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Future of Hydrogen in Energy Transition and Reform

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ABSTRACT

In order to ensure energy supply and cope with climate change, a new round of energy transformation must be carried out. Hydrogen can play an important role in energy transformation with its high energy density and clean and low-carbon energy attributes. First of all, it clarified the development position of hydrogen energy in the transformation of energy. It pointed out that hydrogen energy is an energy carrier that promotes the large-scale development and utilization of renewable energy, and it is an energy medium that realizes the interconnection, complementation, and coordinated optimization of multiple energy networks. Secondly, the technical route for the development of the hydrogen energy industry is analyzed. Combining with the characteristics of China's energy structure and development status, the development of the hydrogen energy industry should focus on the core advantages of clean, low-carbon, flexible and efficient, in the coordinated development of hydrogen and renewable energy, the clean production of industrial hydrogen, and the development of fuel cell technology. In addition, transportation power systems and distributed energy systems can give priority to promoting large-scale development.

1. Introduction

The environmental pollution and climate change brought about by the large-scale development and utilization of fossil energy have exacerbated global concerns about energy issues. Therefore, the energy transition of renewable energy instead of fossil energy is an inevitable trend [1]. With its high energy density and clean and low-carbon energy properties, hydrogen can play an important role in the energy transition and reduce human society's excessive dependence on fossil energy, which is important for achieving the greenhouse gas emission reduction targets the Paris Agreement [2] significance.

Since entering the 21st century, the development and utilization of hydrogen energy have gradually accelerated. Many countries and regions have successively elevated the development of the hydrogen energy industry to the height of the national energy strategy and have continuously increased their support for the development and industrialization of hydrogen energy and fuel cells[3,4,5]. In recent years, countries worldwide have deployed several demonstration projects to promote the large-scale development of the hydrogen energy industry. In July 2019, the German government approved 11 hydrogen energy demonstration projects, including green hydrogen production in megawatt-scale large electrolytic cells, synthetic methane production, and methanol production [6]. In 2016, China listed "Hydrogen Energy and Fuel Cell Technology Innovation" as one of the 15 key tasks of the "Energy Technology Revolution and Innovation Action Plan (2016-2030)"; it will "develop a new generation of energy technologies such as hydrogen energy and fuel cells" "As a disruptive technology that leads industrial change in development, it is included in the "Outline of National Innovation-Driven Development Strategy," marking the inclusion of the hydrogen energy industry in the national energy strategy. In March 2020, the National Development and

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Reform Commission and the Ministry of Justice issued the “Opinions on Accelerating the Establishment of Green Production and Consumption Laws and Policies.” They included the “Research and formulation of standards and supporting policies for developing new energy such as hydrogen and ocean energy” in 27 items. List of key tasks. China’s emphasis on developing the hydrogen energy industry has risen to an unprecedented strategic height[7,8]. However, the hydrogen energy industry is still in its infancy in China. The relevant industrial policies at the national level are not yet clear. The certification and supervision system is not yet complete, and key materials and equipment need technological breakthroughs. Therefore, constructing a hydrogen energy industry chain suitable for China’s energy transformation and transformation, including low-carbon production, safe storage and transportation, and flexible application, faces many challenges [9,10].

At present, China has paid great attention to applying hydrogen energy in fuel cell vehicles and is one of the main sources of hydrogen fuel cell technology in the world [11,12]. Many local governments have formulated industrial support policies to support fuel cell vehicles. Development and investment and construction of hydrogen refueling stations [13,14]. However, based on the urgent need to respond to climate and environmental changes, the clean, low-carbon, flexible, and efficient energy attributes of hydrogen can reduce carbon emissions in the transportation sector through fuel cells and contribute to the transformation of energy production and consumption in China. Therefore, play a more active role in China. Therefore, accurately grasping the development positioning of hydrogen energy in the energy transition and reform is of great significance for promoting the sustainable and healthy development of China’s hydrogen energy industry.

Based on the analysis of the driving factors of the new round of green energy transformation, this article points out that addressing climate change is the main driving force for the development of the hydrogen energy industry and clarifies the important role and development positioning of hydrogen energy in the energy transformation and reform. Analyze China’s hydrogen energy industry technology development current status and propose a large-scale development direction for the hydrogen energy industry suitable for China’s energy transition and reform. The novelty of this paper is to consider hydrogen as the main driver of the energy transition to a greener future.

2. The role of hydrogen in the energy transition

Driven by the rapid growth of energy demand, humanity has undergone two energy transformations in the history of energy development and utilization, from diesel fuel to coal and then from coal to oil and gas, forming the current world with coal, oil, and natural gas. The energy pattern is dominated by fossil fuels [15]. In 2018, the total global primary energy consumption was 198.07×10^8t standard coal, a growth rate of 2.9%, about twice the average level (1.5%) in the past ten years, and reached the highest growth rate since 2010, of which fossil energy consumption was 167.77×10^8 t standard coal, a growth rate of 2.41%, accounting for 84.7% of the total primary energy consumption. In China, the total primary energy consumption in 2018 was 46.77×10^8 t standard coal, a growth rate of 4.28%, of which fossil energy consumption was 39.88×10^8 t standard coal 3.08%, accounting for 85.27% of the total primary energy consumption[16]. With the increase in consumption year by year and the non-renewable characteristics, fossil energy faces reduced reserves, increased difficulty in mining, and rising production costs. The situation of energy security supply that this may trigger is becoming increasingly tense.

The large-scale development and utilization of fossil energy are accompanied by many greenhouse gas emissions, negatively impacting the global climate environment [17]. In the 21st century, countries worldwide have a deeper understanding of climate and environmental changes, and it is urgent to control greenhouse gas emissions and curb global warming. The Paris Agreement adopted by the Paris Climate Conference in 2015 embodies the international community’s consensus on actively responding to climate change and proposes to control the global temperature rise within 2 ℃ (compared to the level of the pre-industrial period) and strive to control it within 1.5 ℃. Emission reduction goals. In 2018, carbon emissions from global energy consumption reached 331×108 t, an increase of 1.7% over 2017, which was the fastest-growing year since 2013.

Moreover, emissions from energy consumption account for two-thirds of the total global emissions. The latest research of the International Energy Agency points out that if the emission reduction target of a temperature rise of not more than 2 ℃ is achieved, global greenhouse gas emissions in 2030 will be reduced by 25% compared with the 2010 level, and net-zero emissions will be achieved by 2070; if the temperature rise is not more than 1.5 ℃ The emission reduction target of China needs to reduce emissions by 45% in 2030 and achieve net-zero emissions in 2050 [18]. It can be seen from this that the continuous increase in carbon emissions from energy consumption has made it difficult for countries worldwide to work together to achieve the emission reduction targets established by the Paris Agreement.

Therefore, the focus of today’s world energy problem is no longer just to ensure supply but to superimpose the huge challenge of controlling greenhouse gas emissions and curbing global warming, among which the challenge of reducing emissions and controlling temperature is more prominent. Under the dual driving force of ensuring energy supply and responding to climate change, countries worldwide have reached a consensus on building a clean, low-carbon, safe, and efficient green energy system: vigorously develop sustainable renewable energy and improve its performance. The ratio of energy structure to solve greenhouse gas emissions caused by fossil energy and possible energy depletion, and finally realize the transformation and transformation of traditional fossil energy to renewable energy.

In the context of actively responding to climate change, hydrogen's high energy density, clean, low-carbon, flexible, and efficient energy properties have once again attracted global attention. From the 1970s to the beginning of the 21st century, the development of the hydrogen energy industry has experienced two ups and downs. Especially in 1970, General Motors of the United States first proposed the concept of "Hydrogen Economy" [19], hope to use advanced fuel cell technology to replace fossil energy with hydrogen energy to alleviate the dependence on oil and natural gas in the transportation sector and improve air pollution. However, due to the fall of oil and gas prices and the uncertainty of climate change policies, The enthusiasm for hydrogen energy development and utilization has also cooled down, and no large-scale development has been achieved. At the same time, carbon capture, utilization, and storage (CCUS) as an important technology to solve the carbon emissions of fossil energy have received widespread attention, and lithium-ion battery electric vehicle technology has begun to be promoted and applied. These factors are intertwined. This limits the large-scale development of hydrogen energy. It can be seen from this that it is difficult to promote the industrial development of hydrogen energy simply by using hydrogen energy to replace part of fossil energy in the transportation field. Entering 2010, with the increasing pressure on global emission reduction and temperature control, the development of the hydrogen energy industry has once again received extensive attention from governments and energy companies. Therefore, accurately grasping the development positioning of hydrogen energy in energy transformation is an important foundation for promoting the sustainable and healthy development of the hydrogen energy industry.

Responding to climate change is the most important factor for hydrogen energy once again. Based on the urgent need for emission reduction and temperature control, hydrogen energy is no longer limited to the field of transportation because hydrogen can be obtained in large quantities without relying on fossil fuels and can be transported and transported over long distances. Long-term storage, so hydrogen can expand to more industrial fields and more energy production and consumption links and play an active role. As high-energy-density clean energy, hydrogen can use electrolyzed water hydrogen production technology at the energy production end to realize electric energy storage through hydrogen storage, improve the flexibility of the power system, promote the development and use of renewable energy on a larger scale, and accelerate the promotion of renewable energy. Energy is the process of replacing fossil energy in the primary energy structure; as a flexible and efficient secondary energy, hydrogen can use fuel cell technology at the energy consumption end to realize the integration of electricity, gas, heat, and other energy networks through electricity-hydrogen conversion. Complementary interconnection and coordinated optimization promote the development of distributed energy and improve the efficiency of energy terminal utilization. Therefore, in the new round of energy transformation and reform, hydrogen energy is an energy carrier that promotes the large-scale development and utilization of renewable energy and is an energy medium that realizes the interconnection and complementarity and collaborative optimization of multiple energy networks.

3. Hydrogen energy industry development status

The huge market space is China's biggest advantage in developing the hydrogen energy industry, supporting every link in the hydrogen energy industry chain. However, the unbalanced development of the technological level of various links in the hydrogen energy industry chain is the main obstacle that restricts the sustainable and healthy development of China's hydrogen energy industry. The hydrogen energy industry chain includes upstream preparation, midstream storage and transportation, downstream applications, and other links involving materials science, equipment manufacturing, assembly technology, engineering practice, and other technologies. At present, there is still a significant gap between China and the advanced international level in some key technologies, core components, system integration, and other aspects.

3.1. The source and preparation of hydrogen

Thermochemical hydrogen production from fossil fuels (coal, natural gas), hydrogen production from industrial by-products, and hydrogen production from the electrolysis of water are currently the three most important hydrogen production methods in China. Coal-based hydrogen technology is in a leading position globally, and pressure swing adsorption dehydrogenation technology is equivalent to the advanced international level. In terms of electrolyzer technology, which is a piece of key equipment for electrolyzing water to hydrogen, the alkaline electrolyzer technology is mature and close to the international level, with complete supporting facilities for related industries and the lowest cost [20]; proton exchange membrane (PEM) electrolyzer The technology is still in the early stage of industrialization, and there is a certain gap with the advanced level of foreign countries. However, the PEM electrolyzer technology has high working efficiency, safe and reliable operation, high purity and high pressure of hydrogen produced [21,22], and fast start-up, Wide workload range (0%～160%), and other advantages, if connected to the grid, it can become a flexible resource of the grid system and provide auxiliary services; solid oxide electrolyzers (SOE) technology has more than 90% Work efficiency, both at home and abroad are in the laboratory research stage, and they do not have the technical ability to support commercialization.

The original intention of the development of the hydrogen energy industry is based on the clean properties of hydrogen. At present, 96% of hydrogen is produced from fossil fuels. The technology is mature, and the cost is the lowest. However, with a large amount of CO_2 emissions, it is contrary to the clean properties of hydrogen. According to calculations, the carbon emission intensity of hydrogen production from coal, oil, and natural gas is 19 tCO_2/tH_2, 12 tCO_2/tH_2, and 10 tCO_2/tH_2, respectively. There are currently 130 coal-to-hydrogen projects globally, of which more than 80% are in China [23]. Internationally, hydrogen production from natural gas is the mainstream hydrogen production method. Therefore, China’s carbon emission intensity in hydrogen production from fossil fuels is higher, and the pressure to reduce emissions is greater. Due to China’s high coal reserves and abundant renewable resources such as scenery, “fossil fuel + CCUS” and “renewable energy + electrolyzed water” will become clean and efficient hydrogen production technology choices. China’s CCUS industrial technology has made great progress after more than ten years of development. CO2 flooding has become the main technical development direction of CCUS, but there are still many bottlenecks in technology promotion, and economic feasibility and environmental safety are also facing huge challenges[24]. The “renewable energy + electrolyzed water” hydrogen production technology has reached a level that can support commercialization. At present, the main technological breakthroughs are improving the electrolysis efficiency and life of the PEM electrolyzer and reducing renewable energy power generation costs. In recent years, the rapid development of wind power and photovoltaic power generation in China has accelerated the substantial reduction in the cost of renewable energy power generation. The cost of hydrogen production from the electrolysis of water has approached hydrogen production from traditional fossil fuels.

3.2 Hydrogen storage and transportation

High-pressure gas and low-temperature liquid are the most common hydrogen storage methods. In terms of high-pressure hydrogen storage containers, China’s aluminum-lined fiber-wound bottle (Type Ⅲ) technology has matured, 35 MPa pressure type products have been widely used, hydrogen storage density reaches 40 g/L, 70 MPa pressure type products are still In the demonstration stage, there is a certain gap with the advanced level of foreign countries. Domestic vehicle-mounted high-pressure hydrogen storage systems mainly use 35 MPa Ⅲ type bottles, while foreign countries mainly use 70 MPa plastic liner filament-wound bottles (type Ⅳ). The research and development of 70 MPa hydrogen storage bottle technology and equipment is currently the key research direction of many domestic scientific research institutions. The high-pressure hydrogen storage bottle is of great significance for improving the mileage of hydrogen fuel cell vehicles. In terms of high-pressure hydrogen transportation, long-tube trailer technology has reached the advanced international level and is currently the main method of hydrogen transportation in China, with a storage pressure of 20 MPa. The long tube trailer transportation method is economically feasible within a transportation radius of no more than 150 km.

Gas pipelines are an important way to realize large-scale, long-distance, and low-cost hydrogen transportation [25, 26, 27]. The technology of hydrogen transmission pipelines abroad is relatively mature, but China has carried out relatively little technical researches in this area. At present, the total number of hydrogen pipelines is only 400 km. Because China is still in the early stages of the development of the hydrogen energy industry and the one-time investment in the construction of a hydrogen pipeline network is relatively large, it is currently possible to actively explore ways to add hydrogen to natural gas and make full use of the existing natural gas pipeline network facilities. The latest research of the natural project supported by the European Union shows that the proportion of hydrogen-added (volume) is controlled by 20%, and hydrogen-added natural gas has relatively little impact on pipeline network equipment, materials, and terminal gas equipment. There is no need to carry out major technical transformations, but natural

The density of liquid hydrogen is 845 times that of gaseous hydrogen so that low-temperature liquid hydrogen storage can achieve high energy density storage and long-distance transportation. When the transportation distance exceeds 1 500 km, it is more economical to transport the low-temperature liquid hydrogen. Large-scale liquefied hydrogen equipment and non-destructive storage and transportation of liquid hydrogen are important technical options for large-scale, long-distance transportation of hydrogen energy in the future. Hydrogen liquefaction needs to lower the temperature to -253 ℃. If hydrogen itself is used to provide the energy required in the liquefaction process, the current state of the art will consume 25% to 35% of the initial amount of hydrogen. China has made breakthroughs in liquid hydrogen/liquid helium temperature zone refrigeration technology and large-scale cryogenic equipment manufacturing technology, laying a solid technical foundation for realizing large-scale and high-efficiency hydrogen liquefaction and hydrogen liquefier manufacturing.

In addition, solid hydrogen storage and organic liquid hydrogen storage can achieve a hydrogen storage volume density of more than 55 g/L, but the technology still needs to be improved [29,30] and cannot support industrialization.

3.3 Hydrogen application

Fuel cells are electrochemical devices that convert chemical energy into electrical energy and are currently the most effective way to utilize hydrogen energy. The hydrogen refueling station is an important infrastructure that provides hydrogen fuel for hydrogen fuel cells and other hydrogen energy terminal utilization devices. In recent years, China's hydrogen fuel cell core technology has made significant progress. However, core materials such as proton exchange membranes, carbon fiber porous diffusion layers, and platinum-carbon catalysts still rely on imports. The core components such as air compressors and hydrogen circulation pumps are still at the level of world-class technology. Thus, there is a gap; the overall performance and life of the stack need to be further improved. After more than ten years of experience accumulation, it can now design and build a 35 MPa hydrogen refueling station in hydrogen refueling station construction. The localization of key components of core equipment such as hydrogen compressors, hydrogen refueling machines, and hydrogen storage tanks in stations has accelerated. However, the whole machine's manufacturing accuracy and performance stability still lag behind the advanced international level. As for the 70 MPa hydrogen refueling station field currently occupying a mainstream position globally, China is still in the demonstration and verification stage.

It can be seen from this that in the hydrogen energy industry chain, compared with upstream preparation and midstream storage and transportation, the technical shortcomings of downstream application links are still more prominent, resulting in unbalanced technological development in the entire hydrogen energy industry chain. Therefore, focusing on breaking through the key technical bottlenecks in utilizing hydrogen energy and achieving balanced technological development of all links in the industrial chain is an important technical guarantee for the sustainable and healthy development of the hydrogen energy industry.

4. Future Roadmap of Hydrogen industry

Based on the development positioning of hydrogen energy in the transformation of energy and the status quo of technological development, the development of China's hydrogen energy industry must focus on the two advantages of "clean and low-carbon" and "flexible and efficient." Advantageous areas are the first to promote large-scale development.

4.1 Synergistic development of hydrogen energy and renewable energy

Renewable energy is the fastest-growing source of energy. It is estimated that by 2040, half of the world's energy supply increase will come from renewable energy, and renewable energy will become the largest source of electricity by then [31]. China has abundant renewable energy resources. The theoretical reserve of wind energy is 32.26×10^8 kW, and the exploitable wind energy resources exceed 10×10^8 kW[32]. Therefore, vigorously developing renewable energy has become a clean, low-carbon, and important measure for a safe and efficient new energy system. In recent years, renewable energy has achieved rapid development in China. According to statistics from the National Bureau of Statistics and China Electricity Union, the national full-caliber power generation in 2018 was 96939×10^8 kW·h, an increase of 8.4% year-on-year, of which hydropower, wind power, and solar power were $12{,}329\times10^8$ and 3660×10^8 and 102775×10^8 kW·h, in a year-on-year increase of 3.2%, 20.2%, and 50.8%. The total power generation from renewable energy is $17{,}764\times10^8$ kW·h, accounting for 25.4%, which is still far lower than the power generation of thermal power $49{,}231\times10^8$ kW·h (70.39%). There is huge room for the development of renewable energy.

Energy storage is the key to large-scale renewable energy development. However, when the proportion of intermittent renewable energy in the power structure is high, hourly energy storage is difficult to meet the stable operation requirements of the power system [33,34,35]. Through the electrolysis of water to produce hydrogen, renewable energy electricity is converted into hydrogen and stored, realizing daily, monthly, and even seasonal energy storage, effectively solving renewable energy consumption, volatility, and intermittency.

In the short term, in some areas, abandoning wind, light, and water to generate hydrogen can obtain certain market benefits[36,37,38]. However, in the medium and long term, using advanced PEM electrolyzer technology [39,40,41], the prospects for the coordinated development of hydrogen energy and renewable energy are broader. On the one hand, it will promote larger-scale renewable energy grid-connected power generation and promote energy production. Revolution, on the other hand, green hydrogen is used as an industrial raw material in petrochemical, steel, construction, and other industries that are difficult to reduce emissions to achieve deep decarbonization. In addition, through the conversion of electricity-hydrogen and electricity-hydrogen-based fuels [42,43,44], international hydrogen energy trade will be carried out promptly, and China’s abundant renewable energy will be exported to the world.

4.2 Clean production of industrial hydrogen

As an industrial feed gas, hydrogen is widely used in the production of synthetic ammonia and methanol, as well as in the hydrocracking and hydrogenation purification of crude oil refining processes, and as protective gas, reducing gas, and reaction gas for steel, electronics, non-ferrous metals, float glass The production process in various industrial fields [45]. At present, the annual production of hydrogen in China has reached 2×107 t, most of which come from the reforming of fossil fuels such as coal, oil, natural gas, and industrial by-product hydrogen, and the proportion of hydrogen produced by electrolysis of water is less than 1% [46]. According to the China Hydrogen Energy Alliance, China’s hydrogen demand will reach 3.5×107 t in 2030 and 6×107 t in 2050 [47].

Technology, cost, and environmental protection are the three major factors determining how to produce hydrogen in the future. In terms of technology, both fossil fuel hydrogen production and hydrogen production from electrolyzed water has been commercialized; in terms of cost, hydrogen production from fossil fuels has temporary advantages. The cost of hydrogen production from electrolyzed water depends on the price of electricity and the investment and operating costs of electrolyzers; in terms of environmental protection, Renewable energy electrolysis of water to produce hydrogen has an absolute advantage. Although the carbon emissions of hydrogen production from fossil fuels can be reduced through CCUS technology [48], the investment and operating costs will rise. The International Energy Agency’s research shows that CCUS technology can reduce the carbon emission intensity of coal-to-hydrogen production to 2 kg CO_2/kgH_2, but the investment cost increases by 5%, and the operating cost increases by 130%.

In the short term, coal-to-hydrogen will still dominate China, but the downside of cost is very limited. With the increase of environmental protection pressure and the improvement of the carbon market mechanism, the cost of coal-to-hydrogen will rise. Therefore, the development of coal-to-hydrogen Space will be limited; natural gas hydrogen production is the mainstream internationally, but in China, limited by the tight natural gas resources, the development space is limited and may become smaller and smaller; industrial by-product hydrogen is suitable for nearby supply and is effective in the short term. However, the industrial by-product hydrogen is limited by the production capacity of the main product, and there is an upper limit on the production capacity of hydrogen. Therefore, in the medium and long term, as the cost of renewable energy power generation and the investment cost of electrolyzers continue to decline, hydrogen production from renewable energy power generation will become the mainstream hydrogen production method, and the low (zero) hydrocarbon obtained from this can promote industrial hydrogen use. Deep decarbonization of the field.

4.3 The main development direction of hydrogen fuel cell

Fuel cells are the most effective application of hydrogen energy in energy consumption terminals [33,49] and can be applied to transportation [50] and distributed energy systems [41]. The large-scale application of fuel cell technology in the transportation field can promote clean energy terminal consumption, alleviate China’s excessive dependence on oil and natural gas in the transportation field, and reduce the degree of dependence on oil and natural gas. The distributed energy system is one of the important application scenarios of hydrogen fuel cell[51-55], which can be widely used in homes, buildings, and parks to realize the triple supply of cooling, heating, and power and improve energy utilization efficiency system.

The development of fuel cell vehicles is mainly limited by the layout and development speed of hydrogen refueling stations[19]. Therefore, in the short term, the development of public transportation, freight trucks, material forklifts, and other commercial vehicles based on fuel cell power systems can be focused on [23]. In these commercial vehicle fields, the vehicles have the characteristics of high utilization rate, high power requirements, fixed operating routes or operating environment, etc., so they can achieve centralized hydrogenation, increase the utilization rate of hydrogen refueling stations, and reduce the difficulty of hydrogen refueling station layout and investment costs. At the same time, because the fuel cell power system has fewer mechanical moving parts and low noise pollution, the working environment can be effectively improved. Thus, in the long run, fuel cell passenger vehicles are more low-carbon and environmentally friendly than lithium-ion electric vehicles, with long cruising range and fast fuel refueling, and have broad development prospects [22].

Distributed energy systems based on hydrogen fuel cell technology use fuel cells as power generation units instead of traditional gas turbine power generation systems, effectively reducing nitrogen oxide emissions and noise pollution. As a result, and according to the different needs of the energy consumption end, energy level matching and energy supply according to quality can be carried out to meet the energy demand nearby, reduce the loss of the transmission link, and realize the cascade utilization and coordinated supply of cold, heat and electricity, which is to improve the comprehensive energy consumption end. An important means of using efficiency has broad application prospects in industrial parks, large buildings, and concentrated residences.

5. Conclusion

Ensuring the supply of energy and addressing climate change are the dual driving forces of the new round of energy transition and reform, and addressing climate change is the main driving force for the development of hydrogen energy. With its clean, low-carbon, flexible, and efficient energy properties, hydrogen can play an important role in energy transition and reform. Hydrogen is an energy carrier that promotes the large-scale development and utilization of renewable energy and realizes the interconnection, complementation, and collaborative optimization of multiple energy networks. Energy medium.

The unbalanced technological development of various links in the hydrogen energy industry chain is the main obstacle restricting the sustainable and healthy development of China′s hydrogen energy industry. Therefore, concentrating scientific research on key problems and breaking through key technological bottlenecks is an important technical guarantee for the sustainable and healthy development of the hydrogen energy industry.

Combining the development positioning of hydrogen energy in the transformation of energy and the status quo of technological development, China′s hydrogen energy industry can develop in the coordinated development of hydrogen energy and renewable energy, the clean production of industrial hydrogen, and the transportation power system and distribution based on fuel cell technology. Thus, promoting large-scale development first in terms of energy systems and other aspects.

The hydrogen energy industry is still in its infancy in China. The large-scale development should focus on the core advantages of clean, low-carbon, flexible and efficient. At the policy level, a long-term hydrogen energy development strategy needs to be formulated, and at the technical level, it needs to have the independence of key materials and equipment. For intellectual property rights, laws and regulations and certification supervision systems need to be improved at the market level.

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