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Hydrogen in China: Policy, Technology and Recommendations for Development

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HYDROGEN IN CHINA: POLICY, TECHNOLOGY AND RECOMMENDATIONS FOR DEVELOPMENT[1]

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Hydrogen is a clean, efficient and high-quality energy carrier with immense potential in various sectors, including transportation, industry, buildings and power generation. Poised to play a critical role in the global energy transition and industrial revolution, it holds promise as a key solution for decarbonizing energy systems and achieving climate mitigation goals. China, as the world's largest carbon emitter and hydrogen producer, is actively exploring and promoting the widespread adoption of hydrogen technologies in its future energy system.

China boasts abundant renewable resources and has a massive domestic market for clean energy, providing a conducive environment for the development of a robust new energy industry and economy where hydrogen could have a crucial impact. In recent years, hydrogen has taken center stage in China's public policy discussions, and the government has allocated significant resources for hydrogen technology research and market development.

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1. HYDROGEN IN CHINA'S ENERGY SYSTEM AND ECONOMY

Hydrogen is considered a vital component in China's low-carbon energy transition. The driving force behind the development of low-carbon hydrogen in China is the urgent need for energy system decarbonization and climate change mitigation. China has committed in 2020 to peaking carbon emissions before 2030 and achieving carbon neutrality before 2060 after joining the Paris Agreement. In late 2021, China further released the action plan for peaking carbon emissions to accelerate decarbonization across sectors via measures such as clean energy deployment, electrification and carbon capture, utilization, and storage (CCUS) technologies. Hydrogen, as a high-quality carrier of renewable energy, is expected to play a critical role in decarbonizing energy- and emission-intensive sectors such as industry and heavy-duty freight transportation that are otherwise difficult to decarbonize.

The synergistic development of hydrogen production and renewable energy generation presents a promising solution to address China's energy security challenges. The nation confronts a dual imperative: advancing low-carbon transformation while accommodating the escalating demand for energy. Projections indicate a potential increase in total energy consumption of approximately one billion tons of standard coal equivalent (tce) by 2030 compared to the 2020 baseline[2]. China's energy landscape is further complicated by a heavy reliance on imported fossil fuels, with over 70% of oil and 40% of natural gas being sourced from external markets. Contrastingly, China is endowed with abundant renewable energy resources. The estimated exploitable energy from renewable sources, including hydro, wind, and

2 1 kg of coal equivalent = 29.3 MJ.

solar, reaches a staggering 95.84 trillion kWh annually–nearly thirteen times the country's total power consumption in 2020. Achieving carbon neutrality and reducing dependence on fossil fuel imports necessitate a substantial increase in the proportion of renewable energy within the national energy mix throughout this decade. While most of China's renewable energy sources are distant from densely populated coastal regions, and renewable electricity generation have inherent intermittency issues due to its instability, hydrogen emerges as an easily storable and transportable energy carrier and has the potential to effectively address the spatial and temporal supply-demand disparities of renewable energy, thereby enhancing the resilience of the nation's future energy supply.

The advancement of hydrogen technology stands poised to catalyze China's ongoing industrial and economic transformation. Encompassing a comprehensive value chain that spans energy and chemical production, transportation, and steel manufacturing, the rising demand for hydrogen presents a lucrative opportunity for various stakeholders. Raw material and component suppliers, equipment manufacturers, and service providers, among others, stand to benefit significantly from the burgeoning hydrogen market. According to the China Hydrogen Alliance, the nation's foremost collaboration and innovation platform for hydrogen and fuel cell industries, the projected gross annual output value of China's hydrogen sector is set to soar to 10 trillion RMB (approximately $1.58 trillion) by the year 2050. This robust growth aligns seamlessly with China's systematic energy-economic transition, marked by a deliberate deceleration of fossil fuel expansion. In this context, the development of hydrogen and its associated technologies emerges as a pivotal enabler of China's new green economic paradigm, fostering the creation of entirely new industrial value chains.

2. GOVERNMENT STRATEGIES ON HYDROGEN DEVELOPMENT

In the early 2022, China unveiled the "Medium-and-Long-term Plan for the Development of Hydrogen Industry (2021-2035)," outlining ambitious targets for the hydrogen sector over the next 15 years. This comprehensive plan sets forth specific targets for 2025, notably, including the annual production of 100,000 to 200,000 tons of green hydrogen, the ownership of 50,000 hydrogen fuel cell vehicles, and the establishment of a robust and interconnected hydrogen industrial value chain. In the immediate future, a predominant supply of hydrogen is expected to come from industrial by-products and renewable sources, with the latter standing out as the main source in the long term. The application of hydrogen will expand into various sectors, including transportation, energy storage, power generation, as well as the steel and chemical industries. It can be observed that the Chinese government holds an optimistic yet cautious attitude toward hydrogen energy. Prior to 2035, the focus is on hydrogen technology innovation and the establishment of the industrial chain, rather than blindly pursuing large-scale applications.

At the provincial and municipal level, governments have been more proactive in promoting hydrogen development. Regional and local policymaking operates with a considerable degree of independence, often emphasizing regional competitiveness. Hydrogen, beyond its crucial role in the low-carbon transition, is recognized by local governments as a significant opportunity to spur economic growth and facilitate industrial restructuring. As of the end of 2021, over half of all provinces and more than 30 municipalities in China have unveiled specific plans to support the development of hydrogen.

However, hydrogen policy encounters challenges at various levels. On one hand, the long-term development trajectory for hydrogen must undergo continuous optimization and improvement in alignment with industry evolution. This is essential to minimize risks and uncertainties faced by both the industry and investors. On the other hand, existing market resources and policy initiatives, particularly those initiated by local governments, disproportionately emphasize hydrogen applications in transportation, with comparatively less attention given to other sectors. In addressing this imbalance, it is crucial for China to adopt a more comprehensive and coordinated approach in formulating and implementing hydrogen policies, in order to unlock the full potential of hydrogen in various sectors, fostering a more balanced development of hydrogen applications across all segments of the value chain.

3. HYDROGEN PRODUCTION

China is currently the world's largest producer of hydrogen, with an annual production exceeding 30 million tons, accounting for roughly one-third of global production. However, it's essential to note that the majority of China's hydrogen is derived from fossil fuels and is predominantly utilized as an industrial feedstock, and the proportion of hydrogen sourced from clean energy remains relatively small.Nearly 70% of China's hydrogen production originates from coal, natural gas, and petroleum, while around 30% is sourced from industrial by-product gases. Notably, water electrolysis contributes less than 1% to the overall hydrogen production in China.

China's current hydrogen supply chain, primarily reliant on fossil fuels, is anticipated to maintain its central role during the initial phases of the future transition. This is attributed to the cost competitiveness and market proximity of the existing fossil fuel-based infrastructure. Benefiting from abundant coal resources, China has established a substantial coal-chemical industry characterized by widespread capacity and significant annual coal-based hydrogen output. Conversely, natural gas-based hydrogen production faces challenges in terms of cost-effectiveness within the Chinese context, despite the maturity of steam methane reforming (SMR) technology, which is widely applied globally. Several factors hinder its cost competitiveness in China, including limited natural gas availability, high sulfur content, and the significant impact of natural gas prices on hydrogen production costs. Consequently, the production of hydrogen through SMR may only be economically viable in regions that are well-endowed with natural gas resources.

China's hydrogen production will be very likely to transit from 'grey' directly to 'green'. Although China's existing hydrogen production capacity is sufficient to meet current domestic demand, according to the plan, the future hydrogen supply, especially the incremental part, will transition more towards renewable energy sources, bypassing the so-called 'blue hydrogen,' which involves producing hydrogen from coal or natural gas, capturing the emitted carbon dioxide, and storing it underground. The main reasons influencing this decision include the considerable costs linked to CCUS applications in China and the nation's substantial reliance on external natural gas resources. For instance, the adoption of CCUS technology in coal gasification would inflate the total cost of hydrogen production by a factor of 1.5 to 2 as high. Another significant contributing factor is China's long-term commitment to transitioning to a renewable-dominated energy mix, discouraging the use of fossil fuels for hydrogen production.

In the long run, water electrolysis utilizing renewable energy holds great promise to play a dominant role in hydrogen production. Currently, three technology options—alkaline hydrolysis, Proton Exchange Membrane (PEM) electrolysis, and high-temperature steam electrolysis—are available at different stages of maturity. Over time, hydrogen production from electrolysis is projected to become cost-effective in China. Given the immense potential of 95.84 trillion kWh in annual renewable energy production from solar, wind, hydro, geothermal, and biomass power, a 15% utilization of this total output could generate 100 million tons of hydrogen through electrolysis. This quantity would fully satisfy terminal demand. Additionally, other technologies such as coal-to-hydrogen production combined with CCS, bio-hydrogen production, and photocatalytic water splitting are likely to emerge as effective supplements to water electrolysis production.

4. HYDROGEN STORAGE, TRANSMISSION AND DISTRIBUTION

The prevalent approach to transporting hydrogen over short distances in China today is using tube trailers at a pressure of 20 MPa. For longer distances, liquid tanker trucks with higher storage pressure and hydrogen pipelines are much more economically viable. However, due to technical limitations, hydrogen transportation at 50 MPa pressure by road is currently uncommon; similarly, the application of low-temperature liquid hydrogen tanker trucks is also quite limited.

The length of existing hydrogen pipelines in China, mostly from dedicated ones at refineries, is notably less extensive than those found in Europe or the United States. This discrepancy can be attributed to the substantial initial investment required, the high cost and import dependency of composite materials, and a lack of sufficient application scenarios. In recent years, various Chinese cities have been exploring an alternative approach, investigating the transport of hydrogen through the existing gas network by blending it with natural gas. One application of this blended mixture is its use as fuel gas for kitchen stoves and internal combustion engines. An illustrative case is the city of Zhangjiakou, which has initiated a pilot project to explore injecting 4 million cubic meters of hydrogen into the urban gas grid. The aim is to utilize the blended gases for cooking purposes and for Hydrogen enriched with Compressed Natural Gas (HCNG) vehicles. Another potential application involves separating and purifying the hydrogen from the transported gas mixture for reuse in fuel cells or power generators. However, such cases are currently infrequent in China due to high technical barriers and associated costs.

For future large-scale applications, the construction of dedicated long-distance hydrogen pipelines becomes imperative. Hydrogen, due to its impact on pipeline materials, can induce cracking and leakage in pipes. Moreover, there is a limit to the amount of hydrogen that can be blended, and separating hydrogen from natural gas is costly while inefficient. A recent development in this regard is the initiation of the construction of a new hydrogen transmission network in Hebei Province. Boasting a total length of 145 km, it surpasses any existing hydrogen pipeline in China. This network will primarily transport hydrogen from north to south within the Beijing-Tianjin-Hebei region. Meanwhile, China's oil and gas pipeline companies have started to collaborate with businesses, academic research institutions, and other key stakeholders in the hydrogen value chain. Together, they are actively promoting the development of a new hydrogen transmission network and addressing potential technical challenges.

China has established the world's largest network of hydrogen refueling stations. Due to the high cost and limited availability of high-pressure hydrogen storage, most refueling stations in China operate at a pressure of 35 MPa. The majority of these stations depend on external hydrogen supply, although a few have on-site hydrogen production capabilities. For instance, a station in Dalian can produce hydrogen using a wind-solar hybrid power generation system. Meanwhile, a station in Foshan, South China, has the capacity to simultaneously produce hydrogen from natural gas and water electrolysis at rates of 500 Nm^3/h and 50 Nm^3/h, respectively. The latter process is powered by a rooftop solar system.

The development of new hybrid refueling stations may witness an explosive growth in the coming years. One potential trend in developing future refueling infrastructure is the increasing deployment of petrol-hydrogen multi-fuel stations. In 2019, for example, 17.9% of new hydrogen refueling stations constructed were multi-fuel stations, and this ratio surged to about 50% in 2020. The China Petroleum & Chemical Corporation (SINOPEC), which owns and operates China's largest petrol refueling network, has expressed its intention to renovate and convert many of its petrol stations into petrol-hydrogen multi-fuel stations in the future.

5. HYDROGEN APPLICATION

The transportation sector has emerged as the primary driver for new demand for hydrogen in China. Sales of fuel cell vehicles (FCVs) have consistently and rapidly increased annually since 2015. In contrast to many other countries that emphasize hydrogen applications in passenger mobility, China's development path for FCVs is distinct. Commercial applications, particularly hydrogen trucks and buses, take precedence, dominating current sales with a cumulative number surpassing 10,000. Currently, commercial demonstrations of FCVs are underway in approximately 17 provinces across China. Certain regions, such as Guangdong and Shanghai, have deployed over a thousand hydrogen fuel cell vehicles.

However, hydrogen in transportation is presently not cost competitive compared to existing technologies. The total market demand for new hydrogen applications remains relatively small, and there are considerable variations in hydrogen supply, use, and distribution across regions. To overcome these challenges, mature business models must be developed for various segments of the value chain, including production, storage, and transportation, to mitigate the high costs. For instance, the current purchase cost and fuel cost of a 42-ton hydrogen-powered heavy-duty truck in China are 230% and 100% higher, respectively, than its diesel-powered counterparts. Consequently, the total cost of owning and operating a hydrogen heavy-duty truck over its life cycle is approximately 150% higher than that of a regular internal combustion engine truck. However, looking ahead, with ongoing technological advancements, efficiency improvements in the hydrogen supply chain, and potential economies of scale, the utilization cost is anticipated to significantly decrease. Research conducted by Tsinghua University suggests that the cost of hydrogen fuel cell systems may reduce by about 80% in the next decade. Additionally, estimations by PetroChina indicate that hydrogen-powered heavy-duty trucks may achieve cost parity with diesel-powered trucks before 2030.

In addition to FCVs, several hydrogen demonstrations are currently in progress across various sectors in China, with the potential to achieve commercial maturity in the future. These include fuel cell tramcars, fuel cell forklifts, inland shipping, aviation, steel production, combined heat and power (CHP), power generation, energy storage, and renewable methanol.

6. FUTURE POLICY FOCUS

- **Key technologies.**

The lack of advanced technologies stands as a significant limitation in the development of China's hydrogen economy. Current industrial methods for hydrogen production, such as Steam Methane Reforming (SMR) and Coal Gasification (CG), fall short of meeting environmental requirements. Consequently, the direction for the medium and long term involves the production of hydrogen through water electrolysis powered by renewable energy sources. As a result, prioritizing fuel cell-related technologies becomes crucial for advancing the commercialization of hydrogen Fuel Cell Vehicles (FCVs). Presently, key materials essential for fuel cell technology, including catalysts, proton exchange membranes, and carbon papers, are still reliant on imports in China. Additionally, the production of other critical components, such as membrane humidifiers, bipolar plates, air compressors, and hydrogen circulation pumps, lags behind leading countries.

- **Cost competitiveness.**

The determination of the development path for hydrogen requires a comprehensive evaluation of factors such as the maturity of hydrogen fuel cell technology, the source of hydrogen, economic considerations, and the impact on emissions. The current levelized cost of all hydrogen production routes varies from approximately 15.34 to 59.27 yuan per kilogram. This range predominantly reflects the cost disparity between hydrogen production from conventional fossil energy sources (coal, natural gas) and water electrolysis utilizing various renewable energy sources. The learning effect emerges as a crucial factor influencing the future levelized cost of hydrogen production. As a certain production technology level improves, the per-kilogram levelized cost of hydrogen energy is expected to gradually decrease. By 2040, without factoring in carbon prices, the gap in levelized cost among various technologies is projected to narrow, reducing to approximately 15-21 yuan per kilogram by 2040 and 13-19 yuan per kilogram by 2060. In comparison with conventional fossil energy routes, the levelized cost of hydrogen production through water electrolysis powered by hydropower, wind power, and photovoltaic sources is significantly lower.

- **Hydrogen supply infrastructure planning.**

Looking ahead, infrastructure planning is pivotal for the hydrogen economy, but uncertainties persist. The high cost of green hydrogen may lead to initial applications starting with grey hydrogen. It is essential to be aware of and prevent the risk of path singularity, as the energy supply system characteristics of different hydrogen supply paths are notably distinct. In the blue hydrogen path, the installed capacity of hydrogen production is more concentrated, and the hydrogen storage capacity is larger. If blue hydrogen is extensively developed in the initial stages and gradually transitions to green hydrogen, there could be a risk of infrastructure connection mismatch, asset shelving, and unstable hydrogen supply.

- **Fugitive Hydrogen Emissions.** [3]

There is a growing body of evidence indicating that, while emitting no carbon dioxide at the point of use, acts as an indirect greenhouse gas. Hydrogen itself is not a potent absorber of infrared radiation, making it a non-direct greenhouse gas. However, its reaction with and depletion of naturally occurring hydroxyl radicals in the atmosphere, which play a crucial role in methane removal, introduces an indirect greenhouse gas effect. As methane is a potent greenhouse gas, the leakage of hydrogen will extend its atmospheric lifetime as well as climate impact. The latest estimate for the Global Warming Potential (GWP) of hydrogen is 11 ± 5 over a 100-year time horizon.[4] The leakage of hydrogen into the atmosphere, across various stages of its lifecycle, including production, storage, distribution and use, will partially offset some of the economic and climate benefits associated with hydrogen applications.

3 Frazer-Nash Consultancy.Fugitive Hydrogen Emissions in a Future Hydrogen Economy. 2022.

4 Nicola Warwick et al. Atmospheric implications of increased Hydrogen use. 2022.

ABOUT ICCSD

Institute of Climate Change and Sustainable Development (ICCSD) of Tsinghua University was founded in October 2017. ICCSD is committed to building a collaborative platform for strategy and policy research, talent cultivation, international dialogue, bridging the gap between academic research and policy, and providing support and solutions related to climate change and sustainable development.

ICCSD has accomplished several flagship research projects, such as Strategy and Pathway of Low-carbon Transition in China, and Synergizing Actions on the Environment and Climate, etc. Also, ICCSD has established the Methane Emission Reduction Cooperation Platform and Nature-based Solution Cooperation Platform to foster broader collaboration and knowledge sharing. The Institute has also launched extensive bilateral and multilateral dialogues, including "Climate Change Global Lectures" and "Friends of the Paris Agreement"; and provided full support for "Global Alliance of Universities on Climate" and held two South-South cooperation climate training programs.