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Study on the Development of China's Hydrogen Energy Industry Based on the Background of "Double Carbon

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Abstract

Under the background of "double carbon", China's hydrogen energy industry has ushered in a vigorous development. As a clean, safe, and efficient renewable energy source, hydrogen energy is playing an important role in today's energy shortage, environmental pollution, and increasing carbon emissions. Starting from the relevant policies for the development of hydrogen energy in China, this paper compares and analyzes the development of the hydrogen energy industry chain at home and abroad, explores the challenges facing the development of hydrogen energy, and puts forward the suggestions of reducing the cost of transporting and storing hydrogen, breaking through the technical barriers of the industry, speeding up the exploration of sustainable development paths, increasing the efforts of infrastructure construction, and innovating the business model of hydrogen energy application.

Keywords: *Bicarbon background; hydrogen energy industry; industrial chain; sustainable development*

INTRODUCTION

Scientific and technological progress and social development have promoted the widespread use of primary energy sources such as coal, oil and natural gas, etc. With the increasing demand for energy, global energy shortages and climate problems such as environmental pollution have become increasingly severe, and the realization of green, low-carbon sustainable development, has become the consensus and common responsibility of all mankind. At the 75th session of the UN General Assembly in September 2022, China proposed a "dual-carbon" goal, striving to peak and neutralize carbon dioxide emissions by 2030 and 2060, respectively[1]. Compared with the United Kingdom, France, and other countries that have already achieved carbon peak, China has the shortest time set aside for achieving carbon neutrality, only about half of that in Europe and the United States[2]. And in 2020, China's energy system carbon dioxide emissions of about 11.3 billion tons, still occupies about 1/3 of the global carbon emissions [3], the growing energy demand and accelerate the contradiction between carbon reduction and emission reduction is increasing. In order to solve this contradiction, it is necessary to vigorously develop low-carbon and zero-carbon renewable and clean energy to replace fossil energy and reduce the consumption of and dependence on traditional fossil energy.

1. The role of hydrogen energy in the context of the "two-carbon" goal

Hydrogen energy is regarded as a highly promising zero-carbon renewable energy source for the 21st century, and its great potential for development lies not only in its renewability but also in the fact that hydrogen has a very high mass-energy density, which allows it to store more energy in the same volume [4]. Hydrogen has the highest calorific value of all non-nuclear fossil, chemical, and biomass fuels, and it produces only water when burned, whereas traditional fossil energy sources produce large amounts of pollutants and greenhouse gases during combustion, and are not a quality option for promoting the goal of sustainable development [5]. In addition, hydrogen is chemically stable and is more convenient to transport and store. Hydrogen energy is also highly adaptable and can be developed in a highly integrated manner with a wide range of green energy sources such as solar and wind [6]. To accelerate the realization of global energy transition and achieve the goal of global "carbon neutrality", the key lies in the construction of an energy technology system centered on hydrogen energy technology, and ultimately achieve the ultimate goal of sustainable development and energy transition - the complete substitution of fossil energy by renewable clean energy. The ultimate goal of sustainable development and energy transition - the complete substitution of fossil energy by renewable and clean energy.

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2. China's Hydrogen Energy Related Policies and Development Outlook

2.1 Relevant support policies for the development of the hydrogen energy industry

China has been actively exploring the development path of the hydrogen energy industry, in recent years, the central and local governments have been increasing their support for the development of the hydrogen energy industry, and have successively introduced a variety of supporting incentives. In 2019, China's Government Work Report emphasized for the first time the policy on the development of hydrogen energy and explicitly put forward the need to support and promote the construction of supporting infrastructure for the hydrogen energy industry, such as hydrogen refueling stations, on the ground. In 2020, the National Energy Bureau published the Energy Law of the People's Republic of China (Draft for Opinion), which for the first time included hydrogen energy as one of the categories of new energy [7]. Since then, hydrogen energy has officially entered China's energy control system.

The Carbon Peak Action Program by 2030 issued by the State Council explicitly proposes to accelerate the research and development of hydrogen energy technology and the large-scale application of hydrogen energy [8].In 2022, the "14th Five-Year Plan" for a modern energy system proposes to focus on attacking the core technologies of renewable energy hydrogen production and hydrogen energy storage, transportation, application, and fuel cells [9]. The Opinions on Improving the Institutional Mechanisms and Policy Measures for Green and Low-Carbon Transformation of Energy states that hydrogen energy should be promoted as an important component of clean energy transportation, the layout of hydrogen refueling points should be improved, and efficient and safe hydrogen transmission methods should be explored [10]. In March of the same year, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) jointly issued the Medium- and Long-Term Plan for the Development of the National Hydrogen Energy Industry (2021-2035) (hereinafter referred to as the "Plan"), which states that the hydrogen energy industry is an important component of the future national energy system and a strategic emerging industry, as well as a key development direction for future energy transformation. At the same time, the Plan also indicates that a diversified hydrogen energy application ecosystem should be constructed by 2035, covering various fields such as transportation, energy storage, industry, and civil use; and that the proportion of hydrogen energy in China's end-use energy system will be more than 10% by 2050. [11]In March 2023, the National Standards Commission and other six departments jointly issued the "Guidelines for the Construction of Hydrogen Energy Industry Standard System (2023 Edition)", which proposes to systematically build a standard system for the whole industry chain of hydrogen energy, and accelerate the updating and improvement of the industry standard sub-systems.2024 In February 2024, the Ministry of Industry and Information Technology and other seven departments jointly issued the "Guidance on Accelerating the Promotion of Greening of Manufacturing Industry", which puts forward the focus on the "dual carbon" and the "dual carbon". In February 2024, the Ministry of Industry and Information Technology and other seven departments jointly issued the "Guidance Opinions on Accelerating the Greening of Manufacturing Industry", proposing to focus on the needs of the energy revolution and industrial change under the goal of "dual-carbon", focusing on the hydrogen demand in petrochemical and chemical industry, iron and steel industry, transportation, energy storage, power generation, etc., constructing the whole industrial chain technical equipment system of hydrogen energy, and improving the technical economy and industrial chain completeness of hydrogen energy.

2.2 Impact of supporting policies on the development of the hydrogen energy transition

Hydrogen energy in China is mainly used in petrochemical, metallurgy, electronics, and aerospace industries, but the hottest application field now lies in hydrogen fuel cells. In order to promote the transformation of the energy consumption structure, the Chinese government has given the greatest policy support to the development of hydrogen fuel car batteries, and hydrogen energy is taking the lead in the formation of large-scale applications in the field of transportation energy. By the end of 2022, China's fuel cell vehicle ownership has reached 12,682 units, and the sales volume in 2022 reached 3,789 units, a year-on-year increase of 138.90%, and the cumulative number of hydrogen refueling stations that have been built and put into operation has reached 358. The forecast report of China Hydrogen Energy Alliance shows that fuel cell vehicles will remain the core carrier of China's hydrogen energy utilization in the future, and the ownership of hydrogen fuel cell vehicles will reach more than 100,000 by 2025, which will drive further rapid growth in the hydrogen energy market scale. It is expected that by 2050, the demand for hydrogen in China will be close to 60 million tons, of which the demand in the transportation sector will account for more than 40% [12].

Overall, China's significant policy support for the development of hydrogen energy has led to significant progress in the development of the hydrogen energy industry. Policies have been released to support the hydrogen energy industry from the perspectives of industrial system standards, technology research and development, and the whole industry supply chain so that China's hydrogen energy industry has begun to take shape: hydrogen production continues to improve, multiple breakthroughs in storage and transportation, the industry has begun to show its clustering effect, and large-scale centralized enterprises are entering into the industry one after another [13]. Now, a total of 30 provinces in the "14th Five-Year Plan" mentioned the development of hydrogen energy, forward-looking national policies, and intensive, continuous regional policies to form a system, together to ensure the benign and sustainable development of the hydrogen energy industry.

Despite the remarkable progress, the development of China's hydrogen energy industry is still at an early stage, and it is necessary to continue to explore the commercialization and large-scale development model of the hydrogen energy industry. A series of national policies focus on supporting China's hydrogen energy industry to take into account the short- and medium-term economic development goals and long-term climate imp

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rovement goals, accelerate the scale production stage, continue to overcome technical difficulties to solve the cost constraints of the core link of the whole industrial chain of hydrogen energy, to achieve large-scale commercialization of the application of hydrogen energy to increase the proportion of hydrogen energy, give full play to the important strategic role of hydrogen energy as a zero-carbon energy source in the energy transition, and further support the economic and social green development. Support the green development of economy and society.

3. Current status of hydrogen energy industry chain development

3.1 Basic introduction of hydrogen energy industry chain

According to the process order from production to market application, the structure of the hydrogen energy industry chain can be roughly divided into three parts: upstream, midstream, and downstream. the upstream hydrogen production end includes hydrogen production from coal, hydrogen production from renewable energy sources, and hydrogen production from other processes [14]; the midstream storage and transportation end includes four types of storage and transportation methods, including gaseous storage and transportation, liquid storage, and transportation, and solid storage and transportation, and organic liquid storage and transportation; and the downstream application end mainly involves the construction of hydrogen refueling stations and the application of hydrogen in the fields of transportation, industry, and construction. The downstream applications are mainly related to the construction of hydrogen refueling stations and applications in transportation, industry and construction.

3.2 Development status of foreign hydrogen energy industry chain

As for the upstream of the industry chain, hydrogen production is located in the first place in the upstream of the industry chain, and the progress of its technology and equipment will directly affect the construction and development of the middle and lower reaches. According to the cleanliness of the production process, hydrogen energy can be divided into "gray hydrogen", "blue hydrogen", "green hydrogen", of which gray hydrogen is generated from the combustion of fossil fuels and industrial processing by-products. Hydrogen is produced from the combustion of fossil fuels and by-products of industrial processes, which emits a large amount of carbon dioxide and has a low degree of environmental protection; [15]blue hydrogen is further added to the carbon capture technology on the basis of gray hydrogen, which reduces carbon emissions by about 90%; green hydrogen is produced by converting all kinds of renewable energy sources into electrical energy, and then utilizing the electrical power to electrolyze water to produce hydrogen for obtaining the production of which is non-polluting and has zero carbon emissions, with a high degree of environmental protection. Looking at the international arena, Germany, the Netherlands, Australia, the United States and other European and American countries have made great progress in hydrogen preparation technology [16], renewable energy-driven electrolysis of water to produce hydrogen technology is becoming more and more widely used. For example, Germany has been actively promoting the use of renewable energy for hydrogen production, and has formulated a corresponding program for injecting hydrogen generated by wind power into the natural gas pipeline network [17]; the Netherlands has initiated an offshore wind farm development project, and is striving to become a center for green hydrogen production, import and distribution; Australia has utilized its abundant solar energy and wind energy resources, and has been actively developing renewable energy-driven electrolysis facilities, and has built up to become a major exporter of green hydrogen; the United States Increased deployment of the hydrogen production industry in terms of research and development and incentives, and initial commercialization of technologies to produce and store hydrogen using wind and photovoltaic power.

Industry chain midstream, Europe and the United States to develop hydrogen energy pipeline transportation has more than 70 years of history, in the construction and transportation of hydrogen energy pipeline network has been a large scale, European countries have been using undersea tunnels and shipping methods to transport green hydrogen; December 2022, Spain, France, Portugal in 2030 before investing 2.5 billion euros in the construction of a large undersea tunnel from the H2Med, the pipeline will be transported hydrogen to various regions within Europe. Japan's hydrogen energy policy, funding, technology is more complete, limited by the scarcity of natural resources, land area constraints, Japan's renewable energy hydrogen production cost is high, so need to rely heavily on overseas imports. Currently, Japan is developing a maritime transportation chain, mainly relying on maritime hydrogen transportation, and building a liquefied hydrogen + methylcyclohexane (MCH) transportation chain.

As for the downstream of the industrial chain, hydrogen energy in foreign countries is mainly applied in the industrial field, transportation field and energy storage field. In the industrial field, petrochemical and chemical industries are the big head of hydrogen energy consumption, and it is also widely used in metallurgy and electronics, and currently, the use of green hydrogen accelerates the process of decarbonization and sustainable development of the chemical industry[18]. In the field of transportation, hydrogen fuel cell vehicles have become a highly regarded alternative energy vehicle. In the field of energy storage, hydrogen energy can be used for the production of electricity and heat, providing an effective means of storing and utilizing renewable energy sources. In February 2019, the report "European Hydrogen Roadmap: a Sustainable Pathway for Europe's Energy Transition" released by the European Fuel Cell and Hydrogen Joint Organization (EFHJO) clearly pointed out that Europe has already set foot on the path of transitioning to a decarbonized energy system [19], and that by 2030, the industrial applications can account for up to one-third of ultra-low carbon hydrogen energy. The U.S. Hydrogen Economy Roadmap, released in November 2019, says that chemical industries such as ammonia, methanol, and refining use large amounts of gray hydrogen and need to transition to low-carbon hydrogen to reduce carbon emissions.

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3.3 Domestic Hydrogen Energy Industry Chain

From the hydrogen energy industry chain upstream production technology point of view can be seen in China's hydrogen production technology and foreign developed countries is narrowing the gap between the law, electrolysis hydrogen because it has the advantages of green low-carbon, the future has great potential for development. At present, China's cost-effective hydrogen production device configuration is low. Due to the alkaline water electrolysis (AWE) hydrogen production accounted for a large proportion of the weakness of its power adjustment range is small, which limits the efficiency of hydrogen production in China. China's hydrogen energy is mainly gray hydrogen produced from fossil fuels. Although the technology is mature and low-cost, the method is unsustainable due to high carbon emissions and pollution, and the fact that fossil fuels are non-renewable sources of energy. Therefore, China is constantly turning to renewable energy to produce hydrogen. Among them, electrolytic water to hydrogen technology progress is more significant. At present, the domestic AWE technology is mature and occupies a dominant position in the industrialized application by virtue of the advantage of low catalyst cost [20]. Proton exchange membrane (PEM) water electrolysis hydrogen technology is gradually maturing towards industrialization, with low energy consumption, high hydrogen purity, and good adaptability to renewable energy sources, it is the most promising hydrogen technology in the future, but the problems that constrain its industrialization are the short lifespan and the high cost of materials [21]. Solid oxide electrolysis of water (SOEC) hydrogen production technology is still in the preliminary demonstration stage, the relevant industrial technology is still immature, anion exchange membrane (AEM) electrolysis of water hydrogen production technology is still in the laboratory research and development exploration stage [22].

Hydrogen production from electrolytic water	**AWE**	**PEM**	**AEM**	**SOE**
Working fluid	water solution：10%-40% KOH/NaOH	solid polymer	solid polymer	solid ceramics
distant (socially aloof)	Polyphenylene sulfide cloth or composite material	Perfluorosulfonic acid resins	Polyaryl ethers	solid oxide
anode material	Ni	Pt、Ir、Ru	Ni-based alloys	LSMYSZ、CaTiO3
cathode material	Ni合金	Pt、Pt=C	Ni、Ni-Fe、NiFe2O4	金属陶瓷复合材料
temp	65-100°C	70-90°C	50-70°C	650-1000°C
operating pressure	2-10MPa	2-10Mpa	<35MPa	<30Mpa
efficiencies	62%-82%	67-84%	70-90%	90%
current density	0.2-0.4A/cm2	0.6-2A/cm2	0.1-0.5A/cm2	0.3-1A/cm2
power consumption	4.5-5.5kWh/Nm3	3.8-5kWh/Nm3	4.8kWh/Nm3	3.6kWh/Nm3
advantages and disadvantages	Mature technology, industrialized, low cost; however, low current density, corrosive, low purity, large O&M cost	Small-scale industrialization, high current density, high purity of hydrogen production, low operating costs; but short service life, high material costs	In the laboratory R & D stage, simple operation, good stability, high current density; but corrosive, high material cost, there are technical barriers	Laboratory R&D stage, high efficiency and large amount of hydrogen production, but the material involves high requirements, low stability, there are technical barriers

Table 1: Comparison of electrolyzed water to hydrogen production technologies in China

In the midstream of the industry chain, an important prerequisite for the commercial development and application of hydrogen energy is the safety and efficiency of storage and transportation technology. The wide application of hydrogen energy in transportation, construction, and other fields has gradually increased the demand for hydrogen transportation and storage, and safe and efficient hydrogen storage and transportation technology has become an important link in the hydrogen energy industry. At this stage, the main mode of hydrogen transportation in China is long pipe trailer gaseous storage and transportation, which is more costly compared with the pipe network transportation that has formed a system in developed countries in Europe and the United States. At present, China's hydrogen energy demand is scattered, hydrogen refueling stations have not

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yet been put into use on a large scale, the economy of pure hydrogen pipeline transportation is too low, and the main mode of pipeline transportation in China is to utilize the existing natural gas pipeline network for hydrogen doping transportation, which greatly restricts the use of hydrogen energy.

On the downstream side of the industry chain, the industrial field consumes most of the hydrogen produced, while the transportation field is the fastest developing field of hydrogen energy, and hydrogen fuel cell is the main direction of China's hydrogen energy industry development at present. Hydrogen fuel cell vehicles have gained strong support from the state due to the advantages of strong environmental adaptability, cleanliness and non-pollution, etc. Meanwhile, now the domestic hydrogen energy vehicle technology is maturing, and it has made great progress in range and safety, China's hydrogen fuel cell vehicles are gradually being recognized and accepted by the consumer market, and the hydrogen fuel cell vehicles have entered the early stage of commercialization: from 2016 to 2022, the Chinese hydrogen fuel cell vehicle ownership rises year by year, by the end of 2022, China's fuel cell vehicle ownership is close to 13,000 units, and the sales volume reaches 3,789 units in 2022, a year-on-year increase of 138.90%. In addition to the field of hydrogen fuel cell vehicles, China's hydrogen energy application has also made progress in the field of ships, buildings, aviation, etc. In 2021, Danzao Town, Foshan City, carried out a hydrogen smart energy pilot project to equip the community building with a hydrogen fuel cell cogeneration system, with a combined efficiency of up to 90% or more, and a drop of nearly 50% in energy consumption and carbon emissions compared with the pre-modification period. [23] Hydrogen energy in the field of drones has also made great progress, compared with traditional lithium batteries, hydrogen fuel cells have high energy density, low temperature resistance, with obvious advantages, in 2020, the State Administration for Market Supervision and Regulation issued "hydrogen fuel cell power generation system for drones", the first time to publish the manufacturing standards of hydrogen fuel cells for drones. In the future, the diversified application of hydrogen energy will become the trend of new energy development, but at this stage is still in its infancy, there are various problems in cost, technology, regulations, implementation standards, and supervision, and it faces various obstacles in practical application.

4. Challenges in the development path of hydrogen energy industry

4.1 High upstream hydrogen production and midstream storage and transportation costs

Domestic electrolytic water hydrogen production technology is not only high cost, but also requires complex processing, poor economic efficiency. In the process of AWE electrolyzer hydrogen production, the purification operation of removing lye and vapor is complicated and requires expensive auxiliary equipment, which increases the cost of personnel and equipment [24]; while PEM water electrolysis hydrogen production has the bottleneck of higher material cost and shorter lifespan, which undoubtedly accelerates the enterprises to invest more cost. The development cost of SOEC and AEM hydrogen production technology is more stringent on electrode material research, and the larger development cost limits the industrialization of hydrogen production technology.

The commonly used method for transporting small and medium quantities of hydrogen in China's midstream is high-pressure gaseous storage and transportation at 35-70Mpa, which requires larger storage and transportation costs for pressurized operation of pipelines as well as depreciation of storage equipment materials. Secondly, the construction of hydrogen refueling stations has high infrastructure and maintenance costs, and the construction of the corresponding infrastructure is slow.

4.2 Technical barriers impeding hydrogen transportation

China's development in the field of hydrogen energy started later than the developed countries in Europe and the United States, and hydrogen storage and transportation technology barriers are high, resulting in part of the core production technology and materials rely on imports, many key components for the production of fuel cells are provided by foreign countries, a large number of key technologies are monopolized by the developed countries [25], a large number of patents on hydrogen energy technology are mastered by the developed countries, and the independent research and development of China's core components is seriously limited. Now, many of China's hydrogen production technologies still remain in the laboratory stage.

4.3 Challenges of sustainable development

Currently, hydrogen production from fossil fuels is the main method of hydrogen production in China, but in the face of the "dual-carbon" goal, the manufacture of gray hydrogen is not sustainable in the long term. To achieve sustainable development, the development of green hydrogen needs to be the long-term goal of the hydrogen industry, gradually replacing gray hydrogen, which is more polluting and carbon-emitting, and blue hydrogen, which is a transition. However, the development of green hydrogen is hampered by cost, technology, and popularization [26], and there are a series of challenges that need to be overcome for the sustainable development of the hydrogen energy industry.

4.4 Imperfect hydrogen energy supply chain system

The mismatch between supply and demand in the development of China's hydrogen industry is remarkable. The main source of hydrogen in China is the by-product of petrochemical and coal industries, as the origin related to the supply side of hydrogen energy is mainly concentrated in the inland areas in the north, however, the demand side of hydrogen energy is mainly concentrated in the eastern and coastal areas where the development is ahead of the curve, which leads to the storage and transportation of hydrogen energy occupying a huge cost [27]. At present, China has not yet perfected the construction of hydrogen energy storage and transportation infrastructure and the overall layout of the supply chain, and the construction of the whole industrial chain system of hydrogen energy is still incomplete, and it is difficult to form an effective linkage between the upstream and downstream of the industrial chain, as well as the existence of bottlenecks in storage and transportation technology, which restricts the development of hydrogen energy tech

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nology and the development of large-scale commercialization of hydrogen energy.

4.5 Immature market for hydrogen applications

Nowadays, the domestic hydrogen energy consumption market is relatively single, and the development of market potential is only beginning to take shape. In addition to industrial hydrogen, the utilization of hydrogen energy mainly focuses on hydrogen fuel cells. In recent years, the country has continuously issued relevant policies on fuel cell vehicle subsidies and fuel cell demonstration cities. Under the impetus of the subsidy policy, fuel cells have been rapidly developed in the new energy vehicle market [28], and in the process of promoting the market of hydrogen fuel cell vehicles, many related enterprises are concentrated in the field of vehicle research and development and manufacturing, resulting in the situation that the number of vehicles is standardized and the supporting distributed power generation infrastructure is lacking and the diversified and large-scale market application of hydrogen energy is insufficient. In short, the development of hydrogen energy industry with poor degree of agglomeration, high cost of terminal industry to reduce the cost is extremely difficult, we need to start from the technology, market, cost, and other aspects, and gradually explore new areas, new track, to achieve sustainable development of the industry.

5. Recommendations in the path of hydrogen energy industry development

5.1 Reducing the cost of preparing, storing, and transporting hydrogen energy

The high cost of hydrogen manufacturing and storage and transportation is a major obstacle on the road of hydrogen energy scale development. It is necessary to open up the whole industrial chain, dredge up the technical difficulties in hydrogen production, hydrogen supply, and terminal hydrogen application, realize the scale effect completely, and reduce the cost through the scale effect, so as to promote the process of the whole industrial chain. High cost is the biggest obstacle to the development of hydrogen industry, especially the scale of green hydrogen industry. Insufficient dedicated infrastructure for green hydrogen production and high energy loss further increase the cost investment in hydrogen production. In order to reduce the cost of hydrogen preparation, future technological research on catalysts should be tackled, while the stability and safety of electrolyzed water hydrogen production technology should be improved, electrolysis efficiency should be increased, and the comprehensive cost should be reduced. Enterprises should make full use of and develop abundant wind, light, water, and electricity related hydrogen production technology, in the desert, Gobi, ocean, and other wind and water resources rich areas, promote the construction of wind, light, electricity, storage, and hydrogen demonstration areas, forming a wind and light with hydrogen, hydrogen to promote wind and light in depth synergistic integration, carry out demonstrations of renewable energy to produce hydrogen, and gradually expand the scale of demonstration of the industrial hydrogen production aspect, to create a comprehensive hydrogen production system, and to construct a hydrogen energy Structural diversification.

Midstream storage and transportation should consider developing various forms of storage and transportation. In the storage and transportation of gaseous hydrogen, the authoritative officials should increase the development and construction of domestic salt cavern hydrogen storage, vigorously promote large-scale underground hydrogen storage, and optimize the reasonable construction of pipeline network and hydrogen refueling station; for the storage and transportation of liquid hydrogen, the development of other fuels such as ammonia, methanol and other fuel substances with high compression and storage and transportation efficiencies, to reduce the operating costs of storage and transportation; for large-scale and long-distance hydrogen storage and transportation, the solid-state storage of hydrogen has a great potential to reduce the cost of high-pressure hydrogen, improve the efficiency of hydrogen storage, and gradually reduce the cost of hydrogen. Reduce the cost of high-pressure hydrogen, improve the efficiency of hydrogen storage, and gradually reduce the cost of hydrogen [29].

5.2 Breaking through industrial technology barriers

Technical barriers at key nodes of the hydrogen industry are the "short board" that restricts the efficiency of hydrogen production, and authoritative officials should promote scientific and technological innovation, promote local enterprises and institutions of higher learning to carry out basic research on core materials and process mechanisms [30], and increase the development of renewable energy for hydrogen production. Starting from the electrode, catalyst, electrolyte, and other key materials, as well as the diffusion layer, electric stack structure, and system integration technology, to promote the domestic hydrogen industry to realize the development of large-scale applications. At the same time, increase the cooperation between universities, research institutes, and hydrogen-related enterprises, strong combination to build a diversified energy supply system, accelerate the transformation of the latest technology on the ground to realize the domestic independent main technology innovation, industry chain synergistic development. At the same time, it is necessary to break the core technology blockade of hydrogen energy storage and transportation to realize the pattern of high-quality development of domestic hydrogen energy technology. Adhere to the key core technologies and components of the research and development, promote the development of domestic industrial applications, market demand-oriented, increase the investment of manpower and materials, promote the integration of innovative technologies and traditional models, from the source of technology to change China's high carbon fiber technology, liquid hydrogen manufacturing and pressurization technology and other cutting-edge technologies, as well as pipeline transportation of key parts and components of the slow progress of the localization of the situation.

5.3 Accelerating the exploration of sustainable development paths

As industrial hydrogen production relies on primary fossil energy with low sustainability, China should insist on focusing on the development of green hydrogen production to realize sustainable development. Relying on the advantages of state-owned enterprises in terms of policy support and funding, we should lay out ahead of time in all areas of the hydrogen energy ind

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ustry chain, and promote technology and market, supply, and demand to move forward together. In addition, the developme nt of the industry cannot be separated from the empowerment of policies, which can strengthen the core position of green hy drogen in the development of hydrogen energy through policy issuance, include hydrogen energy in the national green fund a nd investment management system, alleviate the burden of hig h costs of the green hydrogen industry, accelerate the breakthr ough of core technology and process bottlenecks, accelerate th e cultivation of new products, new forms and new models, acc elerate the construction and development of the green hydroge n industry, and build a green low-carbon industrial system.

5.4 Increase infrastructure construction efforts

In view of the serious mismatch between the supply and dema nd of hydrogen energy in China, China should build a hydrog en energy storage and transportation supply system focusing o n pipelines as soon as possible. In terms of storage and transp ortation, relying on the existing natural gas pipeline to expand the pilot hydrogen doping business, and gradually establish a cross-provincial long-distance hydrogen pipeline network syst em; in terms of terminal supply, make full use of the existing gas stations to expand and increase the hydrogen service, mak e full use of the land resources and save money, and give full consideration to transportation, cost, market, industry chain sy nergies, upstream resources and other elements in the selectio n of the location of the newly built hydrogen refueling station [31], in order to provide users with a greater convenience for re fueling hydrogen; In the field of hydrogen fuel cell, which is t he main application of hydrogen energy, through the integrate d planning and scheduling of regional hydrogen resources and renewable energy resources, the demonstration application of fuel cell vehicles and the construction of hydrogen refueling st ation on a large scale and in a large scope, effectively guiding the industry chain to reduce the overall cost, and accelerating t he promotion of fuel cell vehicle technology and industrial up grading. Take the state as the leading construction, coordinate the application planning of each link in the industry chain and each region, decompose the tasks to each energy central enter prise and region, and fully implement them, so as to promote t he realization of the overall goal.

5.5 Innovate hydrogen energy application, business model

In order to diversify the application of hydrogen energy indust ry and broaden the scope of hydrogen energy application, it sh ould be closely combined with the relevant policy "top-down" support, and gradually implement the commercialization of hy drogen energy application. In the field of transportation, we ca n make use of the excellent industrial foundation of the easter n coastal areas and the first-tier cities, and focus on the layout of such areas first, and make use of the radiation effect of the key urban agglomerations on the surrounding areas to graduall y drive the neighboring cities and promote the popularization of the application of hydrogen energy. At the same time, as hy drogen energy is in the initial stage of development, the public 's knowledge and credibility

6. Conclusion

The article compares, summarizes, and analyzes the developm ent of the hydrogen energy industry at home and abroad, and describes the challenges that each link of China's hydrogen en ergy industry chain is currently facing in light of the current si tuation. The main conclusions are as follows:

(1) The cost of hydrogen production and storage remain s high, and the future should seek to reduce the cost of hydrogen energy production.

(2) There are large barriers to hydrogen transportation t echnology, which should focus on technical shortco mings and overcome core technologies.

(3) There is a serious supply and demand mismatch in t he development of hydrogen energy in China, and t he investment and construction of infrastructure sho uld be increased, and the industrial chain process sh ould be coordinated to promote the realization of the overall goal.

(4) The development of hydrogen energy industry focus es on the hydrogen fuel cell industry, but the existin g development model is too single, should expand t he application of hydrogen energy in multiple scena rios to further explore the potential of hydrogen ener gy.

(5) Scale production of green hydrogen should be taken as the long-term goal of the hydrogen energy industr y, gradually replacing gray and blue hydrogen, whic h are heavy in pollution and carbon emissions, to re alize a low-carbon, green, and sustainable developm ent path.

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