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Towards the Green Energy Transition

Investigating the Potential for EU - China Collaboration in the Hydrogen Sector

Maria Kienzle
Junior Researcher, EIAS

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Abstract

Keywords: *Green Energy Transition, Hydrogen, EU, China, Collaboration*

In the quest to achieve the EU's ambitious 2050 net-zero carbon emissions target, renewable hydrogen has emerged as a critical element in the green energy transition. Although hydrogen is promising as a clean-burning fuel and energy carrier, its energy-intensive production and high costs pose a challenge for large-scale implementation. China and the EU are key players in the global hydrogen landscape but still primarily rely on fossil-fuel heavy methods of production. As both have released a number of strategic objectives as part of their respective hydrogen strategies, the renewable hydrogen sector is set to change over the next couple of years. The EU's ambitious targets and China's strategic goals for the renewable hydrogen sector create an opportunity for collaborative efforts. This EIAS policy brief will explore the chances and challenges for EU-China collaboration in the renewable hydrogen sector, emphasising the fields of fuel-cell technology, electrolyser manufacturing, and renewable energy production and trade.

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List of Abbreviations

Battery Electric Vehicles (BEVs)
Carbon Capture and Storage (CCS)
Carbon Capture and Utilisation (CCU)
EU-China Energy Cooperation Platform (ECECP)
Fuel Cell Electric Vehicles (FCEVs)

Towards the Green Energy Transition - Investigating the Potential for EU-China Collaboration in the Hydrogen Sector

1.Introducing Hydrogen

Hydrogen (H^2) is both the simplest, and most abundant element in the universe with an atom structure of a single proton (Energy Information Administration [EIA], 2023). Hydrogen occurs on earth in the form of various compounds, such as water (H^2O), hydro-carbons (CxHy), or biomass (CxHyOzNa) (Jianjun & Wang, 2022). However, pure hydrogen does not exist naturally in the earth's crust (EIA, 2023). Thus, it must be produced by separating it from its various compounds (Jianjun & Wang, 2022). However, the production processes of hydrogen all require substantial amounts of energy inputs (Hassan et al., 2023). Once separated from its compounds, hydrogen can act as an energy carrier or clean burning fuel (National Renewable Energy Laboratory [NREL], n.d.). As an energy carrier, hydrogen transports energy in a usable form from one place to another. Compared to other available carriers, such as gasoline, hydrogen can carry nearly three times more energy due to its high energy density (Hassan et al., 2023). Furthermore, when hydrogen is combined with oxygen in a fuel cell, it produces heat and electricity with only water vapour as a by-product (NREL, n.d.). These qualities make hydrogen one of the most promising elements to help achieve the green energy transition.

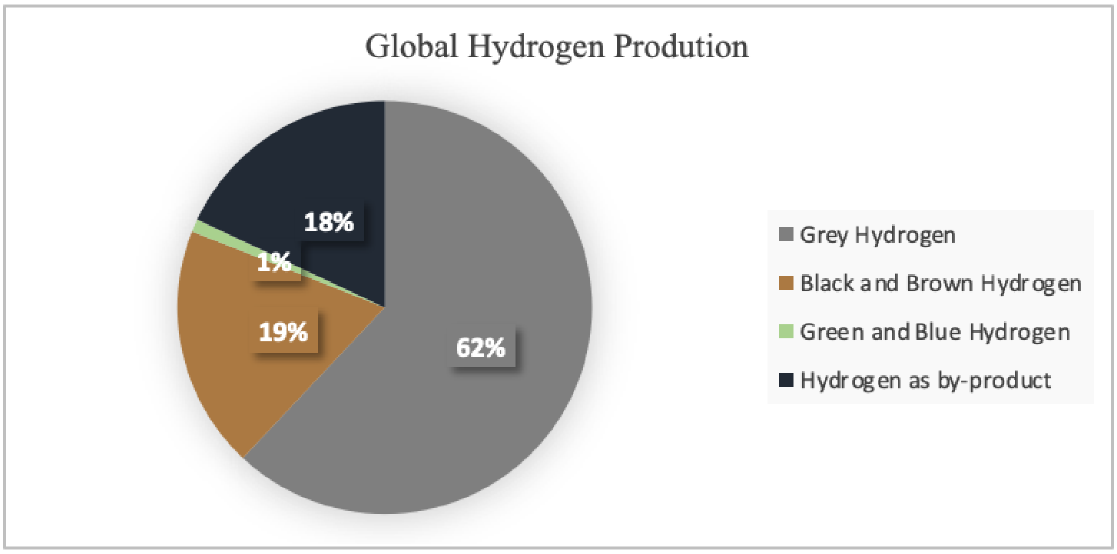
1.1 The Different Colours of Hydrogen

To date, hydrogen is predominantly used in the refining- and chemical sectors and produced using common fossil fuels such as coal and natural gas (Bermudez & Evangelopoulou, 2023). Thus, despite hydrogen's qualities as a clean energy carrier and burning fuel, its production remains responsible for significant carbon dioxide emissions (Bermudez & Evangelopoulou, 2023). Depending on the production method to separate hydrogen from its various compounds, the amount of carbon dioxide released during the process varies significantly. To indicate the production method and associated amount of carbon dioxide released in the process, hydrogen has been given different colour codes (National Grid Group, 2023).

Generally, one differentiates between green-, blue-, grey-, brown-, and black hydrogen (National Grid Group, 2023). Additional colour codes such as pink-, turquoise-, yellow-, and white are less prominent but also used as indicators in some cases. The only hydrogen variant that is produced in a climate-neutral manner, and thus most relevant for the green energy transition, is green hydrogen (World Economic Forum, 2021). Green hydrogen is produced by using clean energy from surplus renewable energy sources, such as solar- or wind power (World Economic Forum, 2021). Powered by renewable energy, an electrolyser is used to create an electrochemical reaction in which water is split into its components of hydrogen and oxygen, producing zero-carbon emissions in the process (National Grid Group, 2023). There are different kinds of electrolysers, the most dominant types being Alkaline- and proton-exchange-membrane electrolysers (Pavan, 2023). Both types are commercially available, but require policy support in order for green hydrogen to become competitive (Pavan, 2023). Thus, while green hydrogen is the most climate-friendly hydrogen variant, it is not yet widely implemented due to high production costs.

Blue hydrogen is another variant that is considered low in carbon emissions (National Grid Group, 2023). It is produced from natural gas in a process of steam reforming. During steam reforming natural gas and heated water are combined in the form of steam to separate hydrogen from its compound hydrocarbons (National Grid Group, 2023). Throughout the process hydrogen and carbon dioxide are produced as by-products (National Grid Group, 2023). Through carbon capture and storage (CCS) the carbon released during the production process is captured and stored (National Grid Group, 2023). However, since between 10 to 20% of the carbon produced cannot be captured, blue hydrogen is not a climate-neutral variant but rather low in emissions (World Economic Forum, 2021).

The most common form of hydrogen production is grey hydrogen (National Grid Group, 2023). Created from natural gas or methane using steam reforming, grey hydrogen is produced in the same manner as blue hydrogen but does not involve CSS (National Grid Group, 2023). However, the most environmentally damaging production method of hydrogen is that of brown- and black hydrogen (National Grid Group, 2023). Brown and black hydrogen are produced using brown- or black coal in a process of gasification, releasing significant amounts of both carbon dioxide and carbon monoxide gases into the atmosphere (Swinburne News Team, 2022). On a global scale, the production of low-emission hydrogen, and especially zero-emission hydrogen remains small. As of 2021, green and blue hydrogen combined covered barely one percent of the global hydrogen production as can be seen in the graph below:



(IEA, 2022b)

2.Hydrogen and the Green Energy Transition

In the Paris Agreement of the 2015 United Nations Climate Conference (COP21), the goal was set to meet net-zero emissions by the year 2050 (UN, n.d.). To meet this deadline, green- or renewable hydrogen applications are expected to play a fundamental role in sectors that are difficult to decarbonize such as heavy industry and transport (Bermudez & Evangelopoulou, 2023). Generally, six possible applications of green hydrogen to decarbonise major sectors of the economy can be identified.

The first is that renewable hydrogen can facilitate large-scale renewable energy integration. Renewable energy sources, such as solar power, vary in their electricity supply on a seasonal basis (The Hydrogen Council, 2017). Thus, the demand and supply of renewable energy do not always align throughout the year. For example, Germany's energy demand is ca. 30% higher in winter than it is in summer, but renewable energy generation is ca. 50% lower during the winter months (The Hydrogen Council, 2017). Via electrolysis, excess electricity generated by renewable sources can be converted into hydrogen during times of oversupply (The Hydrogen Council, 2017). The hydrogen can then be used as backup power during times of power deficit, as long-term carbon-free seasonal storage, or channelled into other energy-intensive sectors such as transport (The Hydrogen Council, 2017).

Second, hydrogen can help with the distribution of energy across sectors and regions. Countries that are not self-sufficient in their renewable energy production will require the import of renewable energy from other countries (The Hydrogen Council, 2017). Given that hydrogen has a high energy density with little energy loss over long-distance transportation, renewable energy could be transported via hydrogen pipelines to recipient countries (The Hydrogen Council, 2017).

Third, hydrogen can act as a buffer to increase systemic energy resilience. Currently, fossil fuels act as backup capacity for energy systems (The Hydrogen Council, 2017). However, as the use of fossil fuels is decreasing, different energy buffers will be needed which do not release greenhouse gases upon consumption. Due to its capacity as an energy carrier and clean energy fuel, hydrogen can act as a strategic energy reserve to safeguard resilience (The Hydrogen Council, 2017).

Fourth, green hydrogen can help in decarbonising the transport sector (The Hydrogen Council, 2017). To fully decarbonise the transport sector and meet the net-zero emissions goal by 2050, zero-emission vehicles need to be deployed on a large scale. Zero-emission vehicles include Battery Electric Vehicles (BEVs), as well as Fuel Cell Electric Vehicles (FCEVs) (U.S. Department of Energy, n.d.). FCEVs are a type of electric vehicle that consists of four major components (Lu, 2022), namely a battery, a hydrogen fuel tank, a fuel cell stack, an electric motor, and an exhaust. Similar to BEVs, FCEVs contain lithium-ion batteries to store electricity. However, they are substantially smaller as they are not the primary power source for an FCEV. Instead, FCEVs have a hydrogen fuel tank that stores hydrogen in its gas form. The hydrogen is then utilised by the fuel cell stack which generates electricity to power the motor (Lu, 2022). Hydrogen gas passes through the cell and is split into protons and electrons. Protons pass through the electrolyte (a liquid or gel material), while electrons are unable to pass. Instead the electrons take an external path which creates an electrical current to power the motor. At the end of this process, the electrons and protons meet and combine with oxygen, causing a chemical reaction that produces water emitted through the exhaust (Lu, 2022).

FCEVs offer several advantages over BEVs, such as quicker refuel times and longer distance range (U.S. Department of Energy, n.d.). However, the main benefit of FCEVs is that they create their own electricity via a hydrogen fuel cell while BEVs contain a large battery to store electricity (Lu, 2022). The BEVs' need for large lithium-ion batteries might pose a problem in the future as a worldwide lithium shortage could be on its way (Lee, 2023). Furthermore, FCEV infrastructure can build on existing gasoline distribution, making it a promising alternative to BEVs (The Hydrogen Council, 2017). However, the total cost of ownership for

FCEVs is currently substantially higher than for BEVs as FCEVs are only slowly starting to become commercially available. Thus, for FCEVs to make a substantial impact in the green energy transition they will need to be entirely fuelled with green hydrogen while remaining cost-competitive.

Fifth, hydrogen can help with the decarbonization of heavy industry. To date, industrial processes leverage gas, oil, and coal as energy providers causing large amounts of annual emissions (The Hydrogen Council, 2017). As a clean energy fuel, green hydrogen can replace these emission-heavy fuels in heavy industry sectors (The Hydrogen Council, 2017). Especially in the chemical industry hydrogen applications can act as both enablers for the industry to become net zero, while also opening opportunities for sustainable revenue streams (Cornelissen, n.d.).

Lastly, hydrogen can serve as feedstock (The Hydrogen Council, 2017). Using captured carbon dioxide and hydrogen in combination with carbon capture and utilisation (CCU) can transform carbon into usable products such as chemicals (IEA, n.d.). This synergy could be especially promising for the decarbonisation of the steel and cement industries.

While hydrogen has promising applications for the green energy transition, there remain several challenges and obstacles in its utilisation. First and foremost, the production of hydrogen in a sustainable and cost-effective manner is challenging (Hassan et al., 2023). Electrolysis, the production method for green hydrogen, has higher expenses than the conventional steam reforming method and as such is not market-competitive yet (Hassan et al., 2023). Furthermore, as the production, storage, and transportation of hydrogen requires substantial energy input, its overall energy efficiency is affected (Hassan et al., 2023). More so, throughout the hydrogen value chain, there can be significant energy losses (Hassan et al., 2023). Regarding the usage of hydrogen for storage of excess renewable energy, hydrogen's low volumetric energy density poses a challenge. Namely, hydrogen takes up large volumes compared to conventional fossil fuels like gasoline or diesel, making it difficult to store sufficient amounts (Hassan et al., 2023). Lastly, the overall economics of hydrogen production, distribution, and utilisation need to become more competitive in regards to existing energy sources for widespread adoption (Hassan et al., 2023). To date, neither renewable/green hydrogen nor low-carbon/blue hydrogen are cost-competitive against fossil-fuel-based hydrogen (European Commission, 2020).

3.Hydrogen on the Global Stage

The chances and challenges of hydrogen in regards to the green energy transition are also reflected in the global hydrogen demand, production, and investment trends. The global demand for hydrogen reached more than 94 million tons in 2021, a 5% increase from the previous year (IEA, 2022b). This increase in demand for hydrogen was partly due to the economic recovery after the COVID-19 pandemic and related mostly to hydrogen applications in the chemical sector (IEA, 2022b). However, the demand for hydrogen in new applications, such as heavy industry or transport sectors set to be decarbonized via hydrogen, was very low in 2021. Only 0.04% of global hydrogen demand stemmed from these sectors, the majority from transport. The increasing demand in this sector is reflective of the rising deployment of FCEVs in China (IEA, 2022b).

In global comparison, China is also the world's largest hydrogen consumer with a demand of ca. 28 million tons of hydrogen in 2021 (IEA, 2022b). The United States (US) takes the second place, followed by the Middle East in third place and the EU in fourth place with a demand of over 8 million tons in 2021 (IEA, 2022b). According to the IEA's stated policy scenario, global hydrogen demand might reach 115 million tons by 2030 (IEA, 2022b). However, most of this demand will stem from traditional hydrogen applications such as grey hydrogen in the refining- and chemical sectors, which would have a limited impact on achieving climate pledges (IEA, 2022b).

As for the current global hydrogen demand, it is almost entirely met by fossil fuel-heavy hydrogen production (IEA, 2022b). In 2021, 94 million tons of hydrogen were produced, associated with an amount of 900 million tons of carbon dioxide emissions (IEA, 2022b). The production of hydrogen via natural gas without any CCS (grey hydrogen) was the most common method of production, accounting for 62% in 2021 (IEA, 2022b). In stark contrast to that, low-emissions-hydrogen was less than 1 million tons in 2021, barely accounting for 1% (IEA, 2022b). Furthermore, the majority of low-emission hydrogen was produced via natural gas employing CCS, rather than hydrogen produced with electrolysers. Nevertheless, although the amount of hydrogen produced via electrolysers is small, green hydrogen production has increased by almost 20% since 2020 (IEA, 2022b). Especially in global finance, spending in green energy has steadily risen over the past years. While in 2015 global energy investments into green energy only reached around 1000 billion USD, 1700 billion USD were invested in green energy projects in 2023 thus far (IEA, 2023). Furthermore, there has been a steady increase in spending for electrolysers, with the majority of investments directed toward industry usage or refining (IEA, 2023).

China leads in investments in electrolysers, closely followed by the EU and the US (IEA, 2023). Overall, global hydrogen spending is mainly driven by several major projects, of which many are set to start up in China and the EU between 2023 and 2025 (IEA, 2023). In the EU, Shell's Holland Hydrogen 1 project is set to construct a 200MW renewable hydrogen plant in the Netherlands that can produce up to 60 tons of hydrogen per day (Shell, 2023). Similarly, France's Air Liquide Normand'Hy is building an electrolyser of at least 200MW for the production of green hydrogen (Air Liquide Normand'Hy, 2023). In China, Sinopec started the construction of a 200MW electrolyser in inner Mongolia (Hui & Min, 2023), as well as a 260MW facility in Xinjiang for green hydrogen production (Collins & Yihe, 2023). Furthermore, the Chinese company Envision has announced its plans to build the world's first net zero industrial park in inner mongolia, which is set to be powered via wind, solar, and hydrogen power (Envision, n.d.).

Lastly, a clear indicator of the growing interest in hydrogen is the growing number of national hydrogen strategies released in 2021. A total of 12 countries, as well as the EU, released national hydrogen strategies in 2021 (World Energy Council, Electric Power Research Institute, & PwC, 2021). An additional 19 countries are set to have national hydrogen strategies or have equivalent documents in preparation. Despite being at the forefront of electrolyser developments, to date China has no official national hydrogen strategy. However, China published an equivalent document titled the "Long-term Plan for the Development of the Hydrogen Energy Industry" in 2021 which will be outlined in the latter part of this brief (National Development and Reform Commission, 2022).

3.1. The EU’s take on Renewable Hydrogen

The EU sets high hopes on hydrogen to help achieve both its climate objectives, as well as to reduce European dependence on Russian energy (European Commission, n.d.b). Already prior to the energy market disruptions caused by Russia’s invasion of Ukraine, the European Clean Hydrogen Alliance had been set up in July 2020 (European Commission, n.d.a). Its members come from industry, public authorities, civil society, and other stakeholders to support the large-scale deployment of clean hydrogen technologies by 2030 (European Commission, n.d.a). Furthermore, the EU adopted its first-ever hydrogen strategy within the same month, providing a detailed account of the EU’s plans to upscale renewable hydrogen production (European Commission, 2020). In its strategy, the EU states to prioritise the development of green hydrogen via wind- and solar energy, as this is most compatible with the EU’s climate neutrality and zero-pollution goals (European Commission, 2020). To achieve a wide-range deployment of hydrogen, a three-phase development plan was developed as part of the EU’s hydrogen strategy.

In its first phase (from 2020 to 2024), the EU’s strategic objective is to install a minimum of 6 GW of renewable hydrogen electrolysers within the EU (European Commission, 2020). Furthermore, up to 1 million tonnes of renewable hydrogen are set to be produced. To achieve these goals, an upscaling of the manufacturing of electrolysers is required (European Commission, 2020). However, how this upscaling itself can be achieved is not addressed specifically. Ideally, the new electrolysers are set to be powered directly by local renewable electricity sources. The overall objective of this first phase is to lay down the regulatory framework for a well-functioning hydrogen market by incentivising both supply and demand for renewable hydrogen (European Commission, 2020).

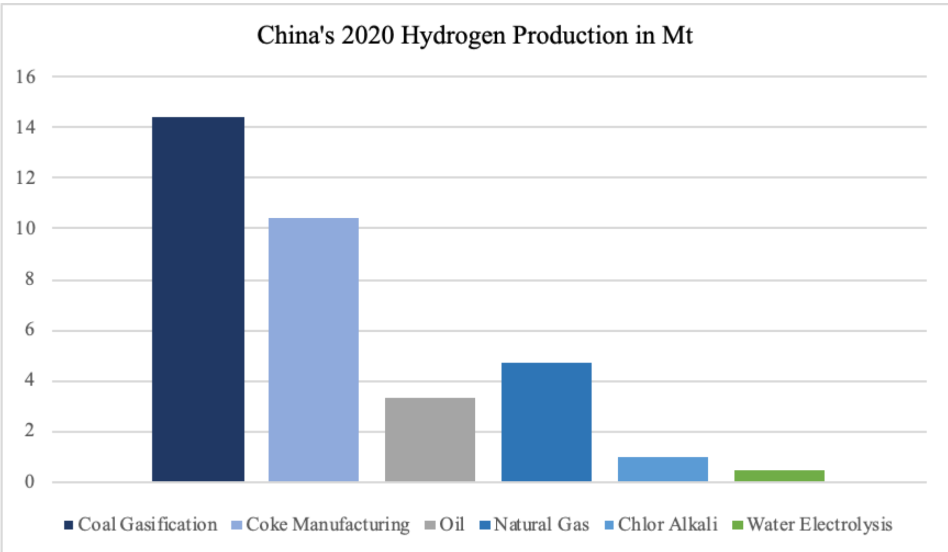
In the second phase, from 2025 to 2030, the EU plans to integrate renewable hydrogen into its energy system. To do so, a strategic objective was set to install at least 40 GW of renewable electrolysers by 2030 to produce up to 10 million tonnes of renewable hydrogen (European Commission, 2020). In this stage, renewable hydrogen is expected to become cost-competitive. Furthermore, so-called “Hydrogen valleys” (local hydrogen clusters) will be developed relying on local hydrogen production and local demand (European Commission, 2020). In this phase, the need for an EU-wide logistical infrastructure will emerge to facilitate the transport of hydrogen from renewable energy-rich areas to demand centres in other member states.

In the last phase, from 2030 to 2050, renewable hydrogen technologies are expected to reach maturity. Ideally, there will be large-scale deployment of renewable hydrogen in all hard-to-decarbonise sectors. To achieve this, renewable electricity production needs to increase substantially, as up to a quarter of renewable electricity will be needed for renewable hydrogen production (European Commission, 2020).

Three years after the EU Hydrogen strategy was released in 2020, a check-in reveals that the strategic objectives from the first phase are far from being met. Currently, less than 0.3 million tonnes of renewable hydrogen are being produced with electrolysers in the EU (European Commission, 2023). Furthermore, only 160 MW electrolyser output capacity is being installed (European Commission, 2023). Meeting the strategic objective of 10 million tonnes of renewable hydrogen would require the installation of 80 to 100 GW electrolyser capacity (European Commission, 2023). Moreover, first another 150 to 210 GW of additional renewable capacity would need to be installed for the production of renewable hydrogen (European Commission, 2023). The total investments required to reach the 10 million tonnes of renewable energy mark are believed to range from 335 billion EUR to 471 billion EUR (European Commission, 2023). Thus, the EU is currently facing major challenges in achieving its strategic objectives as outlined in the initial phase of its hydrogen strategy. This situation prompts the question of how these objectives can still be realised. Establishing bilateral cooperation between the EU and China within the hydrogen sector holds the potential to help the EU regain its momentum.

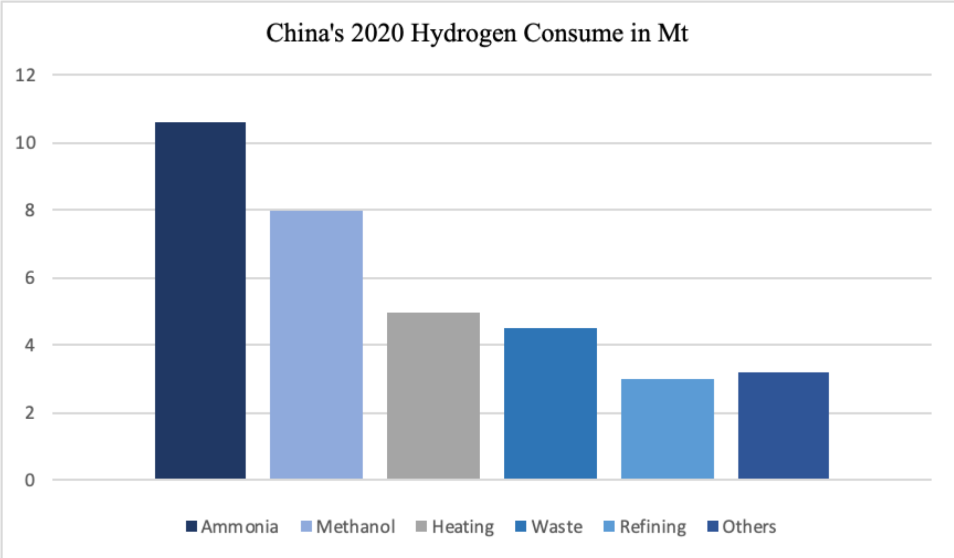
3.2. The Chinese Status Quo

China is the world's biggest producer and consumer of hydrogen and thus plays a major role in the development of hydrogen technologies (IEA, 2022a). However, the large majority of hydrogen produced in China is fossil-fuel-heavy. 96% of hydrogen manufacturing is fuelled with coal, natural gas, or oil (Jianjun & Wang, 2022). The remaining 4% include a mixture of hydrogen produced from electrolysis, or as a chlor-alkali by-product (Jianjun & Wang, 2022). The most dominant way of manufacturing is coal-based hydrogen production with a total market share of 72% (Jianjun & Wang, 2022). The graphic below shows a visualisation of China's 2020 hydrogen production. "Coke manufacturing" refers in this context to the preparing, charging, and heating of coal to produce the industrial fuel "coke".



(Jianjun & Wang, 2022)

As the graphic above illustrates, the production of renewable hydrogen via water electrolysis is still in its infant stage. Furthermore, among coal-derived hydrogen methods, coal gasification outweighs both coke- and chlor-alkali manufacturing. When it comes to the consumption of hydrogen in China, the leading sectors are the ammonia manufacturing sector, followed by methanol synthesis (Jianjun & Wang, 2022). However, as shown in the graphic below, 4.5 Mt of hydrogen goes to waste on an annual basis. Several different factors account for this, one being that it is often economically unattractive to separate hydrogen from other gases that are released during production processes (Jianjun & Wang, 2022). As hydrogen is becoming more valuable, there is a large untapped potential to utilise that by-product hydrogen instead of letting it go to waste (Jianjun & Wang, 2022).



(Jianjun & Wang, 2022)

3.3. China's Take on Renewable Hydrogen

While currently dominated by fossil fuels, China's hydrogen sector is set to change. In its "Medium- and Long-Term Plan for the Development of the Hydrogen Energy Sector", China explicitly favours the development of green hydrogen over other types of hydrogen (Grantham Research Institute, 2022). While spanning over a shorter period of time (2021 to 2035) than the EU's hydrogen strategy and being less rigorous, the Chinese strategy still sets out a number of straightforward targets. One of them is that China aims to bring 50.000 hydrogen fuel-cell vehicles on the road by 2025 (IEA, 2023). Furthermore, China plans to produce between 100.000 to 200.000 tonnes of green hydrogen using renewable feedstock (IEA, 2023). By the end of 2025, China hopes to enjoy a relatively complete system and policy environment for the deployment of the hydrogen energy industry (Grantham Research Institute, 2022). To achieve that, the plan seeks to coordinate and promote the construction of hydrogen energy infrastructure, actively carry out international cooperation on hydrogen technology innovation, and promote fuel-cell medium- and heavy vehicles (Grantham Research Institute, 2022). Furthermore, as regards hydrogen production, there is a clear emphasis on by-product hydrogen and renewable hydrogen.

Chinese regulators laid down three principles to set the stage specifically for by-product- and renewable hydrogen (Energy Iceberg, 2022). The first is "Consumption near Production" (Energy Iceberg, 2022). This principle states that a hydrogen gas market should be set up where hydrogen utilisation is close to the production location. The majority of gas supplies are set to come from industrial by-product gas recovery and renewable hydrogen. The second principle is that of "Diversified Gas Sources" (Energy Iceberg, 2022). Hydrogen production will embark on diversified clean technologies, while the production of fossil-fuel-based grey hydrogen might be restricted. The third principle "By-Product Gas to Lead" states that the most prioritised areas of hydrogen production will be industrial by-product gas and renewable electrolysis hydrogen (Energy Iceberg, 2022).

Furthermore, China's medium- and long-term plan indicates a prioritisation of hydrogen in the mobility market. The plan sets a clear target for the mobility market to deploy 50.000

FCEVs. Coinciding with this target, the Chinese central government approved five four-year pilot programs in Beijing, Shanghai, Guangdong, Henan, and Hebei province (Jianjun & Wang, 2022). These programs are designed to promote the commercialisation of key technologies related to FCEVs. More so, on the regional level, governments have developed their own, often more ambitious, hydrogen strategies (Li et al., 2022). Inner Mongolia has made quick advances in fuel cell technology and green hydrogen. Their local hydrogen industry is expected to be worth 15.4 billion USD by the year 2025 (Li et al., 2022). It will include an annual green hydrogen production capacity of 500.000 tons, as well as 100 hydrogen refuelling stations, and more than 10.000 hydrogen fuel cell vehicles (Li et al., 2022). While renewable hydrogen is not widely available in China yet, its application in FCEVs could help encourage the utilisation of green hydrogen in other applications too.

4.Existing Linkages in the Hydrogen Sector

China and the EU are two of the most important players in the green hydrogen sector. China currently takes the lead on electrolyser capacity additions with a cumulated capacity of 750 MW under construction expected to be online by the end of 2023 (Bermudez & Evangelopoulou, 2023). The EU leads in the area of policy action as it adopted two delegated acts in February 2023. The first act defined rules for renewable hydrogen, the second approved funding for the first two waves of hydrogen-related projects, and announced the first auctions of the European Hydrogen Bank for the end of 2023 (Bermudez & Evangelopoulou, 2023). Despite their leading positions, there exists limited collaboration between China and the EU in the hydrogen sector on the policy level. Cooperation is rather centred on the overarching goal of mitigating the impact of climate change than on niche sectors such as hydrogen specifically. However, existing partnerships and platforms can act as building blocks for future collaboration, and EU companies are actively breaching the borders of Europe in their pursuit of international hydrogen collaboration.

An example of existing partnerships is the “EU-China Partnership on Climate Change" which was announced in 2005 as the result of the China-EU summit (European Commission, 2005). The partnership included two cooperative goals, namely to develop advanced zero-emissions coal technology, and significantly reduce the cost of key energy technologies (European Commission, 2005). However, the cooperation lacks an explicit notion of hydrogen specifically. Fast forward to 2019, the EU-China Energy Cooperation Platform (ECECP) was launched (Press and Information Team of the European Delegation to China, 2023). The ECECP’s objective is to support the implementation of activities announced in the joint statement on the implementation of EU-China energy cooperation (European Commission, 2019). That includes developing innovative solutions for the clean energy transition and upscaling renewable energy deployment (European Commission, 2019). EIRI, the leading executive unit of ECECP, has made ambitious plans to build research labs on developing hydrogen technologies in cooperation with its Chinese and European partners (Press and Information Team of the European Delegation to China, 2023). However, ECECP has yielded no large-scale hydrogen collaborations between China and the EU yet.

Another example of existing collaboration is the high-level EU-China Environment and Climate Dialogue which was launched in 2021 for the first time (European Commission Directorate-General for Climate Action, 2023). Held once a year, the most recent dialogue took place in July 2023 to further avenues for cooperation on climate mitigation and the green energy transition (European Commission Directorate-General for Climate Action, 2023). While deepening the cooperation on the green energy transition is highlighted in the respective report, it lacks any mention of hydrogen (European Commission Directorate-General for Climate Action, 2023).

However, on the EU's member-state level, cooperation in the field of hydrogen is already developing. An example of that is the Sino-German energy partnership (GIZ et al., n.d.). Launched in 2006, the partnership recently yielded a report on the "Prospects of Renewable Hydrogen in China and its Role in Industrial Decarbonization" involving both the German Federal Ministry for Economic Affairs and Climate Action as well as the Chinese National Energy Administration (GIZ et al., n.d.). Within the Sino-German Energy Partnership, China and Germany have agreed to exchange strategies for the production and utilisation of green hydrogen produced from renewable energy sources (Energiepartnerschaft, n.d.). Thus, bilateral cooperation between EU member states and China in the hydrogen sector might be a fruitful starting point for developing larger EU-China cooperation in the field.

5.Exploring Room for Collaboration

Based on the EU's strategic objectives for the first phase of its hydrogen strategy, several promising fields for collaboration with China can be identified. The first is FCEVs in the transport sector (European Environment Agency [EEA], 2023b). Transport is a vital sector in the EU, but simply not sustainable in its current state. Transport is responsible for around a quarter of the EU's total greenhouse gas emissions (EEA, 2023b). While the advancement of electric cars in the EU has contributed to significant emissions reductions, electrical vehicles remain limited in terms of their range and are thus not yet efficient enough for long-haul transport (EEA, 2023c). To cut emissions in the long-haul transport sector, FCEVs are a promising alternative to BEVs. While the average electric vehicle has a range of 250 miles, fuel cell trucks currently have operating ranges of up to 625 miles (Walker, 2023). Yet, the total cost of ownership for FCEVs is higher than that for BEVs. However, FCEVs might still be the cheaper variant for long-distance transport given their on-board hydrogen storage which translates to fewer required stops and a shorter refuel time (Walker, 2023). As the EU has announced its ambitious goal to cut emissions from cars by 55% and from vans by 50%, as well as ban the deployment of carbon-emitting vehicles after 2035 (European Parliament, 2023), there is great demand for technologies to decarbonize the long-haul transport sector. China is currently taking the lead in the fuel-cell technology sector, with a rising deployment of FCEVs throughout the country (IEA, 2022b). Thus, a collaboration between European car manufacturers who hold long-standing expertise in the car sector with Chinese manufacturers that are developing novel fuel-cell technology could be a fruitful endeavour.

Second, electrolyser manufacturing and production can be a promising field for collaboration. To reach their strategic objectives the EU needs to install between 80 to 100 GW of electrolyser capacity by the end of 2024 (European Commission, 2023). Given that currently, only 160 MW electrolyser capacity is being installed (European Commission, 2023), the EU is far from reaching its objective in time. China leads in electrolyser capacity additions with 40% of all electrolysers being produced in China (Baker & Mathis, 2023). The majority of these electrolysers can be classified as alkaline electrolysers (Kindlova, 2023). Alkaline electrolysers have low production costs but require more electricity input per kilogram of hydrogen (Kindlova, 2023). According to statistical research by BloombergNEF, China is building more electrolysers than its industry can absorb in the next two years (Baker & Mathis, 2023). This development is the result of a higher emphasis on quantity, compared to quality. Chinese companies focus on producing as many alkaline electrolysers as possible at the expense of research and development (Parkes, 2023). By the end of 2024, China is expected to have more than 40 GW of electrolyser manufacturing capacity, which will likely outstrip global demand for electrolysers in 2025, which is predicted to be 10 GW (Parkes, 2023). As a result, Chinese factories may be forced to close, or at least significantly reduce their electrolyser production in the future.

In the EU, electrolyser manufacturing capacity is nowhere close to the quantity that China reaches but is convincing in quality. Companies tend to focus on producing proton-exchange membrane (PEM) electrolysers which are more costly in production but require less electricity input (Kindlova, 2023). These PEM electrolysers are especially promising in areas where electricity is costly (Kindlova, 2023). Thus, what Europe is missing in quantity, China is missing in quality. By joining forces, the EU can benefit from China's extensive manufacturing capacity, helping them bridge the gap in quantity needed to even come close to their strategic hydrogen objectives. Conversely, China can learn from the EU's expertise in producing high-quality PEM electrolysers, which are more efficient and suitable for areas with expensive electricity. This collaboration can leverage China's quantitative strengths and the EU's qualitative advantages, creating a win-win situation that aligns with both parties' strategic objectives in the hydrogen sector. Joint ventures between EU companies and Chinese manufacturers could be a good starting point for scaling up production in Europe, and discussing the possibility of technological transfer to China.

The third field where cooperation can be promising is renewable energy production and trade. The upscaling of renewable hydrogen production in the EU requires an upscaling of renewable energy to power the production. In 2021, 21.8% of the EU's energy consumption stemmed from renewable energy sources (Eurostat, 2023). The share of energy from renewable sources varies significantly between member states. While Sweden with around 63% of renewable energy is leading the EU's green energy transition, major European economies such as Germany and France fall below the 20% mark (Eurostat, 2023). In view of the newly set target to reach 42.5% of renewables in the Union's energy mix by 2030, the rate of deployment of renewable energy seen in the past needs to triple (EEA, 2023a). In addition to that, the upscaling of renewable hydrogen will require another 150 to 210 GW in renewable energy (European Commission, 2023). Given that China is the largest producer of solar energy, operating 228 GW in large utility-scale solar capacity and is involved in the manufacturing of over 80% of solar panels (Global Energy Monitor, 2023), cooperation in the renewable energy sector for the sake of upscaling local hydrogen production can be a fruitful endeavour. China is currently by far the largest partner for extra-EU imports of solar panels, covering around 89% in 2021 (Eurostat, 2022). While the EU is upscaling its renewable energy capacity, it is unclear if, and if so when, self-sufficiency would be reached. Given the strict timeline to meet its hydrogen objectives, waiting for self-sufficiency is unlikely to be an option. Thus, renewable energy trade allowing for energy imports from renewable-energy-rich countries is likely to gain momentum. As China operates more solar capacity than the rest of the world combined and is hosting nearly half of the world's wind capacity it can be classified as a renewable-energy-rich country (Mei et al., 2023). Thus, discussing cooperation in the field of renewable energy trade might be a fruitful endeavour.

It is important to emphasise that in the context of the growing global prominence of renewable hydrogen, the need for aligning policies between hydrogen producers and consumers on a global scale cannot be overstated. This alignment is particularly crucial with regard to matters such as subsidies, incentives, and regulations, as it is imperative to foster the competitiveness of renewable hydrogen both locally and internationally (IEA, 2022b). In this light, the EU and China should leverage their existing collaborative efforts and capitalise on platforms like the ECECP to engage in discussions about the governance of renewable hydrogen. Moreover, the objectives outlined in the "EU-China Partnership on Climate Change," including the substantial reduction of costs associated with pivotal energy technologies, remain relevant and should be pursued more vigorously.

Lastly, EU-China collaboration in the field of renewable hydrogen would not be free of challenges. The EU, and especially Germany, have hesitations when it comes to collaboration that involves technological transfer (Amelang, 2020). After the collapse of the German solar panel industry following the global market entry of cheaper Chinese panels, the EU is determined to prevent their hydrogen industry from following this example (Amelang, 2020). Furthermore, intellectual property protection has long been a point of tension between the EU and China. In 2022 the EU launched an official dispute settlement case against China at the WTO for restricting EU high-tech companies from protecting their intellectual property (European Commission, 2023). Lastly, in light of the Russia-Ukraine war that revealed critical vulnerabilities in the energy sector among EU member states, the President of the European Commission Ursula von der Leyen has called for “de-risking” (Schaus & Lannoo, 2023). Increased European dependence on China in the hydrogen sector may thus add an additional challenge to the EU’s strategic interests. Hence, it remains to be seen to what degree EU-China collaboration on renewable hydrogen can materialise considering these challenges.

6.Outlook

In light of the 2050 net-zero carbon emissions target, renewable hydrogen has emerged as a key element in achieving the green energy transition. While hydrogen holds significant promise as an energy carrier and a clean-burning fuel, its production requires large amounts of energy input. Green hydrogen, derived from renewable energy sources, stands out as the most ecologically friendly choice, however, it remains somewhat costly for now. Furthermore, a global overview of the hydrogen landscape underscores that the path to sustainable hydrogen production is still in its infancy, with green and blue hydrogen comprising only a minor fraction of global output. While investments are on the rise, the economics and efficiency of hydrogen production, storage, and distribution must improve to compete with conventional energy sources.

The EU and China, acting as major stakeholders in the hydrogen sector, possess the potential to drive substantial change. The EU's ambitious objectives and China's strategic targets present an opening for collaborative efforts. Particularly in the fields of fuel-cell technology, electrolyser manufacturing, and renewable energy production and trade, the two entities can complement one another's strengths and address their respective weaknesses. However, this collaborative endeavour is not without its challenges, encompassing concerns regarding technological transfer, intellectual property protection, regulatory alignment, and standard-setting. To ensure a successful partnership, EU-China cooperation in renewable hydrogen governance and policy alignment assumes pivotal importance.

Furthermore, a third actor is set to appear on the global hydrogen stage. In 2022 the European investment bank, the international solar alliance, and the African union unveiled a study into Africa's green hydrogen potential. As part of their analysis, potential hubs for harnessing solar power to create green hydrogen were identified, such as Mauritania and Morocco. The report concludes that Africa could secure access to clean and sustainable energy on the continent and become a global energy player through green hydrogen exports (Willis, 2022).

The EU is not the only global player that has come to realise Africa's green hydrogen potential. China has been actively investing into African countries, including into the green energy sector. As China is leading in the production of solar panels , EU-Africa hydrogen collaboration is likely to include China as well. With the Abu Dhabi COP28 approaching, China and the EU are set to further their commitments on climate change (United Nations Climate Change, n.d.). Moreso, they could leverage this chance to advance collaboration in the field of hydrogen, potentially involving African countries as third parties.

As the world grapples with the pressing need to curb carbon emissions and transition to cleaner energy sources, cooperation between the EU and China as the global drivers of hydrogen production, consumption, and technological advancement would represent a promising step towards a greener future. By building on existing cooperation, China and the EU can inch us closer to the critical goal of net-zero carbon emissions.

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European Institute for Asian Studies – EIAS a.s.b.l.
26 Rue de la Loi, 10th Floor
B-1040 Brussels

Tel.: +32 2 230 81 22
E-mail: eias@eias.org
Website: www.eias.org

LinkedIn: European Institute for Asian Studies
Facebook: EiasBrussels
Twitter: @EIASBrussels