Chapter 9

Green Hydrogen Standard in China: Standard and Evaluation of Low-Carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen

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December 2021

This chapter should be cited as

Liu, W., Y. Wan, Y. Xiong, and P. Gao (2021), 'Green Hydrogen Standard in China: Standard and Evaluation of Low-Carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen', in Li, Y., H. Phoumin, and S. Kimura (eds.), *Hydrogen Sourced from Renewables and Clean Energy: A Feasibility Study of Achieving Large-scale Demonstration.* ERIA Research Project Report FY2021 No. 19, Jakarta: ERIA, pp.211-24.

Chapter 9

Green Hydrogen Standard in China: Standard and Evaluation of Low-Carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen

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With the proposal of carbon neutral goals in various countries, the deepening of global action on climate change and the acceleration of green economy recovery in the post epidemic era, building a low-carbon and clean hydrogen supply system has gradually become a global consensus. In order to promote the development of the clean hydrogen market, the standards of green hydrogen have been discussed worldwide. The quantitative definition of different hydrogen production methods based on the emission methods of life cycle greenhouse gases is gradually being recognised by the industry. China issued the 'Standard and Evaluation of Low-carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen' in December 2020. This is the first formal green hydrogen standard worldwide, which provides calculation methods for greenhouse gases of different hydrogen production paths. This chapter discusses the major green hydrogen standards initiatives in the world, analyses the key factors of the global green hydrogen standards, and introduces how to establish the quantitative standards and evaluation system of low-carbon hydrogen, clean hydrogen, and renewable hydrogen by using the method in China.

Keywords: carbon neutral, green hydrogen standard, low-carbon hydrogen, clean hydrogen, renewable hydrogen, life cycle assessment

1. Introduction

In recent years, under the active promotion of major economies such as the European Union (EU), Japan, Republic of Korea, and China, hydrogen energy has gradually become the new international focus and has achieved rapid development. In 2020, 11 regions or countries including the EU, Germany, Spain, and Canada formulated hydrogen energy development strategies. By the end of 2020, 16 of the 27 countries, whose gross domestic product accounted for 52% of global gross domestic product, had drawn up comprehensive national hydrogen energy strategies, and 11 countries were still drafting their national hydrogen energy strategies (NEDO, 2015; Pivovar, Rustagi, and Satyapal, 2018; Alberto, 2020; Hydrogen Council, 2017; Li et al., 2020; Anika, Matej, and Doria, 2021). Many countries also formulated ambitious strategic goals for green hydrogen. For example, the EU plans to install 2x40 gigawatts (GW) of renewable hydrogen electrolytic tanks each of which is capable of producing 1,000 kilograms of renewable hydrogen annually by 2030 (FCH, 2019; Hydrogen Europe, 2020).

As the world’s second largest economy, China has formed a key driving force for controlling global climate and building a community with a shared future for mankind with the announcement of the carbon peak and carbon neutral goal vision: China will enhance its nationally self-determined contributions, adopt more powerful policies and measures, and strive to reach the peak of carbon dioxide emissions by 2030 with carbon neutrality achieved by 2060. In the same year, China issued the ‘Notice on Carrying out Fuel Cell Vehicle Demonstration Applications’ to encourage the use of low-carbon hydrogen and clean hydrogen (Ministry of Finance, 2020). As of the end of 2020, according to news reports in the mass media, about 28 renewable energy hydrogen production projects have been signed in China. China's vision of achieving carbon neutrality sends a clear signal to the world and injects new vitality into the global response to climate change and green recovery. The growing demand for low-carbon and clean hydrogen is expected to promote international hydrogen trade between hydrogen importers and exporters (White et al., 2021; Newborough and Cooley, 2020; Federal Government of Germany, 2020). It is well known that hydrogen is a secondary energy source. In fact, not all hydrogen is good for reducing carbon emissions. The prerequisite for promoting international hydrogen trade is to clarify hydrogen-related quality indicators, especially the origin of hydrogen. The precise definition of ‘hydrogen’ is crucial to the hydrogen trade. Hydrogen can be produced by a variety of processes and energy sources, including production from coal, production from natural gas, production from electrolysis of water, and so on (Grigoriev et al., 2020; IEA, 2019; Arnepalli and Tiwari, 2011; Olabi et al., 2020). For ease of description, the clean energy industry often classifies hydrogen by colour, such as grey hydrogen, blue hydrogen, and green hydrogen (Noussan et al., 2020; IRENA, 2019, 2020). However, the above classification method is difficult to distinguish all types of hydrogen production processes clearly and quantitatively, and even for the same hydrogen production process (such as hydrogen production by electrolysis of water), it is often difficult to define the product by one colour. Therefore, with the introduction of carbon neutrality targets in various countries, the quantitative definition of different hydrogen production methods based on life cycle greenhouse gas (GHG) emissions has gradually been recognised by the industry.

To facilitate the policymaking and trade of green hydrogen, relevant international standards are being discussed across governments, industries, and academia. Recently, the ‘Standard and Evaluation of Low-carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen’ proposed by the China Hydrogen Alliance was officially issued (T/CAB 0078-2020). This is the first time in the world that carbon emissions of hydrogen have been quantified on the basis of official standards. This chapter explores how low-carbon hydrogen and green hydrogen has been defined and confirmed in China, providing experience and reference for other nations or organisations and laying a foundation for mutual recognition of international low carbon green standards.

2. Green Hydrogen Standard Initiatives Worldwide

It should be noted that hydrogen energy can only take a great leap by relying on a unified platform of global energy governance and worldwide market. Therefore, it is necessary to establish and improve the international standard system on hydrogen quality, with the calculation cost of carbon emissions, cross-border compatibility, and mutual recognition taken into account. The initiatives to develop green hydrogen can be found mostly in Europe, as shown in Table 9.1. Key factors were investigated by international standardisation agencies (e.g. CEN CLC JTC 6) and certification bodies, including the outcomes of certain projects and projects under consultation in the areas of energy and climate policy (e.g. EU CertifHy, L'Association Française pour l'Hydrogène et les Piles à Combustible (AFHYPAC), and the governments of California and the United Kingdom) (Abad and Dodds, 2020; Fuel Cells Bulletin, 2017; CEN/CENELEC, 2018).

In terms of these green hydrogen initiatives, there are four key points involved.

(1) The definition of green hydrogen. On the one hand, it refers to whether the hydrogen source must be limited to renewable energy; and on the other hand, it involves whether the definition of green hydrogen is based on the quantification of the life cycle GHG emissions or whether the definition is based on the qualification of hydrogen production technology and hydrogen source.

(2) System boundary. Based on the definition of quantification of life cycle GHG emissions, there are many options for carbon emission accounting boundaries, such as the point of production and the point of use.

(3) Baseline GHG threshold. Major countries choose hydrogen production carbon emissions (such as steam methane reforming, SMR) or well-to-wheel gasoline vehicle carbon emissions as the benchmark according to the system boundary and national conditions.

(4) Qualification level. According to the carbon reduction target or air pollution reduction target in national policies, GHG emissions are further quantified so that the green hydrocarbon emission threshold can be obtained.

Table 9.1: Green Hydrogen Characterisation Initiatives Worldwide

Body (Country)	Main Policy Objective	Qualifying Technical Route	Baseline GHG Threshold	Qualification Level	System Boundary
CertifHy (EU wide)	Reduction of GHG emissions	Any technical route of hydrogen production from renewable energy with a threshold of 99.5% purity	GHG emissions from SMR of natural gas to hydrogen	A reduction of 60% GHG emissions compared to hydrogen produced using SMR (< 36.4gCO2eq/MJH2)	Point of production
AFHYPAC (France)	Deployment of Renewable energy	Any technical route of hydrogen production from renewable energy	None	Must be 100% renewable	Point of production
BEIS (United Kingdom)	Reduction of CO2 emissions	Technology Neutral)	Never determined	To be determined.	Point of production
California Low Carbon Fuel Standard	Reduction of GHG emissions. Third of vehicle hydrogen produced from renewable energy	Renewable electrolysis, catalytic cracking or SMR of biomethane or thermochemical conversion of biomass, including MSW	WTW emissions from new gasoline vehicles	30% lower GHG and 50% lower NOX emissions for fuel cell vehicles	Point of use
CEN/CENELEC CLS JCT 6 (International)	Terminology, GO. interfaces, operational management, safety, training and education	Adopted from CertifHy	Adopted from CertifHy	Adopted from CertifHy	Point of production

AFHYPAC = L'Association Française pour l'Hydrogène et les Piles à Combustible, BEIS = Department for Business, Industry & Industrial Strategy, CEN/CENELEC = European Committee for Standardization and the European Committee for Electrotechnical Standardization, EU = European Union, GHG = greenhouse gas, GO =guarantees of origin, MSW = municipal solid waste, SMR = steam methane reforming, WTW = well to wheel.
Source: Authors based on Abad and Dodds (2020).

2.1. Definition of Green Hydrogen

A set of approaches and criteria have been enforced to define green hydrogen, but it is not harmonised on the qualifying feedstock, renewable or not, and technological pathways. When it comes to grey or renewable hydrogen, the opinion is consistent, where grey hydrogen is typically understood as one produced from fossil fuel feedstock. However, in terms of renewable hydrogen from renewable sources, the case is different. Regarding green hydrogen, some initiatives such as AFHYPAC categorise it as the same as renewable hydrogen, while others such as CertifHy add more criteria, i.e. any renewable pathway meeting 99.5% purity threshold is considered as green hydrogen. However, several initiatives choose a more technology-neutral way, paying more attention to GHG emissions, thus emphasising the environment impact. For example, biomethane SMR can be accepted by the California Low Carbon Fuel Standard, and nuclear power by the UK Department for Business, Industry & Industrial Strategy, as long as the carbon emissions are sufficiently low.

With the intention of resolving disparities in different interpretations and improving applicability, the definition of hydrogen energy based on GHG intensity is gaining acceptance. The EU is developing an EU-wide framework involving the definition of a green hydrogen standard under the CertifHy project financed by the Fuel Cells and Hydrogen Joint Undertaking. An emissions threshold of 36.4 g CO_{2eq}/MJ H_2 on the point of production is proposed. When the threshold is met, hydrogen produced from renewables is defined as green hydrogen, while the counterpart forms non-renewables as low carbon hydrogen. In addition to categorising the hydrogen, carbon intensity based method, as a quantified measurement, enhances the interchangeability of hydrogen from different pathways or across different countries, when carbon related cost is considered.

However, it is conceivable that such a method requires more details of the hydrogen supply and consumption, and parameters should be set up, such as system boundary, emissions benchmarks, and reduction threshold, which brings more counting and regulation burdens.

2.2. System Boundary

Based on the principle of reducing GHG emissions, there are different system boundaries and accounting methods for low-carbon clean hydrogen. The system boundaries used in existing plans can be divided into two categories: the point of production and the point of use. From the perspective of the system boundary, the calculation of the ‘factory point’ does not require considering downstream emissions such as storage, transportation, loading and unloading, and supply, nor the fuel loss caused by fuel leakage, thus resulting in higher operability; the system boundary for the ‘consumption point’ calculation is much wider and can more accurately estimate the emissions of a specific route, although the management cost is high. In addition, the underlying basis for hydrogen purity, pressure, state, and carbon accounting standards are also different.

The EU CertifHy project is the longest-running project on guarantees of origin (GO) green hydrogen certification., and it has explored and launched the GO green hydrogen certification. The project is based on the life cycle carbon emission evaluation method. For the hydrogen products that leave the factory, the required purity is equal to or greater than 99.5% with the required pressure being equal to or greater than 30 Bar. If the requirements are not met, the carbon emissions during the purification or pressurisation process should be included.

The system boundary used in existing initiatives can be classified into two categories: the point of production and the point of use. The system boundary is of the hydrogen supply chain, whose components are involved in calculating GHG emissions. The point of use scheme, for example, the California Low Carbon Fuel Standard, covers the whole supply chain from production of feedstock to the delivery of hydrogen to the filling station, to the end customer. The point of production scheme excludes downstream emissions from storage, transportation, supply, and fuel losses due to boil-offs and leakages. Additionally, none of the schemes include emissions involved in constructing and decommissioning hydrogen production plants and other capital infrastructure.

The factors that have impact on both schemes include: (i) the feedstock and any land use changes, (ii) energy inputs (e.g. the electricity emission intensity), (iii) the efficiency of the selected production technologies, and (iv) any additional processes (e.g. compression, liquefaction) to bring the product to specification. In the point of use scheme, the downstream emissions are involved and depend on the type of end-use, such as heating, industrial processes, or transport modes.

2.3. Emissions Benchmark and/or Baseline GHG Threshold

The benchmark plays an important role in bridging the gap between the current and future energy structures, thus promoting energy transition. How to select emissions benchmarks is another issue that lacks consensus, since it is closely related to system boundary, hydrogen supply, and consumption structure. However, the hydrogen supply and consumption structure is not identical from case to case. When the system boundary is point of production, the selection of the benchmark depends on the hydrogen supply structure. For instance, steam methane reforming (SMR) is the dominating pathway of hydrogen supply in Europe, especially in the commercial hydrogen market, where the proportion of hydrogen produced by natural gas is more than 95%. As a result, the use of the carbon intensity of SMR as a benchmark, such as CertifHy, has been widely enforced in Europe. When the system boundary is point of end-use, the selection of the benchmark depends on the hydrogen consumption structure. The California Low Carbon Fuel Standard uses the well-to-wheel oil consumption intensity as a benchmark, since they pay more attention to the application of hydrogen energy in the transportation area.

2.4. Reduction Threshold and/or Qualification Level

Reduction threshold reflects ambition of policy objectives, although practicability must be considered. Reduction threshold and/or qualification level are directly related to the benchmark.

As mentioned earlier, the most representative SMR hydrogen production process with 91 gCO_{2eq}/MJ_{H2} is used as the benchmark in Europe. CertifHy clarifies the green hydrogen carbon emissions intensity threshold as 36.4 g CO_{2eq}/MJ H_2, which is a reduction of 60% compared to hydrogen produced using SMR, according to the 2020 emissions reduction requirements in the EU Renewable Energy Act. As a result, hydrogen is divided into non-low-carbon hydrogen and low-carbon hydrogen. Non-low-carbon hydrogen is grey hydrogen, while low-carbon hydrogen includes both green hydrogen produced by renewable energy and non-renewable hydrogen produced by non-renewable energy.

In California, the Low Carbon Fuel Standard was adopted in 2009 to contribute to state GHG emissions reduction goals under the Global Warming Solutions Act of 2006. The program incentivises the adoption of low-carbon transportation fuels based on the fuel's lifecycle GHG emissions per unit of energy – or carbon intensity as rated by the programme. Hydrogen, as important low-carbon transportation fuel in medium and heavy duty vehicles, is included under the California standard. Senate Bill 1505 Environmental Standards has a requirement that 33% of hydrogen fuel must come from renewable sources, with an emissions reduction requirement of 30% reduction of GHG and 50% reduction of nitrogen oxide.

3. Green Hydrogen Standard in China

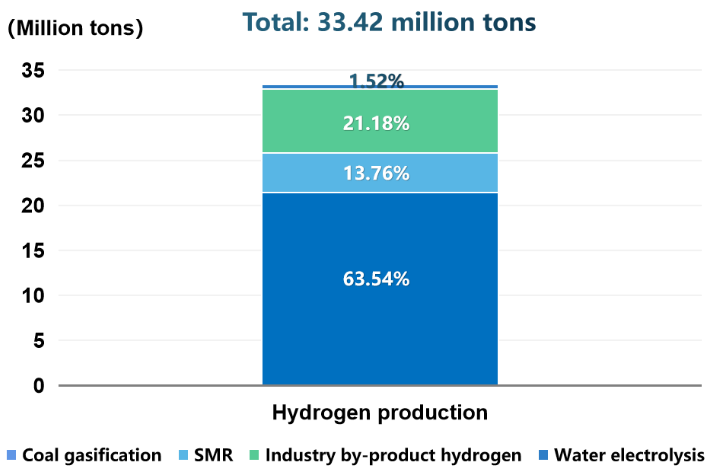
The discussion and practice of international green hydrogen standards have provided valuable experience for China's standard formulation. The formulation of China's green hydrogen standard should also be based on national conditions with international standards considered.

3.1. Status of Hydrogen Energy Production in China

To formulate national or regional green hydrogen standards, the first step is to define the hydrogen supply and consumption structure of the region or country. In the process of formulating China's green hydrogen standard, we followed such experience. The hydrogen supply and consumption structure in China has been investigated based on the statistics with analysis method. First, based on the statistics of the workload conditions of production enterprises in all industries, hydrogen from traditional industries was investigated. The scope of this study includes petrochemical, chemical, and coking industries, including intermediate hydrogen raw materials for refining, petrochemical, synthetic ammonia (nitrogen fertiliser), methanol, modern coal chemical industry, and chlor-alkali, as well as by-product hydrogen from the coking and semi-coking industries. In total, it accounts for more than 95% of the industry's total hydrogen production capacity. In addition, according to the sales of electrolytic cell equipment in China, the capacity of hydrogen production by water electrolysis is also estimated.

According to statistics from the China Hydrogen Alliance, China's current hydrogen production capacity is about 41 million tons annually, and the output is about 33.42 million tons (CHA, 2020a). In terms of the raw materials used for production, they mainly include fossil energy such as coal and natural gas, and industrial by-product gas. Coal to hydrogen production is the largest, reaching 21.24 million tons, annually accounting for 63.54%, followed by industrial by-product hydrogen and natural gas hydrogen production, with an annual output of 7.08 million tons (of which coking and semi-coking by-product gas is 6.04 million tons) and an annual output of 4.6 million tons, respectively. The output of hydrogen production by water electrolysis is only 500,000 tons annually.

Figure 9.1: Hydrogen Production Structure in China



SMR = steam methane reforming.
Source: CHA (2020a), authorized by CHA.

3.2. Baseline GHG Threshold in China

Through the above research results, it can be found that China's hydrogen supply structure is dominated by coal to hydrogen. Based on this actual situation, we choose the carbon emissions of hydrogen from coal as the benchmark. This section mainly uses actual case data in China as the accounting basis for calculating the carbon emissions from coal to hydrogen and the carbon emissions from coal to hydrogen with carbon capture and storage (CCS).

According to the process flow, the hydrogen production system is divided into three stages: the raw material acquisition stage, the raw material transportation stage, and the hydrogen production stage (Ren, Zhou, and Ou, 2020; Dufour et al., 2011). The system boundary is divided as shown in Figure 9.2. The description of the system and its boundary is as follows:

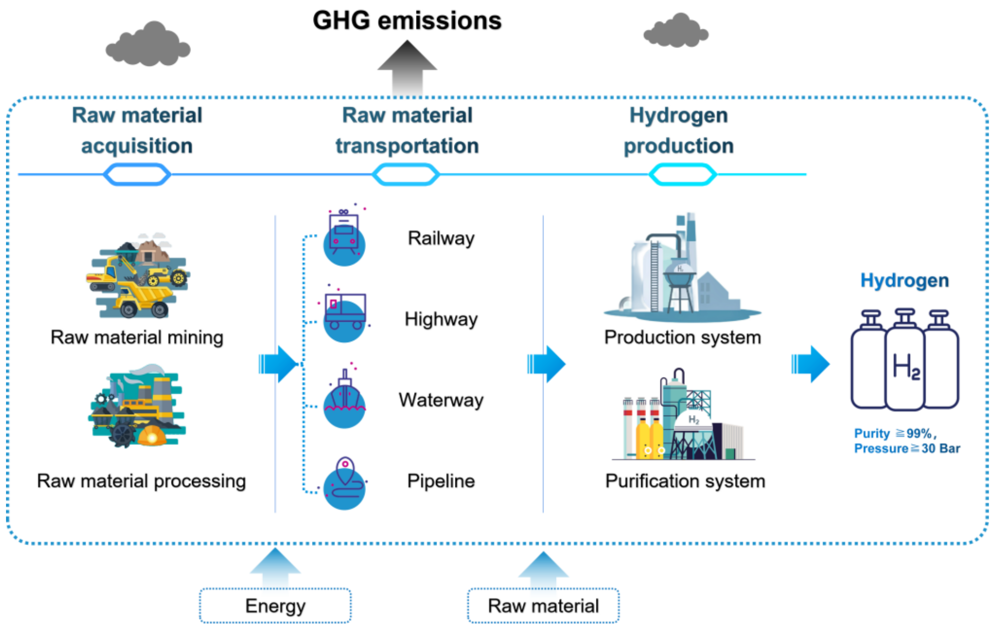
1) The system includes all links from raw material mining and transportation to hydrogen production.
2) In the system, raw materials include coal, natural gas, water, and methanol, and energy includes primary energy (coal, natural gas, diesel) and secondary energy (electricity).

3) The total material consumption of the system includes the material consumption in raw material extraction, transportation, and hydrogen production. The total energy consumption of the system includes the energy consumption corresponding to the material consumption and the energy consumption corresponding to the production process. The total greenhouse gas emissions of the system include the greenhouse gas emissions corresponding to the material consumption (GHG emissions from raw material production), GHG emissions during transportation, GHG emissions during production, and GHG emissions corresponding to energy consumption (GHG emissions corresponding to electricity consumption).

4) The GHG emissions from activities such as factory construction, equipment manufacturing, and transportation tool manufacturing are not considered.

5) The six GHGs specified in Appendix A of the Kyoto Protocol are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). The GHG produced in the hydrogen production process is mainly CO_2. In addition to CO_2, the GHGs produced in the process of hydrogen production and transportation also include CH_4 and N_2O. According to the Intergovernmental Panel on Climate Change's Fourth Assessment Report, 1 ton of CH_4 is equivalent to 25 tons of CO_2 in terms of 100-year global warming potential, so GWP_{CH_4} = 25; 1 ton of N_2O in the 100-year time scale is equivalent to 298 tons of CO_2, so GWP_{N_2O} = 298.

Figure 9.2: System Boundary of GHG Emissions in China



GHG = greenhouse gas.
Source:CHA (2020b), authorized by CHA.

The GHG emissions per unit mass of hydrogen produced by the hydrogen production system (hereinafter referred to as the hydrogen production GHG emissions) is equal to the sum of the GHG emissions during the raw material acquisition stage, the raw material transportation stage, and the hydrogen production stage, which is calculated according to equation (1):

$$e = \frac{(E_1 + E_2 + E_3)}{AD_{H_2}} \times \vartheta \tag{1}$$

where:

e —— GHG emissions from hydrogen production, in kilograms of carbon dioxide equivalent per kilogram of hydrogen ($kgCO_2e/kgH_2$)

E_1 —— GHG emissions during the raw material acquisition stage, in kilograms of carbon dioxide equivalent ($kgCO_2e$)

E_2 —— GHG emissions during the raw material transportation stage, in $kgCO_2e$

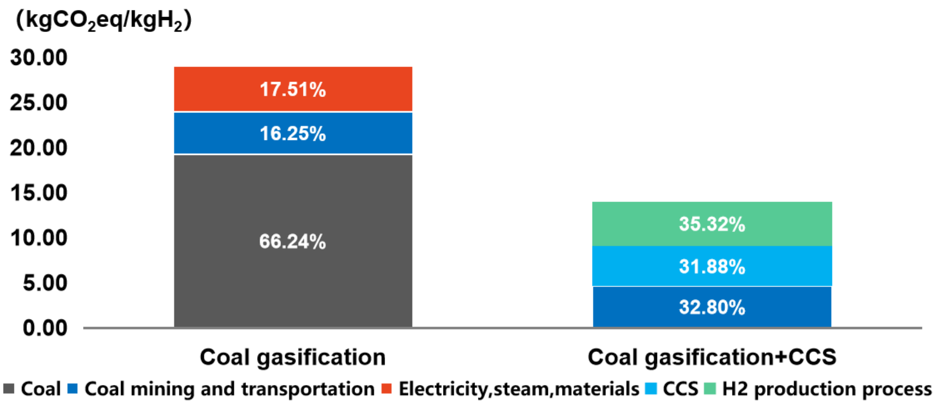
E_3 —— GHG emissions during the hydrogen production stage, in $kgCO_2e$

θ —— Distribution coefficient based on energy production method, that is, the ratio of the energy of product hydrogen to the total energy of product hydrogen and by-products, %

AD_{H_2} —— The production volume of hydrogen within the accounting period, in kilograms (kg).

Figure 9.3 shows the GHG emissions of hydrogen production form coal gasification and hydrogen production form coal gasification with CCS. The corresponding hydrogen production GHG emissions are 29.02 $kgCO_2e/kgH_2$ and 13.99 $kgCO_2e/kgH_2$, respectively.

Figure 9.3: Hydrogen Production Structure in China



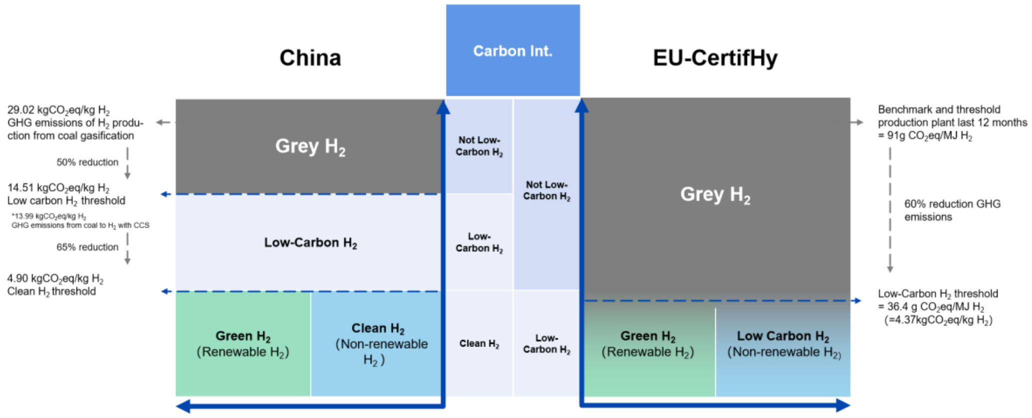
CCS = carbon capture and storage.
GHG emissions of H_2 production process include coal, electricity, steam, and other materials
Source: Authors.

3.3. Definition of Low-Carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen

In order to clarify the definitions and the quality criteria of hydrogen from different pathways or sources in China, the Standard and Evaluation of Low-carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen*,* proposed by China Hydrogen Alliance, was implemented on 29 December 2020. This standard uses the life cycle assessment method to establish the quantitative evaluation system of low-carbon hydrogen, clean hydrogen, and renewable hydrogen, and promotes the sustainable development of a hydrogen energy industry chain from the source. For the first time in the world, carbon emissions of hydrogen have been quantified in an official standard.

The proposed standard is in line with the CertifHy project in Europe in methodology. Specifically, the 'point of production' scheme is adopted to reduce the calculation and administrative cost, the same as in CertifHy. However, the selection of benchmark and threshold varies with the current status of hydrogen supply and development needs in China being considered. The standard proposed two thresholds to categorise the GHG emissions of hydrogen into three intervals, instead of one threshold and two intervals as in CertifHy. This is mainly on account of the current situation of China's carbon emissions levels. In order to make a smooth transition of China's carbon reduction mission, the standard puts forward two thresholds: low-carbon hydrogen threshold and clean hydrogen threshold. The low-carbon hydrogen benchmark is based on the GHG emissions of hydrogen production from coal gasification, which is 29.02 $kgCO_2eq/kgH_2$. According to the carbon reduction requirement of 50% in the 'National Plan For Tackling Climate Change 2014–2020', the low-carbon hydrogen threshold is set at 14.51 $kgCO_2eq/kgH_2$, which is reduced by 50% compared with hydrogen production from coal gasification. The clean hydrogen benchmark is 13.99 $kgCO_2eq/kgH_2$, which is the GHG emissions of hydrogen production from coal gasification with CCS. According to the carbon reduction demand of 65% in 'Energy Supply and Consumption Revolution Strategy 2016–2030', the clean hydrogen threshold is set at 4.90 $kgCO_2eq/kgH_2$, which is reduced by 65% compared with hydrogen production from coal gasification with CCS. In addition, it should be pointed out that the renewable hydrogen in the standard is equivalent to green hydrogen, which means the GHG emissions threshold is lower than 4.90 $kgCO_2eq/kgH_2$, at the same time, raw materials for hydrogen production are derived from renewable energy sources. The threshold of clean hydrogen or renewable hydrogen aligns with the threshold in the low carbon hydrogen or green hydrogen in CertifHy. The comparison between CertifHy and the proposed standard is shown in Figure 9.4.

Figure 9.4: The Comparison Between CertifHy and the Proposed Standard in China



EU = European Union.

Sources: Authors based on CHA (2020b) and CertifHy.

The utilisation of two thresholds and three intervals is based on the actual situation in China, and is both creative and practical. This is because hydrogen mainly comes from coal with higher carbon emissions in China than in Europe. The median threshold in the initial stage is conducive to guiding the transition from high-carbon hydrogen production to low-carbon hydrogen production, such as CCS technology and renewable energy electrolysis of water, and realise the clean and low-carbon transformation of the hydrogen energy industry and the energy industry.

4. Qualification Assessment

In the standard, a qualification assessment process is also presented from which the producer can be given certification that it is qualified to produce certain kinds of hydrogen. There are several main steps in the whole governing process of certification. The first step is the certification application where the applicant needs to file a formal application to the regulating body, and prepare related documents, including the hydrogen production flow chart of the applicant unit, main equipment, hydrogen production life cycle assessment report, production raw materials list, and main energy types and sources. The second step is document verification and on-site verification, where the regulating body reviews the documents submitted above and checks the authenticity of the production appliances to confirm whether the applicant meets the requirements of low-carbon hydrogen and clean hydrogen or renewable hydrogen. After the verification, the regulating body will issue an evaluation conclusion and file it on the service platform. Once the application is approved, the producer gets the respective certification and could give the hydrogen it produces with a corresponding label. Then, the hydrogen and its certification label could be traded, together or separately.

5. Conclusion and Recommendations

Building a clean and beautiful world requires down-to-earth action. Low-carbon and clean hydrogen energy will bring more space and opportunities for cooperation between countries. Promoting the formulation of a global low-carbon clean hydrogen standard as soon as possible will lay the foundation for cooperation in international hydrogen trade. Different organisations have put forward different initiatives related to green hydrogen energy. The European Union and China proposed their own green hydrogen standards based on the steam methane reforming hydrogen production process and the coal gasification hydrogen production process, which fully embodies the system thinking of 'harmonious but different' – carbon emissions calculation method, hydrogen quality, and the system boundary are consistent, but the local mainstream hydrogen production processes and carbon neutrality goals are fully respected, further accelerating the pace of unifying the global low-carbon clean hydrogen indicators.

In the future, China should undertake more work around the standard. The first is to strengthen policy support and start the basic capacity building of the low-carbon clean hydrogen market. The second is to carry out mutual recognition of indicators with Europe, Japan, Australia, and other countries to promote the global unification of green hydrogen standards and facilitate international hydrogen trade.

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