represented by the Renewable Energy Directive II (RED II), unless RED II does not cover the respective aspect, yet (see social impact chapter 4.7). CertifHy started as an EU project with the aim of setting up a Guarantees of Origin (GO) (→ **Glossary**) scheme for hydrogen. However, CertifHy is now aiming to be recognised as a

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[10] The production pathways of hydrogen are often categorised according to colours. Although there is no universally accepted colour coding, grey hydrogen usually refers to hydrogen which was produced based on fossil fuels, like natural gas or coal. Blue hydrogen refers to hydrogen from fossil fuels where the CO2 is captured and stored. Turquoise hydrogen is hydrogen that has been produced via methane pyrolysis. Instead of CO2, solid carbon is produced in the process.

Voluntary Scheme under the EC as well. In Australia, the Smart Energy Council (SME) – a non-profit organisation for the solar, storage and smart energy industries – launched the Zero Carbon Certification Scheme for hydrogen and its derivatives for the domestic as well as international market in December 2020 (KAS, 2022).

This report presents an overview of regulations and associated standards concerning hydrogen production for the transport sector and the industry, as shown in Table 2.

Table 2: Overview of regulations and associated standards for renewable hydrogen covered in this paper

Scope	Regulation	Status	Sectors	Standard(s)
AU	National Hydrogen Strategy[11]	Under consultation	Transport and Industry	Zero Carbon Certification Scheme (under development)
CA	Clean Fuel Standard[12]	Under development	Transport	CertifHy Canada (planned)
CH	MinöStG, MinöStV	Implemented	Transport	Principle of the Swiss gas industry relating to biogas and other renewable gases (gaz energie, 2020)
CN	Hydrogen Fuel Cell Vehicle (FCV) Technology Roadmap	Implemented	Energy industry	China Hydrogen Alliance's Standard
EU	RED II	Implemented (detailed definition[13] and national implementation pending)	Transport	Variety of private sector players in place or seeking recognition by EU: ISCC, RSB, CertifHy
JP	Strategic Roadmap for Hydrogen and Fuel Cells[14]	Implemented	Transport and Industry	Not foreseen
KR	Hydrogen Economy Promotion and Hydrogen Safety Management Act ("Hydrogen Act")[15]	Implemented	All (Transport and Industry)	Proposal of extension of the Renewable Portfolio Standards (RPS) and the Renewable Energy Certificate (REC) scheme
UK	UK Renewable Transport Fuel Obligation (RTFO)[16]	Implemented	Transport	Voluntary Schemes that cover GHG methodology according to RTFO
US/CA	Low Carbon Fuel Standard (LCFS)[17]	Implemented	Transport	30 accredited verification bodies[18] (e.g. Tetra Tech Inc., Trinity Consultants Inc.)

As depicted in the above table, the variety of proposals is large, but the standards are, so far, geographically limited and little concrete. That calls for the necessity for potential exporting countries to certify their products

[11] Australian Government (2019)
[12] Government of Canada (2021)
[13] Two delegated acts on Art. 27 and 28.
[14] Adelphi (2019)
[15] Azni & Md Khalid (2021); Velazquez, Abad & Dodds (2020)
[16] RTFO (2018)
[17] CARB (2018b)
[18] CARB (2021b), List of Accredited Verification Bodies as of 02-19-2021 – UPDATED.

according to several standards or a producer would have to decide on one customer region. This restriction means that producers need to decide at an early stage with what country they aim to trade the energy carrier volumes with, in order to demonstrate compliance with the respective renewable criteria. This entails limited flexibility as well as increased efforts and thus higher prices for the products and might create dependencies by limiting a few producers to certain regions. Therefore, it is necessary to open the discussion about harmonising the different systems. This paper enables market players to see where sustainability criteria of the different schemes share commonalities, and which criteria divert from one another and could be certified at a later stage as an "add-on".

When the paper refers to *sustainability criteria*, it is referring to the totality of all criteria related to renewable hydrogen, such as renewable electricity consumption, tracking models, GHG emissions, eligible carbon sources, land use change, water consumption, and social impacts.

Further publications that compare hydrogen standards were published by BEIS, Velazquez, Abad and Dodd (2020), Azni and Md Khalid (2021) as well as Adelphi (2019).

In the last chapter of the paper a plant concept is presented, that complies with all eleven standards/regulatory frameworks (Table 1) for renewable hydrogen, which have been assessed.

2 Requirements for Green Hydrogen

Requirements for green hydrogen and its derivatives are dependent on the regulatory framework. However, the definitions elaborated in these regulatory frameworks may differ not only between countries but also between application sectors. The hydrogen strategy and roadmaps often give a first impression of how governments set the terms and requirements in the field of renewable hydrogen.

Australia

The Australian government adopted a national hydrogen strategy in November 2019. This provides for various parameters to ensure the success of the strategy. The strategy aims to establish a certification system that is internationally recognised and ensures that the carbon intensity of Australian hydrogen production decreases over time. Furthermore, the strategy will only be considered a success if water use in hydrogen production has improved and the safety track record is excellent (Australian Government, 2019). The Australian government focuses more on coal and gas based production pathways than renewable ones (KAS, 2022). The government does not yet have any regulation for the certification and recognition of renewable hydrogen in place. The Department of Industry, Science, Energy and Resources has developed a proposal in cooperation with the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). The consultation phase on this proposal ended in August 2021 (Australian government, 2021). For the time being, the proposal provides for a well-to-gate approach to calculate emissions and discusses the question of accounting for captured emissions. The trial phase of such a scheme has already started (Minister for industry, 2021). To implement a GO scheme with a central registry on the federal level, either new legislation could be passed or integration into the National Greenhouse and Energy Reporting (NGER) Act could be sought. The Clean Energy Regulator would be in charge of collecting, analysing and using the information about producer and consumer. The Department of Industry, Science, Energy and Resources proposes that Large-scale Generation Certificates (LGC) could be used to track and verify renewable electricity claims of hydrogen producers.
The industry-led initiative Smart Energy Council launched its Zero Carbon Certification Scheme in December 2020 (KAS, 2022). Among the founding partners are four regional governments. The focus is on renewable hydrogen, renewable ammonia, and on renewable metals produced in Australia, where renewable hydrogen is used in production (Smart Energy Council, 2020). The first pilot certification was conducted on a hydrogen refuelling station in March 2021 (KAS, 2022).

Canada

In 2020, Canada released its National Hydrogen Strategy, and is currently developing a Clean Fuel Standard. The standard covers biofuels and hydrogen. It sets a net-zero emission target by 2050 and aims to develop a lifecycle approach regarding its GHG methodology. Furthermore, it points to establish a credit market for fuels with low carbon intensity. The CertifHy Canada Scheme is currently under development and aims to mirror the requirements of the Clean Fuel Standard (Government of Canada, 2021). The Bureau de normalisation du Québec (BNQ) is also currently working on a national standard on the traceability of renewable hydrogen. This project will measure the environmental impact of the energy source and the hydrogen production process overall.

China

In 2016, China released its first Hydrogen Fuel Cell Vehicle (FCV) Technology Roadmap with the aim to have 5,000 FCVs and 100 hydrogen refuelling stations by 2020 (ISPI, 2021). In 2021, China has released a China Hydrogen Alliance's Standard, which distinguishes between low-carbon (14.51 kgCO_{2e}/kgH2), clean and renewable hydrogen (4.9 kgCO_{2e}/kgH2) (China Electricity Council, 2021).

European Union

The European Union released its "**Hydrogen strategy** for a climate-neutral Europe" on June 2020. The European Hydrogen Strategy aims to decarbonise hydrogen production and widen its application onto sectors in which it substitutes fossil fuels. It focuses on renewable hydrogen and is the first step towards a regulatory framework for the respective energy carrier in the EU. It voices that life cycle GHG emissions should be close to zero. Hydrogen is regarded as renewable, when it results from electrolysis, renewable sources and reforming of biogas or biochemical conversion of biomass, as long as it complies with sustainability requirements. The EU **Taxonomy** regulation for assessing whether an economic activity contributes to the climate goals mentions explicit emission reduction targets for hydrogen production.

In the EU, the **Renewable Energy Directive II (RED II)** [19] is the only regulation so far, which sets criteria for the production and use of renewable hydrogen[20]. RED II promotes the use of renewable energy sources in the transport sector. No regulations are currently available on sustainability requirements for hydrogen applications in the industry sector, which will change with the undergoing revision of the RED II.
Sustainability requirements were already made mandatory for biofuels under RED I and have been continuously developed to ensure the protection of land and biodiversity and to document target compliance for renewable biofuels in the transport sector. RED II also includes RFNBOs as an option for meeting the renewable energy targets in the transport sector.

RED II Art. 27 defines rules for renewable electricity production for the transport sector. It covers "Rules for counting electricity sourced from directly connected installations as fully renewable" as well as "Rules for counting electricity taken from the grid as fully renewable". The Commission in its proposal aims to introduce PPAs -as a bilateral contract- for the second option. The criteria for **renewable electricity consumption** of RFNBOs via the grid will be further refined by a **Delegated Act on Art 27**. The publication of this Delegated Act by the European Commission is still pending. This paper, however, considers the content of leaked draft documents.

A further **Delegated Act on RED II Art. 28** will outline the **methodology for assessing GHG emission savings** from RFNBOs, including sustainability criteria regarding eligible carbon sources for hydrocarbon powerfuels.
RED II contains the following sustainability requirements for renewable hydrogen: renewable electricity criteria (Art. 27), mass balancing of the produced volumes along the value chain (Art. 30), and information on received state aid (Art. 30) (for more detail see chapter 4). Mass balancing is also an essential requirement in the *Implementing Act on rules on rules to verify sustainability and greenhouse gas emissions saving criteria and low indirect land-use change-risk criteria.*

[19] Currently under revision.
[20] 'renewable hydrogen' is defined in RED II as hydrogen derived only from renewable energy sources other than biomass.

EXCURSUS: Germany's Funding Programme H2Global

H2Global is a funding concept to achieve the goals set out in the German National Hydrogen Strategy. The Federal Ministry of Finance is tasked with its implementation. The funding is intended for large-volume projects in third countries that intend to export the renewable hydrogen to Germany. Traded volumes should reach a level that makes hydrogen usage attractive. For this purpose, purchase contracts are auctioned abroad, which include a fixed quantity at fixed prices for 10 years (BMWi, 2021). Hydrogen volumes imported via and compliant with H2Global requirements are eligible for the EU-ETS. The concept was developed by the German Society for International Cooperation (GIZ) and is now being further developed by German Hydrogen and Fuel Cell Association (DWV). The funding programme follows a market-based approach through compensation of differential costs between purchase and sales price (Contracts for Difference). Maximum amount of funding is €15 million per applicant and project. Detailed funding guidelines are yet to be published.

Funding requirements

- Permanent establishment or branch in Germany at the time of payment of the grant
- Country of implementation: States outside the EU and EFTA
- Obligation to operate: Systems must be operated for at least 3 years after commissioning
- Project implementation not possible without funding
- Proof of the pre-development status of the project (e.g. preliminary studies, availability of land in the country of implementation of the project, permits)

The preliminary sustainability criteria cover the renewable electricity criteria, similar to RED II, eligible carbon sources, GHG performance, water consumption, compliance with land use requirements, land use change and forestry (LULUFC), and local labour standards based on the ILO standards (for more detail see chapter 4) (Altrock, 2021).

Japan

Japan aims to be carbon-neutral by 2050 (KAS, 2022). The Japanese government has granted hydrogen and fuel cells a central role in its fourth Strategic Energy Plan. In 2018 the fifth Strategic Energy Plan was released which focuses on mobility and the power sector (Adelphi, 2019). The detailed roadmap of hydrogen expansion is laid out in the **Basic Hydrogen Strategy and the Strategic Roadmap** for Hydrogen and Fuel Cells. In 2019, Japan adopted its third Roadmap for Hydrogen and Fuel Cells. The strategy focuses on the reduction of production costs of fossil-based hydrogen as well as carbon capture and utilization (CCU) technologies. It also mentions the importance of GHG reductions along the hydrogen supply chain. Furthermore, the regulation sets a strong emphasis on hydrogen imports. For that reason, the roadmap entails the plan to establish a global hydrogen supply chain and foster international partnerships (New Zealand Embassy, 2020). So far, there is no clear definition of the term "clean hydrogen" which is why it covers hydrogen produced from fossil sources and nuclear sources in combination with renewable sources and CCS. A government committee discussed the need for standards and a certification scheme, but up to now, there are no further developments known on this matter. However, on a regional level the Aichi Prefecture has established a certification scheme for CO_2-free hydrogen in 2018. The Aichi Prefecture is also where the headquarter of Toyota is located. Toyota aims to be carbon neutral by 2050. The scheme defines renewable hydrogen as hydrogen from water electrolysis using renewable electricity sources or from steam-reforming using biomass (Adelphi, 2019). Five projects have already been certified by the Aichi scheme, of which four are projects undertaken by Toyota (KAS, 2022). Japan has also a carbon credit scheme (J-Credit Scheme) in place in order to certify GHG reductions and removals (J-Credit Scheme, 2020).

Switzerland

The Swiss Federal Office for the Environment sets the standards for sustainable fuel production. The regulations in Switzerland are spread across various legislations, which are currently under revision, including a referendum on the reduction of GHG emissions on June 13, 2021.Produced hydrogen volumes must comply to the Mineral Oil Tax Act (MinöStG), the Mineral Oil Tax Regulation (MinöStV) and the UVEK (Federal Energy Department) Regulation concerning evidence of compliance with ecological requirements (BTrV) (gaz energie, 2020). Furthermore, gaz energie has also developed principles for the production of renewable gases, which are also accepted as voluntary standards by market players. One of those principles is to exclusively use renewable electricity and provide proof that the gas was actually fed into the gas grid. The competent authority for the sustainability certification of biofuel is the Swiss Federal Department for Environment, Transports, Energy and Telecommunications. The Swiss regulations require renewable input for renewable RFNBO production (MinöStG, Art. 2(3); MinöStV, Art. 19e). Hydrogen volumes placed on the market must be registered with the Clearing Center (MinöStV, Art. 45e).

South Korea

In 2019, South Korea has adopted a Hydrogen Roadmap for the transport and industry sector until 2030 (Azni & Md Khalid, 2021). The Roadmap proposes the extension of the Renewable Portfolio Standards (RPS) and the Renewable Energy Certificate (REC) scheme. The RPS requires energy producers to provide a certain percentage of their energy portfolio from renewable energy either by own renewable energy installations or the purchase of certificates (Velazquez Abad & Dodds, 2020). In February 2021, the **Hydrogen Economy Promotion** and **Hydrogen Safety Management Act** was implemented. Compared to the other regulatory frameworks in this paper, South Korea is the only studied country with a hydrogen-specific law in place. This act promotes producers through subsidies, loans and tax exemptions (Azni & Md Khalid, 2021). However, the law mainly focuses on safety and technology standards. It has been criticized that the law neglects the aspect of GHG emission reduction (Sun-Jae et al., 2020). Sun-Jae et al. (2020) also calls for a certification scheme.

United Kingdom

The **Renewable Transport Fuel Obligation (RTFO)** regulates the market for renewable fuels in the UK. It sets sustainability criteria for biofuels, hydrogen and RFNBOs supplied under the RTFO and provides guidance how to demonstrate compliance. The RTFO allows also for the case, if the fuel is partially produced by RE and partially by fossil-based electricity. It is defined part RFNBO and part fossil fuel. However, both consignments are assigned to the same GHG intensity. Detailed information on the sustainability criteria are laid out in the Carbon and Sustainability requirements (C & S requirements) of the RTFO (RTFO, 2018). Producers register with the UK Renewable Transport Fuel Obligation (RTFO) in order to be able to claim both, Renewable Transport Fuel Certificates (RTFC) and Greenhouse gas credits. The C & S requirements of the RTFO also provide a GHG emission methodology for the production and use of RFNBOs (see chapter 4.3). The UK is currently in the process of designing a low-carbon and renewable hydrogen standard, for which a first report with recommendations has recently been published. In the next step the results of the report will be discussed with stakeholder (BEIS, 2021).

United States - California

In 2006, California introduced the Senate Bill No. 1505 to promote hydrogen production from renewable sources. The California Air Resources Board (CARB) governs the Bill and sets the target to produce 33% of total hydrogen volumes from renewable sources. In 2018, California has adopted the Renewable Hydrogen Roadmap. California has one of the most advanced legal frameworks for hydrogen (Azni & Md Khalid, 2021). Since 2011, the State of California adopted the **Low Carbon Fuel Standard (LFCS)**, which aims to reduce GHG emissions. One LCFS credit – released through emission reduction, equals one Mt CO_{2equ}. In the LFCS, renewable hydrogen is defined as (Velazquez Abad & Dodds, 2020):

1. Hydrogen from electrolysis based on renewable energy
2. Catalytic cracking or steam methane reforming based on biomethane
3. Thermochemical conversion of biomass

Guidance for CCS projects is provided by the Carbon Capture and Sequestration Protocol under the LCFS, which provides information on the application and certification of the protocol as well as its monitoring. Thus, also DAC projects are eligible to receive LCFS credits (CARB, 2018b).
Hydrogen is currently an opt-in fuel in the Low Carbon Fuels Standard (LCFS) program, in which entities can volunteer to participate in the program to generate credits. There are currently three default categories where hydrogen can generate credits, for fuel reported in light-duty, heavy-duty, and forklifts (CARB, 2020).

3 Certification Governance

In order to demonstrate compliance with the sustainability requirements listed in chapter 2, certification is required. This chapter describes the certification structure in China, the EU, the UK and California regarding the application process, certification bodies and data handling.

3.1 China

For the China Hydrogen Alliance's Standard, the applicant has to submit a formal verification application form to the public service platform recognised by the national energy authority. A third party, recognised by the service platform, will conduct the on-site audit to prove the submitted documents in accordance to the standard. Certification is conducted annually. The producer has to inform the auditor, if the production process changes. It is then up to the auditor to decide, if additional audits are required (FuelCellChina, 2020).

3.2 European Union

To show compliance with the obligation regarding the usage of renewable fuels, the producer shall report the quantity of RFNBOs placed on the market and their associated greenhouse gas emissions towards the responsible authority. This can be done by Proofs of Sustainability (PoS), if a national registry is in place.

This is preceded by a chain of evidence starting with the purchase of electricity and ending with the consumption of the fuel. A comprehensive certification process has been established to ensure that sustainability is fully documented. An overview of the certification process in the EU is illustrated in Figure 1.

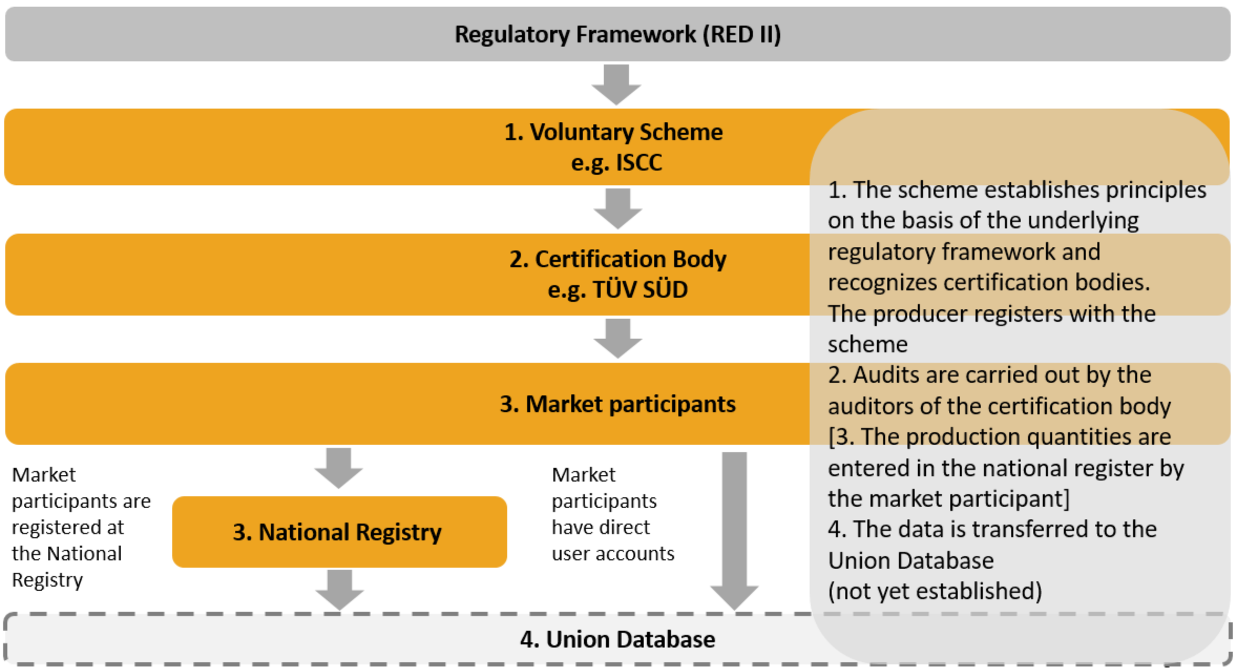


Figure 1: PoS certification process and linked competent bodies (modified from Sailer et al. (2021))

Voluntary Schemes

Voluntary Schemes help to ensure that the respective renewable fuel has been sustainably produced according to RED II. Currently, the recognized schemes mirror the criteria set in the RED. Some schemes also cover additional aspects such as soil, water and air protection as well as social criteria (Mai-Moulin et al., 2019). The schemes are either national schemes (e.g. in Italy) or privately owned. After the Delegated Acts regarding the renewable electricity criteria and the GHG methodology including carbon sources are released, certification schemes can seek recognition by the EC in order to certify powerfuels. Recognition for a Voluntary Scheme can last for a period of five years. Within the biofuel domain, there are currently 16 Voluntary Schemes recognized by the EC. Some of them are expected to widen their portfolio towards hydrogen and seek recognition by the EC for it, for instance ISCC. However, there will be also new players entering the field of certification (e.g. CertifHy, Zero Carbon Certification Scheme).

Certification Bodies

Certification Bodies are recognized under different Voluntary Schemes according to their portfolio and are responsible for conducting the respective audits. They audit the production installations and batches in regard to GHG emission reductions or, in the future, validate renewable electricity consumption via the public grid in the case of electricity-based gases.

National registries and their issuing bodies

Some countries have national registries, which issue PoS for biofuels. In Germany, the respective registry is Nabisy and in Austria it is elNA. In Germany, the responsible authority for PoS is the German Federal Agency for Agriculture and Food (BLE). However, not every member state has such a centralized registry in place.

Union Database

In order to prevent double/multiple counting (→ **Glossary**) of sustainability certificates, the RED II Art. 28 (2; 4) foresees a Union Database (UDB) on EU level. This will centrally store the respective certificates and their linked aggregated data for liquid and gaseous fuels that

(1) are eligible for being counted towards the national renewable energy transport targets (RED II, Art. 3), and

(2) fulfil the set sustainability and GHG reduction criteria.

The UDB aims to enhance transparency and traceability regarding PoS (Sailer et al., 2021). Guidehouse (2020) published a report on the scoping and specific technical requirements of such a database. The report diverts from RED II by not only offering the option for certificate storage, but also providing user accounts for producers who might not have a national registry in place (yet). This means that the UDB will not only be linked to national registries (e.g. Nabisy in Germany), but will also enable direct user accounts (see Figure 1).

During an interactive event stakeholder in April 2021 the Directorate-General for Energy (DG ENER) of the EC presented that the UDB will entail two different system boundaries depending on the level of fraud risk regarding the respective value chain:

1) **Low risk value chain**: Starting from the collection point/trader
2) **High risk value chain**: Starting from point of origin (farms, restaurants, etc.).

Furthermore, with the revision of RED II, the EC envisages to extend the sectoral scope of the UDB from transport further to the industry, power production as well as heating & cooling – excluding solid biomass fuels. The final implementation of the UDB is envisaged for December 2022 (EC, 2021).

3.3 United Kingdom

The UK Department for Transport (DfT) operates the RTFO Operating System (ROS). Fuel producers are obliged to report their fuel volumes and their sustainability performance in ROS, if they place at least 450,000 litres per year on the British market. Other suppliers can report their volumes in ROS on a voluntary basis. Suppliers with an obligation have to register for an account with the administrator. Once the data is complete, an independent third party according to the ISAE 3000 standard must verify it. For this purpose, Voluntary Schemes – recognized by the EC – can be used, e.g. ISCC and RED Tractor for biodiesel. For hydrogen, there are no Voluntary Schemes mentioned in the guidance documents of the RTFO yet. The DfT has requested ISCC to include the RFNBO requirements of RTFO within ISCC EU and provide guidance for the verification process. So far, it has not been taken up on. Once, the verification is conducted, the producer is responsible for submitting the application in the ROS. RTFCs are issued on a monthly cycle (RTFO, 2018).

3.4 United States – California

The California Air Resources Board (CARB) developed the LCFS Data Management System, which comprises of three modules:

- LCFS Reporting Tool (LRT)
- Credit Bank and Transfer System (CBTS)
- Alternative Fuel Portal (AFP).

The three modules have different functionalities and the AFP requires a separate account. If an entity seeks to be accepted under zero-CI electricity and hydrogen (section 95488.1(b)(2)(A) through (F)), it must register at the AFP. The AFP offers a fuel pathway certification application and evaluation process. The Californian Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (CA-GREET) model is used to calculate carbon intensities (CI). The process distinguishes between Lookup Table pathway, Tier 1 and Tier 2 pathway. The certification process of Tier 1 is designed as follows (CARB, 2021a):

1. Facility registration in AFP
2. Application submission to AFP
3. Validation performed by accredited verification bodies (CARB, 2021b)
4. Final evaluation through CARB staff
5. Certification
6. Verification through verification body.

The reporting takes place on a quarterly basis. Any pathways with biomethane attributes are required to be verified by an approved third-party verifier, while electricity attributes are verified by CARB staff.

The LCFS has 30 accredited verification bodies (e.g. Tetra Tech Inc., Trinity Consultants Inc.) in place, which conduct the audits (CARB, 2021b).

In principle, all three certification structures (EU, UK and USA/CA) are similar. The producers have to register their generated volumes in a registry and a third linked party audits the production installations and the production batches, based on which a competent body issues the PoS.

4 Verification process

As shown in the previous chapters, the requirements for the products are different. The following chapter elaborates on the different sustainability aspects of renewable hydrogen/RFNBO production covered in the different regulatory frameworks and standards. When the paper refers to *sustainability criteria*, it is referring to the totality of all criteria related to renewable hydrogen, such as renewable electricity consumption, tracking models, GHG emissions, eligible carbon sources, land use change, water consumption, and social impacts.

The relevant aspects are arranged along the energy carrier's value chain. First, the requirements for demonstrating use of sustainable electricity and models for tracking the product from production to end-use are explained, followed by the existing methodologies for calculating the greenhouse gas emissions saved as well as eligible carbon sources. Finally, criteria for water consumption, land use and social impacts are presented.

4.1 Renewable electricity consumption

In order to ensure that the electricity used to produce electrolysis-based hydrogen has itself been generated sustainably, very different requirements exist in the various laws and standards on hydrogen/RFNBOs (see Table 3). In RED II, for example, the EU places a strong focus on utilising additionally produced electricity capacities for the RFNBO production. In contrast, other regulatory frameworks – outside of the EU – focus more on the exclusive consumption of renewable electricity as an input.

Regarding the dena Biogasregister, as soon as the Delegated Acts will officially be published, the register will also cover the foreseen national adaption of subsequent ordinances of the Federal Immission Control Act (BImSCHG), as well as the criteria of the H2Global funding programme for international hydrogen projects.

TÜV Süd and CertifHy are awaiting the adoption of the Delegated Act specifying the EU's requirements for electricity sources to extend their sustainability criteria in respect to the RED II criteria as well.

Table 3: Requirements for sustainable electricity inputs for renewable hydrogen production

Regulation/standard	Renewable electricity criteria
CertifHy	- 100% renewable energy - Proof of GO cancellation must be provided in accordance with electricity volumes consumed. - Data field on received state aid in order to prove the additionality criterion (→ **Glossary**) according to RED II (CertifHy, 2019; Edel et al., 2021).
China Hydrogen Alliance's Standard[21]	- Renewable hydrogen is defined as hydrogen produced from wind, solar, hydro, biomass, geothermal and ocean energy
CH - MinöStG	- 100% renewable energy - Proof of GO cancellation must be provided in accordance with electricity volumes consumed (MinöStG, Art. 2(3); MinöStV, Art. 19e; Gaz energie, 2020).
dena Biogasregister	- 100% renewable energy; criteria # 44(b) (dena, 2021b) - Data field on received state aid is implemented

[21] FuelCellChina (2020)

H2Global[22]	This content will be guided by the Delegated Act on Art. 27 (see RED II)
Certification scheme of the Aichi Prefecture (Japan)	Renewable electricity or grid electricity accompanied by renewable electricity certificates. **Additionality**[23] - Renewable electricity installations that will be used for hydrogen production should be new or unused. - Existing renewable facilities can be included in the short-term.
LCFS	Plausibility check that renewable energy carrier input was sufficient for energy carrier output by utility receipts/invoices or metered data for off-grid electricity use.[24]
RED II[25]**, D.A. of Art. 27 as per leaked information**	**Renewability** The consumed electricity must be 100% renewable and proven by a Power Purchase Agreement (PPA). Direct connection + indirect connection (grid): Proof with smart meter that the hydrogen was solely produced through direct connection (→ Glossary). **Geographical correlation (→ Glossary)** The criteria for the geographical correlation between the electricity plants and the electrolyser is set at the same bidding zone or two different bidding zones, if they have the same electricity price on the day-ahead market + one hour correlation. **Additionality & System serviceability (→ Glossary)**[26] The renewable electricity must not be subsidised. Direct connection: New installations must be commissioned within a maximum of 12 months prior to the electrolyser or the electricity installation must be produced by an installation that has undergone major refurbishment[27]. Indirect connection (grid): **Option 1:** electricity installation was implemented max. 24 months prior to the electrolyser or must be produced by an installation that has undergone major refurbishment + the renewable electricity must not be subsidised, or **Option 2:** one hour correlation + proof that power-generating facilities were downward redispatched + both installations are located on the same side of the congestion causing the redispatch, or **Option 3:** one hour correlation + price of electricity in the bidding zone is lower or equal to 0€ per MWh.

[22] Altrock (2021). Nachweisanforderungen an grünen Wasserstoff. Presentation at the dena-Workshop "Wasserstoffzertifizierung – Anforderungen und Durchführung".
[23] Personal communication, The Institute of Energy Economics Japan & MITSUBISHI, 27.09.2021.
[24] Adelphi (2019)
[25] These criteria are not yet legally binding, but are currently under discussion.
[26] These criteria will only come into force from 2025.
[27] Major refurbishment is defined by a 30% investment of the costs for implementing a new plant.

	Temporal correlation (→ Glossary) **Option 1:** same calendar hour + PPA, or **Option 2:** same calendar hour + higher RE-share in the respective bidding zone compared to the bidding zone three years prior, or **Option 3:** same calendar hour + power-generating facilities using renewable energy sources were downward redispatched + located on the same side of the congestion causing the redispatch, or; **Option 4:** from a storage asset located behind the same grid connection point as the electrolyser that has been charged in during a calendar hour fulfilling the criteria in option 1, 2, or 3.
TÜV Süd CMS 70	**Input electricity** - 100% renewable electricity - Proof of GO cancellation must be provided in accordance with electricity volumes consumed. - The electricity has not received any state aid per produced kWh, except for national auctions according to RED II. **Temporal correlation**[28] **Option 1:** New installation - 30% of the electricity must be produced from new installations with an operational date of max. 36 ahead of the first certificate. - Installation should be max. 10 years old. **Option 2:** Fund model - Certification holders or electricity suppliers pay at least 0.2 ct/kWh into a fund that promotes projects with the aim to expand renewable energies. **Option 3:** Technology mix Minimum shares for accounting year: o Hydropower < 2MW: 15%, or o Wind: 30%, or o Solar-PV, geothermal, biomass, biogas/biomethane, <2 MW_{el}: 5% - Operational date must be after the 01.01.2000 - A mix from the above mentioned technology is possible, considering their weighting. - For biomethane used for heating GOs need to be provided.
UK RTFO	- Renewable energy, excluding bioenergy - Proof that no electricity was imported from the wider grid. The fuel plant must be either: o Directly connected to the electricity plant

[28] Upcoming release scheduled for August/September will implement temporal correlation on monthly base. If hourly temporal correlation is fulfilled then percentages of option 1 and option 3 are reduced to 50% each.

	o Directly connected to the electricity plant, which is also connected to the grid - Additionality (BEIS, 2021): o Actual data such as records of historical generation from the electricity plant o (where applicable), planning proposals for new sites that will be constructed at the same time or after the hydrogen plant o (where applicable), or evidence of curtailment. RFNBOs are exempt from land use criteria.
Zero Carbon Certification Scheme[29]	- 100% renewable energy - PPA

4.2 Tracking models

For renewable electricity, many functioning systems worldwide for tracking the origin or sustainability of the product already exist. In contrast to electricity, hydrogen and its derivatives are molecules, which can have different physical properties depending on the manufacturing process or similar. To trace the chain of custody two approaches were identified among the assessed hydrogen regulations/standards: mass balancing and Book & Claim.

Book & Claim

In the case of Book & Claim, the physical delivery of the energy carrier and the issuance of the respective certificate are not linked to each other (dena, 2021a). Book & Claim is therefore a mechanism of pure certificate trading. The certificates represent a precisely determinable quantity of sustainable hydrogen that is produced, but not physically traded as certified goods. Similar to renewable electricity, a tradable certificate is issued to the producers, which can be auctioned by the manufacturers of end-products via a bidding process (FONAP, 2021). GO schemes under RED II Art. 19 follow the Book & Claim principle.

A Book & Claim principle would allow certificates to be traded separately from the physical product, thus paving the way for more flexibility. This aspect is relevant against the background that any trading restrictions in form of physical transport obligations between individual countries may lead to the creation of separate national and less liquid markets for renewable and low-carbon gases, which would then have the potential to further split the market into small submarkets for e.g. renewable hydrogen, low-carbon and other kind of renewable gases.

Mass balancing

The mass balancing approach links the certificate with the respective physical delivery of the energy carrier. Sustainability certificates are traded via mass balancing, so that a physical delivery of an energy carrier goes hand in hand with the certificate. Within the framework of the mass balance, an exchange of qualitative properties is possible via the PoS. In addition, the renewable energy carrier can still be traced if it is mixed with fossil

[29] KAS (2022)

energy carriers. The mass balance primarily serves the purpose of tracing a renewable energy carrier from its use to its production. Thus, a physical link is established throughout the value chain. There are, however, different views regarding the delivery form in a mass balance system. The use of the natural gas grid, into which hydrogen can be fed but not withdrawn in its pure form, would only be possible if the definition of renewable hydrogen refers only to the energy content.

In the dena Biogasregister, mass balancing of hydrogen starts at the electrolyser and ends at the end consumer. However, the consumed renewable electricity is traced as well, but the electricity plant is not registered in the system.

Requirements for mass balancing of hydrogen are the following (Sailer et al., 2021):

- Supply contract for renewable hydrogen and meter data must be provided along the entire chain of custody.
- The delivery has been documented in a mass balance system (e.g. dena Biogasregister).
- Gaseous RFNBO: Documentation of interface point (injection and extraction meter points).
- Liquid RFNBO: Delivery notes from transport companies.

In case of multiple outputs, the produced hydrogen volume is distributed among the outputs by percentage basis or attribution. An example for multiple outputs would be to produce multiple end-products from the renewable hydrogen e.g. e-methanol for the transport sector and green metal for the industry.

Table 4: Tracking models for tracing renewable properties along the hydrogen/RFNBO value chain

Regulation/standard	Tracking model
CertifHy	Book & Claim (Edel et al., 2021)
CH - MinöStG	Mass balancing
Dena Biogasregister	Book & Claim and Mass balancing from the electrolyser until it is fed into the natural gas grid (criteria 27(b))
Certification Scheme (Japan)	Mass balancing[30][31]
LCFS	Book & Claim[32]
RED II	Mass balancing (Art. 30)
RTFO	Mass balancing
TÜV Süd CMS 70	Book & Claim and Mass balancing
UK RTFO	Mass balancing
Zero Carbon Certification Scheme	Book & Claim

[30] Personal communication, The Institute of Energy Economics Japan & MITSUBISHI, 27.09.2021
[31] CARB (2019b)
[32] CARB (2019a)

4.3 GHG emissions

According to the EU REGATRACE project[33], the main drivers of the GHG performance of hydrogen generated from electrolysis are the emissions from the electricity production and the emissions caused by the electrolyser itself (Majer et al., 2021). Wulf et al. (2018) conclude that in case of distribution by pressure tank on a truck, truck driving has the largest share of emissions, while in case of pipeline transport, the electricity used for the electrolysis has the strongest influence. In contrast to hydrogen, the production of other RFNBO such as Power-to-Liquid (PtL) jet fuel requires additional process steps. Further processing with carbon sources as well as conditioning have a significant impact on the GHG emissions results. The same applies to the different transport and distribution modes or retail options depending on the end use.

To ensure creditability, renewable hydrogen producers are obliged to provide a GHG calculation of their production volumes in accordance to the respective regulatory requirements (chapter 2). During the audit of the production batch, the GHG calculation is checked for accuracy and plausibility.

The UK RTFO, CertifHy and TÜV Süd CMS 70 already have a GHG calculation methodology in place. The methodology must comply with the requirements of ISO 14040, 14044 (Life-cycle assessment) or 14067 (Product carbon footprint).

It is foreseen that the EC will publish a Delegated Act in 2022, which further specifies the GHG methodology for RFNBOs and how to account for different carbon sources. Either the individual values of such a methodology are calculated individually or one falls back on default values, which mostly amount to an average value for this kind of value chain step. Regarding biofuels, RED II offers the possibility for an individual, manual calculation as well as a calculation according to default values, which are published by the Joint Research Centre (JRC). It can be assumed, that the EC will also provide these two options for RFNBOs.

GHG reduction targets

The different regulations and standards have different GHG reduction targets and reference baselines in place as shown in Table. The TÜV Süd standard's GHG targets distinguish between sectors and installations implemented before 2016 and after. RTFO does the same for installations before and after 2015.

Table 5: GHG emission reduction targets of hydrogen/RFNBOs according to different regulatory frameworks and standards

Regulation/ standard	Sector	H_2 type	Reduction target	Reference Baseline	Threshold
CertifHy	Transport	H_2 from renewable sources	60%[34]	91 gCO_{2equ}/MJ	36.4 gCO_{2equ}/MJ

[33] The EU REGATRACE project is funded under Horizon2020. REGATRACE (Renewable GAs TRAde Centre in Europe) aims to create an efficient trade system based on issuing and trading renewable gases Guarantees of Origin (GoO). https://www.regatrace.eu/.
[34] Will be updated to 70% with the delegated act (BEIS, 2021).

China Hydrogen Alliance's Standard[35]	-	Low-carbon hydrogen	-	-	14.51 gCO_{2equ}/kgH_2
	-	Clean and renewable hydrogen	-	-	4.9 gCO_{2equ}/kgH_2
LCFS	Transport	H_2 from electrolysis, and bio-based H_2	20%	94 gCO_{2equ}/MJ	76.1 gCO_{2equ}/MJ[36]
RED II	Transport	H_2 from renewable sources	70%	94 gCO_{2equ}/MJ	28.2 gCO_{2equ}/MJ
RTFO	Transport	H_2 (excl. biomass)	60%	83.8 gCO_{2equ}/MJ (petrol + diesel)[37]	33.52 gCO_{2equ}/MJ
TÜV Süd CMS 70[38]	Transport	H_2 (excl. electrolysis)	60%	Fossil fuel 94 gCO_{2equ}/MJ	37.6 gCO_{2equ}/MJ
	All, except transport	H_2 (excl. electrolysis)	60%	Grey hydrogen 89,7 gCO_{2equ}/MJ	35.9 gCO_{2equ}/MJ
	All	H_2 from electrolysis	75%	Fossil fuel/grey hydrogen (depending on application)	23.5 gCO_{2equ}/MJ - 22.42 gCO_{2equ}/MJ

System boundaries

The different regulations listed in chapter 2 as well as the Voluntary Schemes and Certification bodies in chapter 3 have different carbon accounting boundaries in place. This makes their comparability very challenging. The RED II methodology, the Swiss MinöStV, RTFO, California LCFS, and TÜV Süd CMS 70 cover the system

[35] BEIS (2021)
[36] Velazquez Abad & Dodds (2020). Green hydrogen characterisation initiatives: Definitions, standards, guarantees of origin, and challenges. Energy Policy. DOI: 10.1016/j.enpol.2020.111300.
[37] Requirements of RED I (2009).
[38] The updated version of the standard (2021) will remove the differentiation of the application or production and introduce a uniform threshold value of 70% in relation to the fossil reference value of 94 gCO_{2equ}/MJ. Transitional regulations for old plants will be added (TÜV Süd, personnel correspondents, 2021)

boundaries from the electricity input to hydrogen usage (Well-to-Wheel). Dena Biogasregister, CertifHy and Zero Carbon Certification Scheme cover GHG system boundaries from Well-to-Gate.

In comparison to Life-Cycle-Assessment approaches, there is no scheme worldwide to date that accounts for the embedded emissions in CAPEX (e.g. building material of electrolyser) or the end of life phase – although it has been proven that emissions from the actual construction of hydrogen infrastructure such as the electrolyser can be significant (Majer et al., 2021).

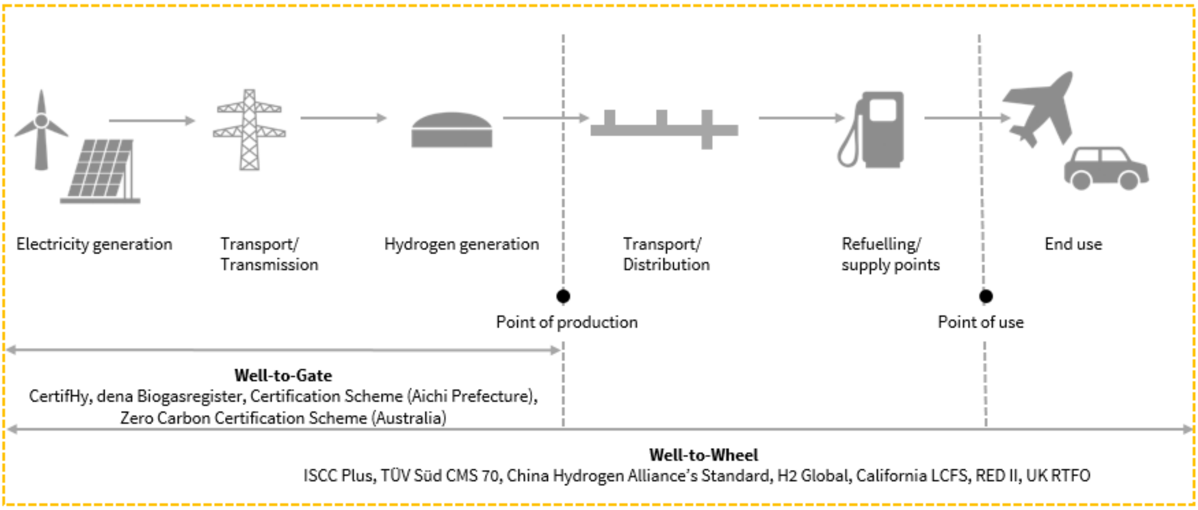


Figure 2: Carbon accounting system boundaries

Another similar approach of the existing certification schemes, such as the California LCFS or CertifHy is to divide the value chain into different life cycle stages: (1) emissions before the point of production, (2) between production and point of use, and (3) the end use and end of life phase.

GHG emission calculation methodology

The UK RTFO is the only regulation, which offers a methodology for calculating the GHG performance of RFNBOs (see Equation 1). According to the UK RTFO GHG methodology for RFNBOs, the electricity gets the GHG value assigned, which is equal to the GHG intensity of the average electricity production and distribution of the respective country measured two years prior to the year in question. The emissions associated with the fuel in use for renewable liquid and gaseous transport fuels of non-biological origin can be assigned to a value of 0 gCO_{2equ}/MJ (RTFO, 2018). The LCFS published carbon intensity default values for six different hydrogen pathways (see Table F.3 (CARB, 2018a)).

Equation 1: GHG emission methodology for the production and use of RFNBOs according to the C & S requirements of the UK RTFO

$$E = e_{ec} + e_p + e_{td} + e_u - e_{ccs} - e_{ee}$$

E	=	total emissions from the use of the fuel;
e_{ec}	=	emissions from the extraction or collection of raw materials;
e_p	=	emissions from processing;
e_{td}	=	emissions from transport and distribution;
e_u	=	emissions from the fuel in use;
e_{ccs}	=	emissions savings from carbon capture and geological storage;
e_{ee}	=	emissions savings from excess electricity from cogeneration.

4.4 Eligible carbon sources

Three different types of carbon sources could be utilised for powerfuels production: **fossil-based carbon, biogenic carbon**, and **atmospheric carbon**. Fossil-based carbon originates from industrial CO_2 point sources such as a coal plant. Biogenic carbon is released from biomass through fermentation, combustion, decomposition or processing. Atmospheric carbon is harnessed via Direct Air Capture (DAC) technologies (Global Alliance Powerfuels, 2020). In the UK RTFO, instead of atmospheric carbon, the term of **naturally occurring carbon** was introduced which contains atmospheric as well as geothermal carbon.

The main challenge with regard to the certification of RFNBOs is that it is not clear, yet, which carbon sources will be eligible for RFNBOs and how the different sources should be accounted for in the GHG calculation methodology in order to ensure an attractive business case for all actors involved in CCU (Sailer et al., 2021). CCS is commonly applied in standards, whereas there are yet no harmonised or consistent rules for CCU in place (BEIS, 2021; DG ENER, 2020; Sailer et al., 2021). TÜV Süd and LCFS do currently not allow for CCU, and RED II and RTFO only allow for biogenic CCU. LCFS even accounts for avoided landfilling benefits (BEIS, 2021).

In the EU, a Delegated Act of RED II should provide more clarity on this matter. So far, the EC in its proposal for the revision of the EU Emission Trading System has already proposed that the emitter should be treated unchanged, while the conversion plant gets the carbon reduction credited. The emissions associated with the carbon capture should be assigned to the conversion plant, except the carbon would have been captured anyway to obtain a marketable product (DG ENER, 2020; Sailer et al., 2021).

The Californian LCFS has a methodology for greenhouse gas emissions reductions calculation in place:

$$GHG_{reduction} = CO_{2\,injection} - GHG_{project}$$

Table 6: Eligible carbon sources and their associated sustainability criteria in different regulations and standards

Regulation/standard	Eligible Carbon sources	Criteria
dena Biogasregister	All	No deliberate production of CO_2; criteria 46(b) (dena, 2021b)
H2Global[39]	All	No deliberate production of CO_2; accounting obligation for fossil-based carbon
Low Carbon Fuel Standard (LCFS)[40]	**CO_2 emissions from venting**, incl. biogenic carbon and carbon from DAC **Fugitive CO_2 emissions** from surface equipment, incl. biogenic carbon and carbon from DAC	Methodology for GHG emissions reductions calculation for CCS projects in place Mass balancing of carbon if It comes from several sources
UK RTFO	All	Carbon must not be deliberately produced. **Biogenic carbon:** proof that the GHG reduction was not credited in the bioenergy supply chain already (double claim) and would otherwise have been emitted to the atmosphere **Naturally occurring/geothermal carbon:** proof that these emissions have not been increased by the extraction of the carbon
Zero Carbon Certification Scheme	All	-

4.5 Land use change

Land use change criteria are already implemented in RED II for biofuels, not for powerfuels. Only H2Global, ISCC PLUS, and LCFS address land use criteria for powerfuels. However, it can be expected that the criteria to mitigate ILUC-risk in the biofuel sector will simply be transferred to powerfuels and biogenic carbon sources. BEIS (2021) recommends to include emissions related to ILUC into the UK low carbon hydrogen standard.

[39] Altrock (2021). Nachweisanforderungen an grünen Wasserstoff. Presentation at the dena-Workshop "Wasserstoffzertifizierung – Anforderungen und Durchführung".
[40] CARB (2018). Carbon Capture and Sequestration Protocol under the Low Carbon Fuel Standard.

Table 7: Land use change in different regulations and standards

Regulation/standard	Land use change
H2Global	Compliance with land use requirements, land use change and forestry (LULUFC)
ISCC PLUS	Protection of biodiverse and carbon rich areas Good agricultural practice
LCFS	Land use change emissions are considered

4.6 Water consumption

Water consumption is only mentioned implicitly in RED II and H2Global funding requirements. Both aim to avoid excessive water use. However, ISCC considers it within its GHG methodology, in which water from a desalination plant has 44 times higher GHG emissions than European tab water (filtrated, disinfected).[41] Considering the total GHG emissions of renewable hydrogen (26 g CO_2/kWh (Greenpeace Energy, 2020), the emissions associated with water are negligible. Water consumption should be prioritised not according to its GHG value, but with reference to its sustainable use. The LCFS provides a detailed list of an ex-ante hydrological on-site evaluation, which needs to be conducted before the CCS project is implemented. Among others, geologic and topographic maps as well as information on local basins, freshwater aquifers, water wells, and springs must be provided (CARB, 2018). The research institute Fraunhofer IEE developed an atlas for PtX potential[42] in the form of a web-based GIS tool. In this spatial analysis, regions with high water stress were excluded from the regions with potential for PtX production. The underlying data are based on the Aqueduct Global Maps by the World Resources Institute (Fraunhofer IEE, 2021). Such tools facilitate the identification of suitable locations of electrolysers and prevent negative environmental impacts.

Table 8: Water consumption criteria for hydrogen/RFNBOs

Regulation/standard	Water consumption criteria
H2Global	Sustainability of water consumption, including water competition (Altrock, 2021).
ISCC PLUS	Water is considered through the good agricultural practice and the GHG methodology. European tap water (filtrated, disinfected) has an assigned GHG value of 0.00013 CO_{2equ}/kg water and tap water from desalination plants have a GHG value of 0.0057 CO_{2equ}/kg water (ISCC, 2021).
LCFS	Ex-ante evaluation of the hydrological sequestration zone in regard to e.g. freshwater aquifers, water wells, springs etc. (CARB, 2018b).
RED II	Water protection and avoidance of excessive water consumption (RED II Art. 30 (4)).
Zero Carbon Certification Scheme	Approval for connection by the local water supply authority. Compliance with acceptable international water NGO principles for equal water access.

[41] European tab water (filtrated, disinfected) has an assigned GHG value of 0.00013 CO_{2equ}/kg water and tab water from desalination plants have a GHG value of 0.0057 CO2equ/kg water (ISCC, 2021).

[42] PtX-Atlas. https://maps.iee.fraunhofer.de/ptx-atlas/

4.7 Social impact

In the EU, criteria covering the social impact are only implemented on a voluntary basis among Voluntary Schemes (e.g. ISCC, RSB). Common social criteria among the Voluntary Schemes are e.g. safe working conditions, compliance with human, labour and land rights, compliance with local laws and international treaties etc. To what extend those social criteria are harmonised among different Voluntary Schemes has been assessed by Mai-Moulin (2019). The harmonisation for “worker rights” among the Voluntary Schemes was assessed as high, whereas “human health impacts” and “compliance with local law rights & international treaties” were only harmonised on a medium level (Mai-Moulin et al., 2019). It can be expected that the social impact criteria – where they are already in place, e.g. within Voluntary Schemes or the UK RTFO, – will be transferred to powerfuels as well.

Table 9: Social impact criteria in different regulations and standards

Regulation/standard	Social impact criteria
H2Global	Local labour standards must at least meet the relevant ILO standards
ISCC PLUS	Safe working conditions Compliance with human, labour and land rights Compliance with laws and international treaties Good management practices and continuous improvement
LCFS	Evaluation of social risk is required, based on the World Justice Project Rule of Law Index

5 Outlook on international certification

After examining existing standards and regulatory frameworks for renewable hydrogen, it becomes apparent that there are very different approaches in different regions of the world. The systems often agree on the essential points, however. With regard to the regulatory framework, the Californian LCFS, the European RED II and the UK RTFO, are the most advanced. The following section looks at commonalities of the analysed systems and identifies where they deviate from one another. It determines challenges that remain to be solved in the implementation of global hydrogen trade.

5.1 Harmonisation possibilities of sustainability criteria

In order to be able to make a statement about how flexible renewable hydrogen quantities can be used within international trade and under fluctuating prices, the different sustainability requirements have to be compared and possibilities for harmonisation identified (Table 10). The most harmonised sustainability requirements are the use of renewable electricity inputs, mass balancing as the tracking model, GHG performance as well as the use of all carbon sources – as long as they are not deliberately produced for the synthetic fuel production.

The sustainable electricity criteria foreseen by RED II (additionality, temporal and geographical correlation) aim to reserve renewable electricity volumes for the electricity sector. CertifHy, the dena Biogasregister, as well as TÜV Süd will implement those criteria once they are implemented within national legislations. Water has been mentioned in H2Global, LCFS and RED II as a good that must be protected, but no specific sustainability criteria regarding water consumption has been formulated.

It is important to note, that production batches outside the geographical scope of the relevant regulatory standard must still comply with the prevailing criteria when imported into that specific territory. For example, renewable hydrogen from Chile must meet the RED II requirements to be able to enjoy state benefits and count towards the transport targets when imported to the EU.

Table 10: Harmonisation options of sustainability criteria in different regulations/standards for hydrogen/RFNBO (1/3)

Sustainability criteria for hydrogen/ RFNBOs	Schemes							Funding Programme	Regulations		
Regulation/ standard	**ISCC PLUS**	**CertifHy**	**dena Biogasregister**	**TÜV Süd CMS 70**	**China Hydrogen Alliance's Standard**[41]	**Certification Scheme (Japan)**[42 43]	**Zero Carbon Certification Scheme**	**H2Global**	**LCFS**	**RED II**	**RTFO**
Market	**EU**	**EU**	**DE**	**DE**	**CN**	**JP**	**AU**	**DE**	**US/CA**	**EU**	**UK**
Purpose	v	v	r	v	n/a	v	v	r	r	r	r
Renewable electricity											
Renewability	+	+	+	+	+	+	+	+	+	+	+
Additionality	tbu	tbu	tbu	+	-	+	-	+	-	+	+
Temporal correlation	tbu	tbu	tbu	tbu[44]	-	n/a	-	+	-	+	-
Geographical correlation	tbu	tbu	tbu	tbu	-	n/a	-	tbu	-	+	-
Tracking models	MB	B&C	MB	MB; B&C	n/a	B&C	MB	MB	B&C[45]	MB	MB

[43] FuelCellChina (2020)
[44] The scheme operates on a regional level in the Aichi Prefecture (Adelphi, 2019).
[45] Personal communication with MITSUBISHI Japan, 24.09.2021.
[46] Upcoming with the new update
[47] BEIS (2021)

Table 10: Harmonisation options of sustainability criteria in different regulations/standards for hydrogen/RFNBO (2/3)

Regulation/ standard	ISCC PLUS	CertifHy	dena Biogas-register	TÜV Süd CMS 70	China Hy-drogen Alli-ance's Standard[46]	Certifica-tion Scheme (Japan)[47 48]	Zero Car-bon Certifi-cation Scheme	H2Global	LCFS	RED II	RTFO
GHG emissions	Well-to-Wheel	Well-to-Gate	According to demand	Well-to-Wheel	Well-to-Wheel	Well-to-Gate	Well-to-Gate	Well-to-Wheel	Well-to-Wheel	Well-to-Wheel	Well-to-Wheel[49]
Eligible carbon sources											
Fossil-based car-bon	+	tbu	+	Out of Scope	Out of Scope	n/a	+	+	+	Pending Delegated Act	+
Biogenic carbon	+	tbu	+	Out of Scope	Out of Scope	n/a	+	+	+	Pending Delegated Act	+
Carbon from DAC	-	tbu	+	Out of Scope	Out of Scope	n/a	+	tbu	+	Pending Delegated Act	+
Additional criteria											
Land use	+	-	-	-	-	-	-	+	+	-	-[50]
Water consumption	+/-	-	-	-	-	-	+/-	+/-	+/-	+/-	-

[48] FuelCellChina (2020)
[49] The scheme operates on a regional level in the Aichi Prefecture (Adelphi, 2019).
[50] Personal communication with MITSUBISHI Japan, 24.09.2021.
[51] BEIS (2021) discusses cradle-to-gate.
[52] It is currently discussed to implement emissions resulting from iLUC in the methodology to calculate GHG emissions for RFNBOS within the UK low carbon hydrogen standard (BEIS, 2021).

Table 10: Harmonisation options of sustainability criteria in different regulations/standards for hydrogen/RFNBO (3/3)

Regulation/ standard	ISCC PLUS	CertifHy	dena Biogas-register	TÜV Süd CMS 70	China Hy-drogen Al-liance's Standard[51]	Certifica-tion Scheme (Japan)[52 53]	Zero Car-bon Certifi-cation Scheme	H2Global	LCFS	RED II	RTFO
Social impact	+	-	-	-	-	-	-	+	+	-	-

Map legend	
+	Criteria is covered
-	Criteria is not covered
+/-	The topic is mentioned, but no actual criteria is implemented
n/a	No information available, if the respective criteria is covered in the standard/regulation
tbu	to be updated
v	voluntary
r	is based on the national framework in order to get state benefits granted

[53] FuelCellChina (2020)
[54] The scheme operates on a regional level in the Aichi Prefecture (Adelphi, 2019).
[55] Personal communication with MITSUBISHI Japan, 24.09.2021.

5.2 Challenges for global harmonisation

For an all-encompassing global certification system, the requirements placed on the products would have to be harmonised. This concerns in particular the definition of renewable electricity and the definition of the system boundaries for the GHG calculation, as illustrated in Table 10. But is such a system desirable? What advantages or disadvantages would it bring? For instance, would European market players and policy makers be willing to abandon the criteria which are meant to reserve the electricity first and foremost for the renewable electricity sector (additionality, temporal and geographical correlation) for the sake of having a globally harmonised certification scheme? For some regulations/standards, agreeing on the lowest common denominator would mean abandoning elaborate and ambitious requirements.

On a different note, when new structures are created or new issuing bodies are assigned, it also offers opportunities to rethink the system from the ground up, bypassing the mistakes of past systems from the start. Table 10 gives an overview of existing renewable hydrogen regulations and standards.

In the case of global trade and the transfer of hydrogen quantities (or its derivatives) from one certification system to another, it must be ensured that the quantities in the sending register are cancelled, so that **double/multiple counting (→ Glossary)** does not occur.

For many of the illustrated challenges solutions are already available. They would only need to be coordinated and implemented. The differences in the **system boundaries of GHG calculation methodologies** could be overcome by setting up a modular system, for instance. The National University Australia, for example, proposes that each actor along the supply chain should take responsibility for the certification of its share. An added benefit of this approach would be that the party responsible for procuring the certification also has decision-making authority over that part of the supply chain. For example, a renewable hydrogen producer could certify the production and conversion modules. The producer sells hydrogen to an exporter, who would have additional responsibility for certifying the transport stage. This allows different national requirements for system boundaries to be covered, as standards may differ (White et al., 2021). For that, a common **definition for renewable electricity** is unavoidable.

A modular approach could also introduce different classes depending on the GHG emissions of the electricity sources, so that the certification of other products such as low-carbon hydrogen would also be possible. However, mixing of certifications within one production unit must be avoided at all times. It must also be ensured that the accountability on transport targets (RED II, Art. 25) is maintained in order to benefit from state aid.

The physical traceability through **mass balancing** seems to benefit from a common agreement among the majority of the assessed regulations and standards. CertifHy has a Book & Claim system in place since it complies with Art. 19 RED II referring to GOs, not PoS. Nevertheless, a Book & Claim system would also have its advantages, especially in the ramp-up phase for hydrogen. It allows certificates to be traded separately from the physical product, thus allowing for more flexibility for producers as well as customers, increasing competition intensity and resolving infrastructure issues like pipeline expansions. Any trading restrictions in form of physical transport obligations between individual countries might cause separate regional and less liquid markets, which could further split the market into small submarkets. A system in which product and certificate can be traded independently would also reduce both transport costs and emissions. For some products, such as renewable ammonium or renewable kerosene, a global infrastructure is already in place. The danger of a delay in infrastructure development does not exist here, so that the application of the book & claim principles is more obvious here.

So far, however, mass balancing is required in all investigated regulatory frameworks (except for the Californian LCFS) in order to count the renewable hydrogen volumes towards national (transport) targets.

The different **carbon sources** (fossil-based industrial point source, biogenic and naturally occurring) have different economic and environmental performances, which should be accounted for within the regulatory framework. The Global Alliance Powerfuels (2020) found that atmospheric carbon has a positive environmental performance, but is significantly more expensive (300-600 €/tCO_2) than utilising other carbon sources. In the medium to long term, however, this cost should drop significantly. (Global Alliance Powerfuels, 2020). Those differences should be taken into account by the GHG calculation methodology of the standards/regulations.

The increased use of **new digital technologies** in form of emerging concepts such as the use of artificial intelligence or smart contracts, can strengthen the resilience of the system by keeping data secure and trustworthy, if implemented correctly. Intelligent use of digitalised platforms could even lower transaction costs and other barriers to participation in the global market for small-scale producers. Furthermore, the blockchain technology allows users from different parties to access a system, e.g. in form of a registry without violating ownership rights (Königsberger et al., 2020). In addition, the potential for scalability of the technology for a more precise tracing of the hydrogen volumes is an advantage of the blockchain technology. Obstacles of the blockchain technology are limited trust and experience of system/registry operators, the slowness of the energy sector to adapt to blockchain technology, insecurities about implementation costs and the requirement of highly trained staff of certification schemes (Königsberger et al., 2020). The openness towards new technologies such as blockchain could, however, be offset by demonstrating the feasibility of such a solution in pilot projects. Several projects currently involve well-known energy market players cooperating with start-ups that are testing or even operating a certification solution based on the distributed ledger technology (DLT). For instance, GreenH2chain – operated by ACCIONA and FlexiDAO (ACCIONA, 2021) – is developing a blockchain-based platform to track and prove the sustainable origin of renewable hydrogen. Also, a cooperation between Engie and Ledger is currently developing a blockchain hardware device for securing data at the source of the energy production and transferring it to a decentralized system (Engie, 2018). The project EnergyTag, involving Eneco, FlexiDao and CertiQ, establishes a platform for daily matching of electricity volumes, supporting the transactional process by trading renewable energy certificates provided by Power Ledger (Power Ledger, 2020).

Moreover, it is important to be aware of the **implications** of applying sustainability criteria to the degree of sustainability of hydrogen. For instance, if the qualification as renewable hydrogen is only based on the cancellation of GOs, then the specification of the GO becomes relevant for whether truly renewable hydrogen was produced or whether a kind of *green washing* took place.

With regard to a uniform certification system, it is also important to investigate to what **extent criteria should be differentiated regionally** depending on the country of production. This is, among other, relevant for water consumption criteria as well as criteria regarding the renewable electricity consumption. Here, the explicit requirements in the EU regarding the priority of renewable electricity for direct power applications ultimately reflects the regional / local problem that in many European countries coal-fired power generation still represents a significant part of the overall energy mix. It is essential to lift the targets for the expansion of renewable energies to consider the increased demand for renewable hydrogen - and to initiate the construction of new plants as quickly as possible.

Based on this, it would not make sense to apply the same criteria to all countries. A new system designed on the blank page could **introduce potential new aspects** to ensure the sustainability of the systems, however, disproportionate complexity and additional (administrative) burdens should be avoided, as this would hamper the market ramp-up of renewable hydrogen already in the early stage. An example for new aspects to be covered could be a more explicit criterion on **water consumption** could contribute to this goal. Sailer et al. (2021) propose to implement a water consumption threshold in form of a water efficiency criteria [l/kWh hydrogen output]. The stoichiometric – i.e. optimum – amount of water required to produce one cubic meter of hydrogen amounts to 0.81 litres (or 8.92 litres to produce 1 kg of hydrogen). However, the amount of water required in practice is usually 25% higher (Barbir, 2005) – a water efficiency threshold would thus help to avoid unnecessary excessive water consumption. Since water stress looks different in different regions of the world, this threshold value should be based on a water stress map to avoid excessive water consumption. Such a criterion would be especially crucial for hydrogen production in arid regions such as MENA. In addition to a water efficiency criterion, the Global Alliance Powerfuels (2021) suggests to require operators of renewable hydrogen production plants to demonstrate ex-ante, based on data on water consumption and availability at regional level, that the electrolyser does not increase the risk of declining water levels or negatively affects the existing water supply. This could be based on existing administrative subdivisions, e.g. corresponding to population sizes of approximately 1-3 million. The World Resources Institute's Aqueduct Water Risk Atlas contains global data on water consumption and availability for regions at this level. Before the installation is implemented, it could also be made mandatory for operators to conduct in advance an evaluation of the hydrological condition of the construction site implemented (California Energy Commission and California Natural Resources Agency, 2018), which could be audited as part of the certification process.

Social impact criteria hold companies accountable to, for example, worker's rights such as the ILO standard, which usually only governments are bound to. However, if social criteria are integrated into the hydrogen standard, companies are also obliged to comply with them. Adherence to social justice makes transnational cooperation and global supply chains more trustworthy for business partners and end customers.

Finally, the **different developments** and specific problems that are currently being dealt with in the various countries might constitute the greatest challenge today. This includes the different stages of development regarding certification of renewable electricity, but also covers the differences in national hydrogen strategies with wide ranges of expected demand for hydrogen in the upcoming years, as well as the diverging sizes and development stages of hydrogen projects.

5.3 A practical approach within existing regulations

Thought experiment: A Plant concept that complies with all hydrogen standards/regulations globally

Companies are currently evaluating which countries are economically attractive for hydrogen production and in which markets they can sell the energy carrier best. Instead of speculating that there will be a globally harmonised certification system for renewable hydrogen, the problem can be solved in another way: A plant concept that complies with the requirements of all (or at least most) regulatory frameworks, as depicted in Figure 3. This plant concept guarantees the largest addressable market for renewable hydrogen quantities. In doing so, it excludes the purchase of electricity via the grid, as this is where the greatest differences between the various standards occur. The exclusion of the grid connection in the plant concept in Figure 3 is carried out only based on the fact that the standards differ most in the criteria of the grid connection. The heterogeneity of the various hydrogen standards around the world can therefore be avoided by a system concept with direct connection. However, this does not mean that hydrogen production is less sustainable with a grid connection.

For the GHG reduction, the EU target was taken instead of the more ambitious TÜV Süd target, since the TÜV standard is market-based and does not, for instance, grant any state aid.

A plant concept addressing the largest global offtake market*:

1. **Direct connection** between the renewable power source and the electrolyser
2. **GHG reduction of 70%** (target value: 28.2 gCO_{2equ}/MJ) compared to a fossil baseline of 94,1 gCO_{2equ}/MJ
3. Carbon source: Atmospheric (**DAC)**

*Proof for mass balance needs to be provided along the value chain

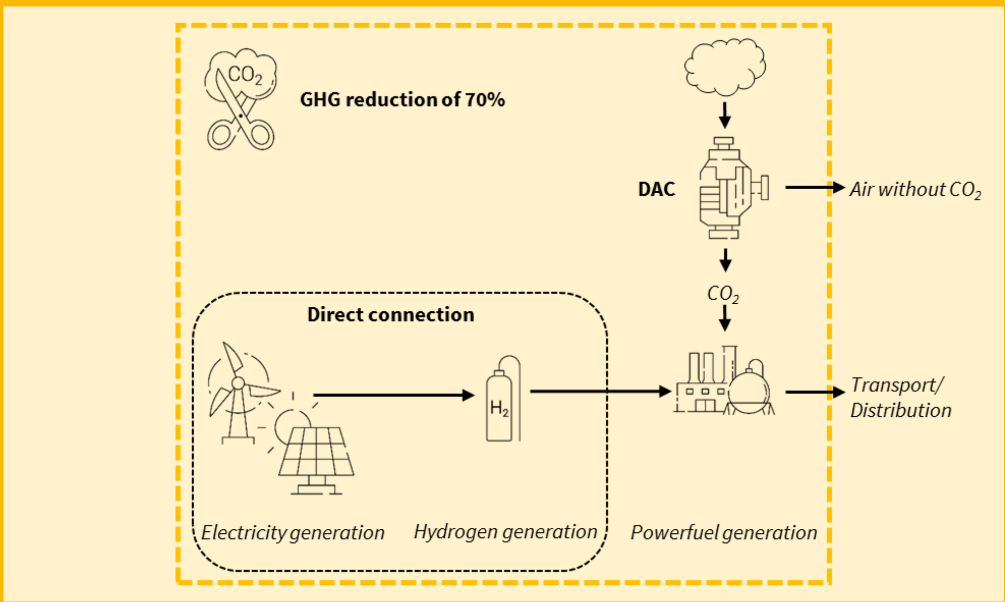


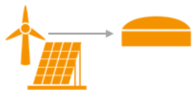
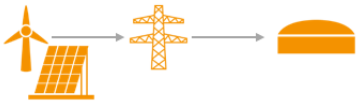
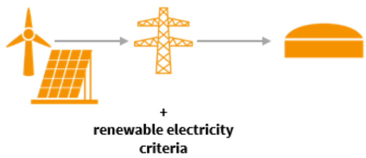
Figure 3: Hydrogen plant concept addressing the largest global offtake market

This plant concept merely specifies how hydrogen quantities can be produced that can be sold worldwide as renewable. However, it does not imply that these criteria should be adopted in the regulatory framework, as they would lead to severe obstacles to the market ramp-up of hydrogen due to the high production costs. Therefore, it does not constitute a target vision, but a theoretical compromise for the current lack of the harmonisation potential of global standards.

Further plant concepts and their eligibility for certain markets

As an alternative to the illustrated concept above, which complies with all hydrogen standards/regulations globally, global requirements for renewable hydrogen and the necessary certification also allow for other plant concepts. For a large part of the market *leaner* plant concepts would also satisfy the existing criteria for renewable hydrogen. Certification schemes in China, Japan and California/USA, for instance, allow the use of electricity from the grid. Table 11 shows different plant concepts and the respective hydrogen standard/regulations they comply with.

Table 11: Hydrogen standards/regulations to demonstrate compliance for different plant concepts

	Hydrogen plant concept	Hydrogen standards/regulations to demonstrate compliance
Direct connection		All assessed hydrogen standards & regulations
Indirect connection		China, Japan, Australia, CA/USA
Indirect connection + renewable electricity criteria		ISCC Plus, CertifHy, dena biogasregister, TÜV Süd CMS 70, H2Global, RED II, UK

6 Conclusion

This paper assesses the potential for harmonising global hydrogen regulations and standards in order to create an all-encompassing global certification system for renewable hydrogen and its derivatives. One of the findings of the analysis of eleven standards/regulatory frameworks worldwide is that the most harmonised sustainability requirements are the use of renewable electricity inputs, mass balancing as the tracking model as well as the eligibility of all carbon sources, as long as they are not deliberately produced for the generation of hydrogen or its derivatives.

In the end, this paper draws the conclusion that a global certification scheme for renewable hydrogen will be challenging to achieve. For some standards/regulations it would mean to give up on the most ambitious requirements regarding the production of renewable hydrogen – such as the EU's renewable electricity criteria according to Art 27. RED II, which are currently valid only for the transport sector, but shall be enlarged to the industry, heating and cooling as well with the revision of the legislation. Thereupon, the paper shows a theoretical plant concept for the production of renewable hydrogen, which is recognised among all eleven hydrogen regulations/standards assessed. It is based on a direct connection between the electrolyser and the renewable electricity plant, a 70% GHG reduction of the produced hydrogen compared to the reference value of 94 gCO_{2equ}/MJ, and the use of atmospheric carbon from DAC. This concept is not a target framework. It is solely based on the fact that the standards/regulations differ most in the criteria of the grid connection. The heterogeneity of the various hydrogen standards around the world can therefore be avoided by a system concept with direct connection. However, this does not mean that hydrogen production is less sustainable with a grid connection. The chain of custody must be traced by mass balancing, a tracking model where the physical delivery of an energy carrier goes hand in hand with the certificate. By fulfilling these criteria, producers would gain access to all analysed markets.

In order to be able to withdraw renewable hydrogen volumes from this plant concept and to place it on all markets, the following aspects for the global use/tradability of certificates are pivotal:

- Global recognition of certification bodies in order to conduct the audits: In order for certification bodies to conduct audits concerning standard compliance, they must be officially recognised by a competent authority. E.g., TÜV Süd as a certification body for the EU market can only conduct plant audits for the British market according to the RTFO as well, if TÜV Süd is officially recognised by the UK's Department for Transport. Thus, to foster the global harmonisation of certification, global recognition of certification bodies by the respective competent bodies of the various markets is required to enable the conduction of the audits.
- Reliability and trust towards hydrogen standards, certification schemes, certification bodies of different markets.
- Robust mechanisms for avoidance of double counting/claims. When transferring hydrogen quantities (or its derivatives) from one certification system to another, it must be ensured, for example, that the quantities in the sending register are cancelled.
- Certificates from different schemes must be comparable and recognised on different markets (e.g. standardised data fields). To give an example: The harmonisation of data field names on the certificate creates a common language among markets which facilitates the verification of target compliance. It also ensures that stakeholders talk about the same thing when referring to a specific term.

- Harmonisation of the certification governance: At the moment, different certification structures regarding the application process, certification bodies and data handling are in place in different regions of the world (Chapter 3). One global certification standard is required with regard to the general certification governance, which sets the rules on certificate handling and the process of official recognition by a competent authority.
- Openness to other standards: Recognition of other standards among certification schemes.

It is important to note, that different requirements for the generation of renewable hydrogen go hand in hand with different production costs and availability of hydrogen and its derivatives. The hydrogen production costs of the plant concept above are, therefore, relatively high. Thus, this analysis offers an overview of alternative plant concepts and the respective hydrogen standards/regulations they comply with. For a large part of the assessed markets, leaner plant concepts would also satisfy the existing criteria for renewable hydrogen. For instance, certification schemes in China, Japan and California/USA allow the use of electricity from the grid.

In the end, it is likely that the European standard set by the RED II – despite its high ambition – will prevail, as the market is driven by significant political incentives due to the currently still high hydrogen production costs. With its regulatory conditions and the associated support instruments for market take-up, the EU has created an incentive for the production of renewable hydrogen that is particularly attractive to market players around the world. However, although the EU is considered an international role model in terms of standard-setting, a global hydrogen market could also be characterised by other conditions.

The EU is perceived primarily as a large (future) consumer of renewable hydrogen. Nevertheless, if the regulatory conditions prove to be too strict, there is a risk that large hydrogen producers will opt for other certification or sales markets altogether and the EU market becomes less attractive in the long-term. This development would be contrary to the EU's ambition to strengthen its leadership in the hydrogen economy in terms of technical standards, regulations and definitions on hydrogen, as defined in the EU’s hydrogen strategy. Policymakers should therefore ensure that an EU-wide hydrogen regulatory framework does not hinder trade and market development for renewable hydrogen in the end.

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Abbreviations

AFP	Alternative Fuel Portal
AU	Australia
BLE	German Federal Agency for Agriculture and Food
BMWi (now: BMWK)	Bundesministerium für Wirtschaft und Energie/Federal Ministry for Economic Affairs and Energy (since December 2021: Bundesministerium für Wirtschaft und Klimaschutz / Federal Ministry for Economic Affairs and Climate Action)
BTrV	Regulation concerning evidence of compliance with ecological requirements (Verordnung über den Nachweis der Erfüllung der ökologischen Anforderungen an biogene Treibstoffe)
CA	Canada
CAPEX	Capital Expenditure
CARB	California Air Resources Board
CBTS	Credit Bank and Transfer System
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CH	Switzerland
CN	China
CO_{2equ}	CO_2 equivalent
C & S	Carbon and Sustainability
D. A.	Delegated Act
DAC	Direct-Air-Capture
DE	Germany
DG ENER	Directorate-General for Energy
DfT	Department for Transport
DWV	Deutscher Wasserstoff- und Brennstoffzellenverband/ German Hydrogen and Fuel Cell Association
EC	European Commission
EEG	Erneuerbare-Energien-Gesetz/ Renewable Energy Sources Act
EFTA	European Free Trade Association

elNA	The electrical sustainability certificate (German: “Der elektronische Nachhaltigkeitsnachweis”)
ETS	Emission trading scheme
EU	European Union
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit/ German Society for International Cooperation
GO	Guarantee of Origin
ILO	International Labour Organization
ILUC	Indirect Land Use Change
JP	Japan
ISCC	International Sustainability and Carbon Certification
ISO	International Organization for Standardization
KR	South Korea
LCFS	Low Carbon Fuel Standard
LRT	LCFS Reporting Tool
LULUFC	Land Use, Land-Use Change and Forestry
MinöStG	Swiss Mineral Oil Tax Act
MinöStV	Swiss Mineral Oil Tax Regulation
MT	Million tonnes
PoS	Proof of Sustainability
PPA	Power Purchase Agreement
PtL	Power-to-Liquid
REC	Renewable Energy Certificate
RED	Renewable Energy Directive
RFNBO	Renewable Fuel of Non-Biological Origin
ROS	RTFO Operating System
RPS	Renewable Portfolio Standards
SME	Smart Energy Council (Australia)
RTFC	Renewable transport fuel certificates
RTFO	Renewable Transport Fuel Obligation
UDB	Union Database

UK	United Kingdom
US/CA	United States of America, California

Glossary

Term	Definition
Additionality	Electricity produced in addition to the existing electricity sector, which is available for the production of RFNBOs. According to RED II, additionality can be proven by the absence of state aid.
Direct connection (to the renewable energy plant)	Electricity consumed by an electrolyser from a direct connection to a renewable power installation – in comparison to electricity from the grid.
Double/multiple counting	Claiming credits associated to the renewable properties of a fuel unit more than once. If a renewable energy consignment has been counted towards meeting one application (e.g. fuel or heating & cooling), then the respective renewable energy consignment is not eligible for a second/multiple allocation to other applications (Königsberger et al., 2020).
Guarantee of Origin (GO)	Certificate for consumer disclosure according to RED II Art 19.
Geographical correlation	Limited geographical area in which the power installation and the electrolyser are located.
System serviceability	System efficiency describes the implementation of measures (e.g. the use of an electrolyser) to balance the electricity grid in times of grid congestions.
Temporal correlation	Timely difference between electricity and hydrogen production.
Voluntary Scheme	Certification schemes that are officially recognized by the EC to mirror the requirements set by RED II. For biofuels there are 16 certification schemes that are recognized as Voluntary Schemes.

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