Development Status and Trends of Hydrogen Energy under the Goal of Carbon Peaking and Carbon Neutrality

Shupeng Guo [1, *], Zihan Li [2], Yimeng Zhang [3]

[1] Department of Energy and Power Engineering, North China University of Water Resources and Electric Power, Zhengzhou, China
[2] School of The High School Affiliated to Soochow University, Suzhou, China
[3] School of Xi'an Gaoxin No. 1 High School, Xi'an, China

* Corresponding Author Email: zackaria@asu.edu.pl

Abstract. With the aggravation of the problem of global climate change, Realizing the double carbon target of CO_2 peak and carbon neutrality is a major issue for all nations. Under these circumstances, as a new type of renewable, environmentally friendly, and widely used second-generation energy, hydrogen has become the key factor to transform and develop the world's energy. In this article, we introduce the process of preparing hydrogen, storing and transferring it, its applied areas, and some related proposals for developing it. In this article, the author points out that the Chinese hydrogen industry has achieved great development, rapid development rate, rapid growth in size, and wide application cases. However, there are a lot of issues and challenges to developing the hydrogen power industry from the aspects of cost, technique, and size. So it should enhance science and technological innovation to lower the cost of hydrogen and increase its practicality so that it can be applied in more areas.

Keywords: Double carbon target, renewable energy, Hydrogen energy.

1. Introduction

Hydrogen energy, as one of the most potential clean energies in the 21st century, has attracted much attention because of its zero carbon emissions, high-efficiency density, and renewability. Recently, along with the world's focus on protecting the environment and transforming energy, the study and application of hydrogen have achieved significant development. Global climate change has already been one of humanity's greatest pressing problems. Cutting carbon emissions is a crucial issue in addressing climate change, which is highly valued by all nations. In 2020, China declared that it would aim to reach the CO2 summit by 2030 and CO2 neutral by 2060. Renewable energy has a vital effect on all kinds of energy conversion. Hydrogen exists primarily as a chemical substance on Earth, and is the largest distribution of material in the cosmos, accounting for 75 percent of the Universe [1].

Hydrogen energy is the energy released in the process of physical and chemical changes. It's a second pure energy, called the 21st century's most powerful energy. Under the present circumstances, it is very important to speed up the exploitation and use of hydrogen to conserve energy and reduce emissions. Hydrogen has the features of high burning heat, three times more than petrol, 3.9 times more than ethanol, and 4.5 times more than coke [2]. Hydrogen burning produces water, it is the purest energy in the world, has abundant resources, and can develop continuously. The Chinese Government has made some policies for developing hydrogen power, has set out its strategy target, and put forward that it should accelerate its R&D, demonstration, and use. support the widespread use of hydrogen for industrial, transport, and power storage [3]. In this article, the present situation of developing hydrogen is discussed, and some proposals for developing it are put forward.

2. Five Common Methods of Hydrogen Energy Production

2.1. Hydrogen Production from Fossil Fuel

Hydrogen production from fossil fuels is the production of hydrogen, carbon monoxide, and other products from natural gas, coal, oil, and other fuels through complex chemical reactions, which are

separated and extracted to obtain high-purity hydrogen, as shown in Fig. 1. This technique has many merits such as maturity, large scale, and low cost, which can satisfy the requirement of producing hydrogen on a large scale. The drawback is that the requirement of high-temperature and high-pressure conditions results in a large amount of power, as well as the emission of large amounts of carbon dioxide and other harmful substances in the manufacturing process, which is not in line with the "double carbon" goal.

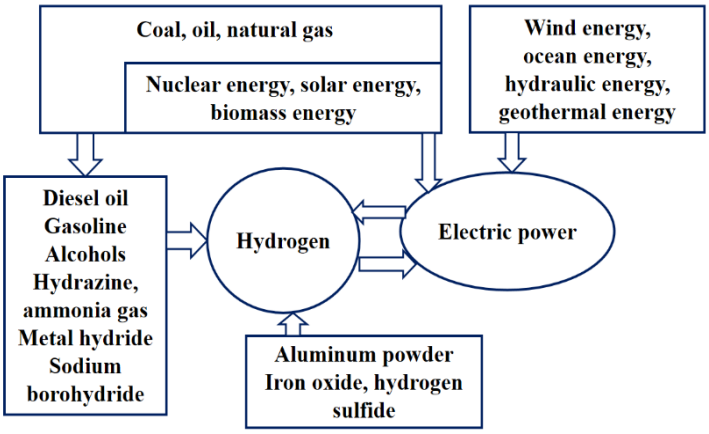

Fig. 1 Hydrogen production technology from fossil fuels diagram (Original)

2.2. Hydrogen Production by Electrolysis of Water

Hydrogen production from electrolyte water is a process of decomposing water into hydrogen and oxygen by electrolyte method. Specifically, the principle is that direct current is used to pass through the aqueous solution, and the water molecules are electrochemically reacted on the electrode to produce hydrogen and oxygen. The generation of hydrogen by this technique is illustrated in Fig. 2. This process has the merit of abundant raw materials, and the formation of water during the process of hydrogen burning will not lead to environmental pollution. The disadvantage is that it needs a lot of power to support high energy consumption, professional electrolysis equipment, and catalysts are needed in the initial stage, and the initial investment is large. However, with technological progress and scale expansion, it will be economically feasible in the future.

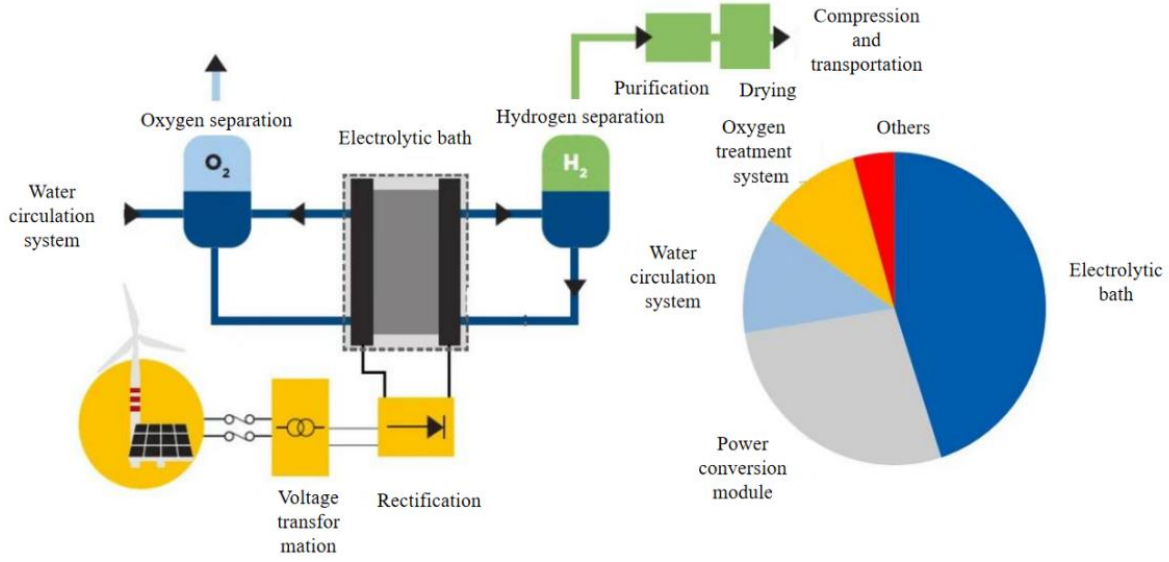

Fig. 2 Electrolytic water hydrogen production technology diagram (Original)

2.3. Hydrogen Production from Biomass

The generation of hydrogen from biomass is the process of producing hydrogen through anaerobically fermented or biogasified, as illustrated in Fig. 3. The advantage of this method is a

potential low-carbon mode of production. Biomass raw materials can be obtained from renewable resources such as agricultural wastes, plants, and straws, which are sustainable and do not need expensive equipment, which reduces the production of hydrogen. However, the technique of producing hydrogen from biomass is still in its developing phase, and it has some technical difficulties, including low yield rate, unmatured technique, economic questions, and waste disposal. Along with scientific and technological advances, relevant techniques continue to improve, these problems are expected to be solved, making hydrogen production from biomass a more feasible and sustainable way of hydrogen production.

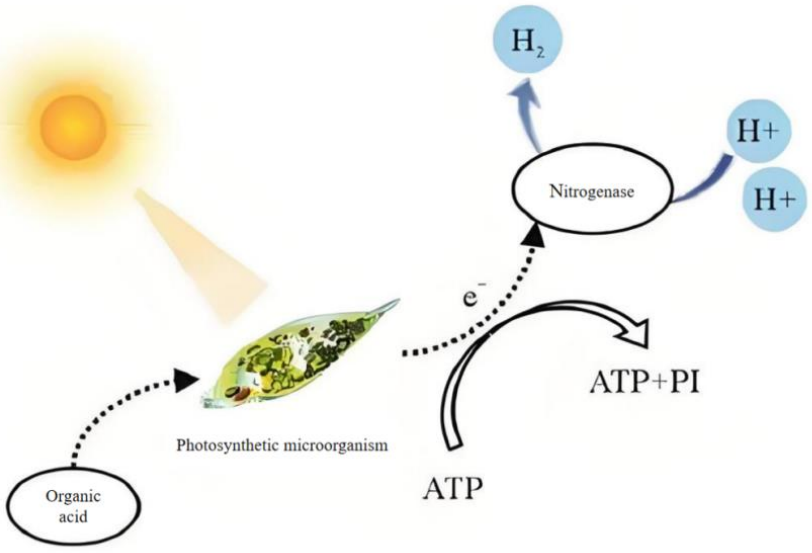

Fig. 3 Biomass hydrogen production technology diagram (Original)

2.4. Hydrogen Production from Solar Energy

There is no harmful gas or dust pollution in the process, and the hydrogen produced has the characteristics of high purity and low impurities. It is suitable for various occasions and can be used in industrial production and family life. The disadvantage is that it is greatly affected by climatic conditions, and although the technology is relatively mature, Continuous improvements are required to increase efficiency and cut costs. The start-up capital for PV generation is very large, and it is predicted that the cost will decrease with technological advances and mass production (Fig. 4).

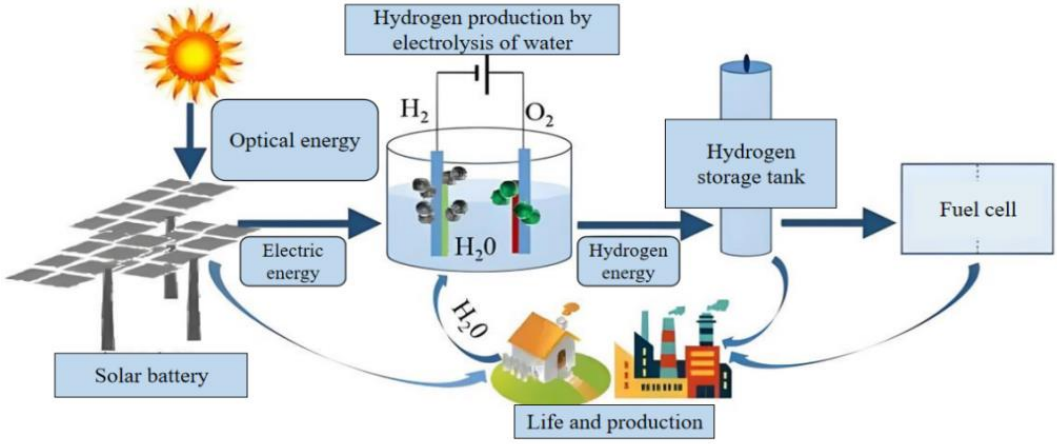

Fig. 4 Solar hydrogen production technology diagram (Original)

2.5. Hydrogen Production from Industrial By-Product

Hydrogen production from industrial by-products is produced by the separation and purification of hydrogen-containing by-products from coking, petrochemical, and other industrial production, as

shown in Fig. 5. This approach has the merit of taking byproducts from the industry as raw materials, there is no need to build special hydrogen production facilities, the construction cost is relatively low, the resource utilization efficiency is high and the carbon emission is low. The disadvantage is that the processing and storage technology of hydrogen is not mature enough, to ensure the safety of hydrogen, further research and development are needed, and the maturity still needs to be further improved and improved.

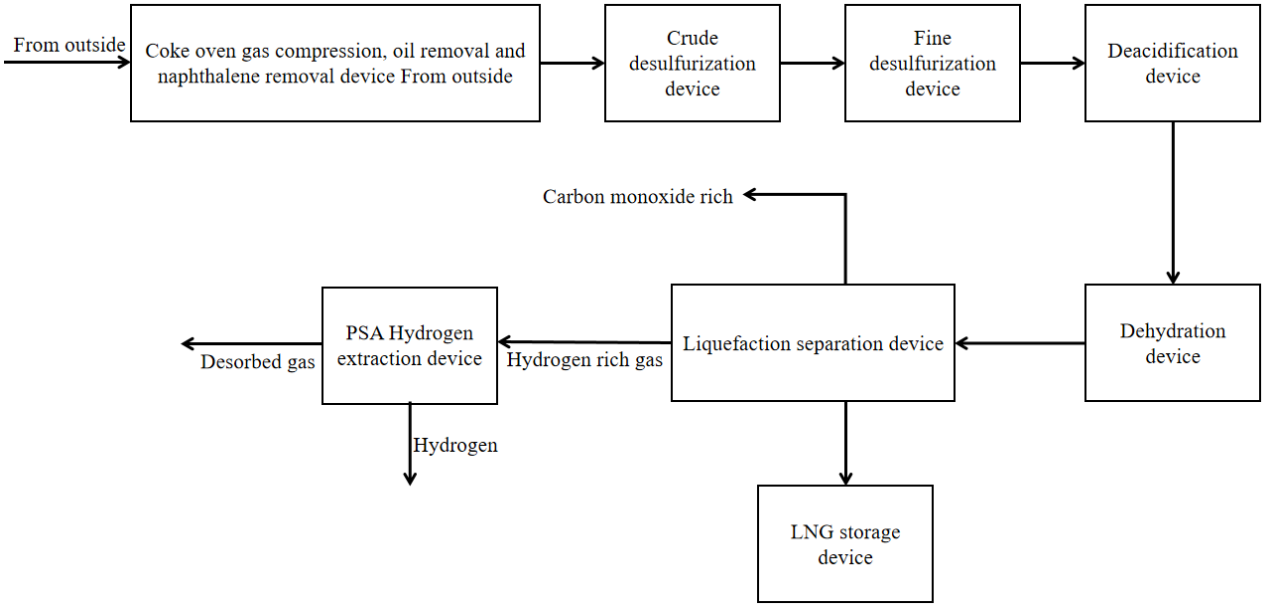

Fig. 5 Industrial by-product hydrogen production technology diagram (Original)

3. Hydrogen Energy Storage and Transport

3.1. Three Common Methods of Hydrogen Energy Storage

High-Pressure gas storage is one of the most commonly used methods of storing hydrogen. Due to its low density, it is possible to store it in a high-pressure environment, where it is often necessary to have a pressure greater than 1.5 MP. It is possible to control the hydrogen emission, and to regulate the quantity of exhaust gas with a pressure-relief valve. It is also possible to adopt underground storage for large quantities of hydrogen stored in a specific place, for example in enclosed caverns, goaf or salt caves. The proposed approach does not need to invest in hydrogen storage tanks, so it can decrease the cost of storing hydrogen and make it more economic and safety. But the proper geology, geography, and the proper sealing technique must be found. Currently, there exist worldwide lightweight gas bottles capable of bearing a pressure of 80 MPa [4].

Low-temperature liquid hydrogen storage means that the hydrogen is cooled down to 252.72 degrees Celsius at normal temperature, which is turned into a liquid, and then stored in a special low-temperature Dewar flask (high vacuum insulation vessel). Because of its high density and small size, its capacity can exceed 5,000 cubic meters, but its cost is too high to be applied. Currently, the main application of the liquid hydrogen is the rocket fuel.

Metallic hydride storage is a novel way to store hydrogen. Hydrogen reversibly reacts with hydrogen, and when the outside temperature is applied to the metal hydride, it breaks down into hydrophiles and releases hydrogen. The reaction of the opposite hydrogen with the hydroxides creates a hydride, and the hydrogen is kept in a solid state. The majority of hydroxides for storage of hydrogen are made up of a variety of elements. The results show that Ti, Nb, Mg, and its alloys can accumulate hydrogen like a sponge, and can be discharged whenever necessary, thus making it convenient for storing, transporting, and utilizing hydrogen. These three approaches are illustrated in Fig. 6.

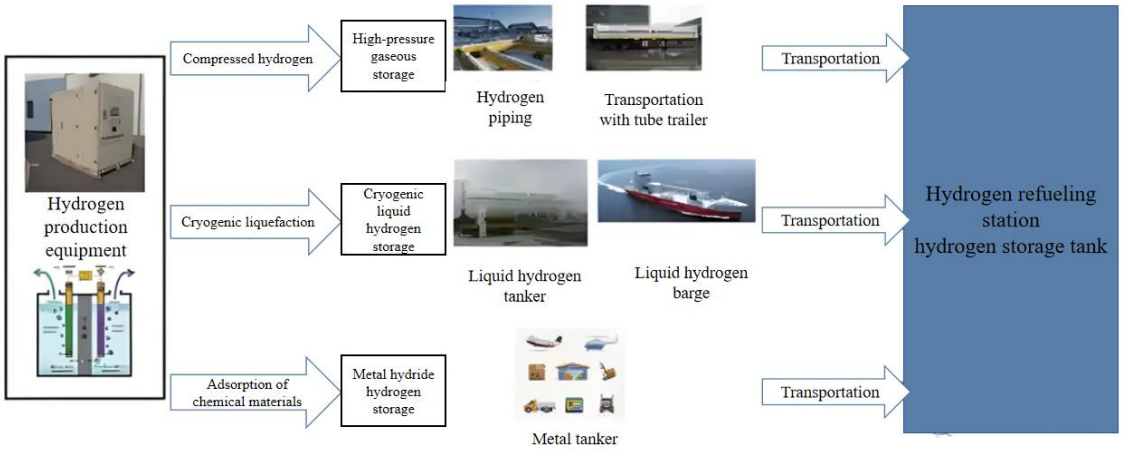

Fig. 6 Hydrogen storage diagram (Original)

3.2. Four Common Ways of Hydrogen Energy Transport

Liquid hydrogen is generally stored in special containers called liquid hydrogen tanks and transported through special transport vehicles or pipes.

Gaseous hydrogen transport is compressed or liquefied by a gas compressor or gas liquefaction device, and then transported through high-pressure cylinders or high-pressure pipelines. The transportation of gaseous hydrogen needs to pay attention to safety protection and the risk of leakage.

Hydrogen alloy transport is the chemical reaction of hydrogen with other substances to form stable and safe compounds for transport. For example, hydrogen reacts with lithium metal to form a hydrogen alloy, which is then stored in a container for transportation.

Hydride transport is to make a hydride (such as a metal hydride) into a powder or block and then store it in a container for transportation. Hydrides can release hydrogen by heating or other methods when hydrogen is needed. Table 1 shows the comparison of hydrogen transport in various physical states.

Table 1. Logistics of hydrogen in various physical states (Original)

Physical state	Storage form	Storage volume	Storage duration	Transportation mode
Gaseous state	Cavern storage	Medium - large	Several weeks – several months	Pipeline (pure hydrogen/mixed), truck trailer, train
	Depleted gas field	Large	Quarter	
	Pressurized container	Small	Day	
Liquid state	Liquified hydrogen	Small - medium	Several days – several weeks	Steamer, truck trailer, train
	Nitrogen	Large	Several weeks – several months	Pipeline, steamer, truck trailer, train
	Liquid organic hydrogen carrier	Small - large	Several weeks – several months	Pipeline, steamer, truck trailer, train
Solid state	Metal hydride	Small	Several days – several weeks	Steamer, truck trailer, train

4. The Applications of Hydrogen Energy are Mainly in the Following Four Areas

4.1. Industrial Field

Hydrogen can be used as an industrial gas, fuel, or raw material, such as the basic gas-oxygen reaction used in iron and steel production, manufacturing gas quenching systems, etc., as a reducing

agent, it can be used in iron and steel, and chemical industries to replace traditional fuels with high carbon emissions and reduce industrial carbon emissions.

4.2. Traffic Field

Hydrogen has a bright future in transport. Hydrogen fuel cell vehicle (FCEV) is regarded as an ideal choice to replace traditional fossil fuel vehicles because of their short hydrogenation time and long mileage, it will be a trend for the auto industry in the future. A trial run of Hydrogen Fuel Cell Buses and Logistic Vehicles has been conducted in some cities in China.

4.3. Field of Electric Power and Energy Storage

Hydrogen can be used for power and storage in various ways, including hydrogen storage power stations, coupled hydrogen production and sales stations, and hydrogen fuel cells. A hydrogen storage power station is a kind of energy storage mode that uses electricity to produce hydrogen when electricity is sufficient and hydrogen to produce electricity when electricity is insufficient. This method can achieve long-term energy storage across the sky, which has a longer time than chemical batteries and has less impact on the environment. Electricity-hydrogen coupled hydrogen production and sales stations produce hydrogen from electricity when the electricity is sufficient, and then sell it to the manufacturers who need the raw material. The proposed approach can be used to keep the fluctuation of electricity production to guarantee the stability of the network. Hydrogen Fuel Cell is a kind of electric generator which can be used to transform the chemical energy of hydrogen and oxygen into electrical energy. Though these techniques are still immature and expensive, they have many uses like lithium batteries.

4.4. Construction Field

The use of hydrogen in buildings will contribute to cutting down on CO2 and making it more efficient. The IEA report shows that the Chinese building industry will make up almost 20 percent of final energy use by 2020, and carbon dioxide emissions can be significantly reduced by replacing stone fuel with hydrogen energy. By 2050, it is estimated that 10% of global construction heating and 8% of the building energy supply will be provided by hydrogen, reducing annual emissions of 700 million tons of carbon dioxide [5]. The above four areas are shown in Fig. 7.

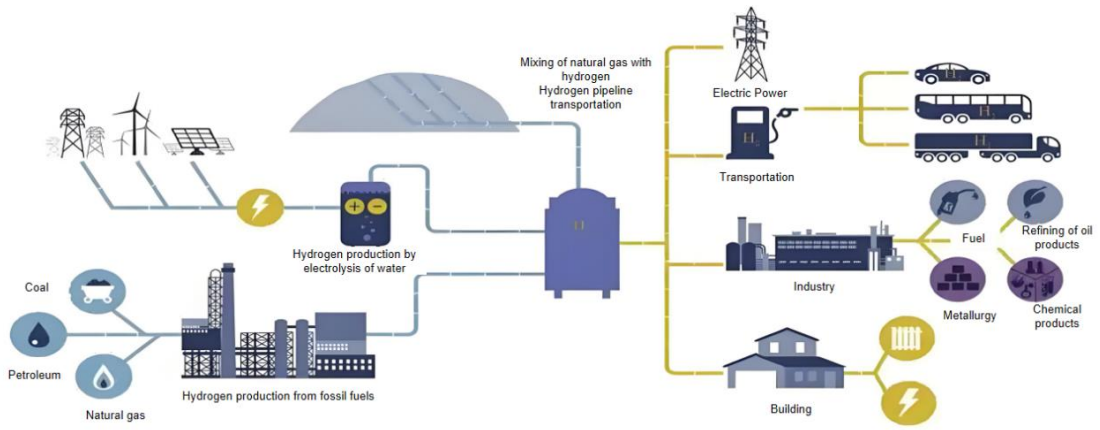

Fig. 7 Hydrogen energy application fields chart (Original)

5. The Main Challenges Facing Hydrogen Energy

5.1. The Cost is High and the Industrial Competitiveness is Seriously Insufficient

The total cost of the hydrogen manufacturing chain is very high. According to a German project, the cost of producing hydrogen remains as high as €6 to 8 per kilogram, well above the price of fossil fuels. Production of hydrogen from renewable sources and large-scale storage and transportation

technology are still in their infancy, and a variety of components and materials have not yet been completely self-controlled, resulting in high costs for hydrogen preparation, Storage, and transport Because of the high cost and the severe shortage of competitive power in the industry, the ultimate deciding factor for the development of any industry is economic. If the industry's cost is too high, if the company cannot earn money, then it will not be able to develop the industry, and there will be no chance to develop continuously. Most of the development of the Chinese Hydrogen Power Industry is in the Demonstration Phase, the infrastructure construction is seriously lagging and the quantity is insufficient, and the regional distribution of the industry is also very uneven. From the reality that hydrogen energy can not develop rapidly in China for a long time, the core is that this brand-new industry does not have the ability for commercial operation, and the key factor is that the entire industrial chain's cost is too high.

5.2. The Innovation Ability is not Strong, and the Industry is Facing a Technological Bottleneck

The main components of hydrogen energy are very demanding, complicated, and expensive. Though our country has achieved great success, there is still a great distance from the developed countries in the field of hydrogen power. But there are many important parts in the Chinese hydrogen-power industrial chain, which are different from those in the world. For example, there are many important parts in our country, including the film electrode, the air compressor, the hydrogen accumulator, the hydro-generator, the water pump, and the tube. Some of the critical technologies have been monopolized abroad

5.3. The Industrial Development Started Relatively Late, and the Relevant Standards Are Not Yet Perfect

Nowadays, Chinese hydrogen technology is not complete, and there is little technology criterion about hydrogen quality, storing and transporting, hydrogen refueling stations, and security. Firstly, there is still a lack of perfection in the industrial norms system. Hydrogen Power Sector in China, many standards have lagged seriously, and many standards have not yet been formulated, especially the requirements for product safety, reliability, durability, and so on. The second point is the lack of a standard system for the examination and approval of hydrogen station construction, and the key link of hydrogen station construction is land examination and approval. Judging from the current policy, the examination and approval of commercial land is quite complicated, which has, objectively, been a key factor in the development of hydrocracking plants, currently, the land examination and approval process is complicated and inconsistent, although local governments encourage and support the construction of hydrogenation stations, but in fact, it is very difficult to obtain the "birth permit" of the hydrogenation station.

6. Suggestions on the Development of Hydrogen Energy

6.1. Establish a Sound Industrial Chain and Reduce Related Costs

Set up the whole hydrogen industrial chain, including the process of producing, storing, transporting and using hydrogen. At the same time, strengthen the coordinated development with related industries, such as deep integration with electric power, petrochemical, transportation, and other industries, to achieve resource sharing and complementary advantages.

6.2. Establishing personnel Training and Strengthening Scientific and Technological Innovation

More Invest in Hydrogen Energy Training, and build a professional and high-quality team of hydrogen energy talents. Colleges and universities are encouraged to set up hydrogen energy majors, train more hydrogen energy professionals, and offer talented people to develop the hydrogen energy

industry. Enhance the R&D on hydrogen power technique and push forward the technological innovation and breakthrough. We are encouraged to work together with colleges and research institutions to overcome the difficulties in the field of hydrogen power and enhance the R&D and competitive power in the market.

6.3. Establish Norms and Standards and Strengthen Policy Support

To develop the hydrogen industry soundly, it needs to work hard to cooperate internationally and set up a system for checking and certifying products. The related companies shall fully utilize the innovative resources of the world, and take an active part in the FCE and IIR collaboration. Using policy support, market mechanism innovation, and technology advancement, it can be used as an important tool to realize the CO2 peak and CO2 balance and make a contribution to the green transition of the world's energy system. Since the hydrogen sector is nascent, and the construction of hydrogenation stations is a new thing, local governments lack specific policies and systems in planning, project establishment, examination and approval, operation, and supervision.

7. Conclusion

To sum up, the production methods have their pros and cons and applicable scenarios. In practice, proper selection of appropriate methods should be made per the physical circumstances. Meanwhile, as scientific and technological advances, deficiencies will continue to be overcome. In the process of storing and transporting hydrogen, high-pressure gas and liquid hydrogen transport are comparatively mature techniques, that have a wide application prospect, and other storage and transportation technologies are also being studied continuously. it is expected to achieve safer hydrogen energy storage and more diversified modes of transportation in the future. With policy support, hydrogen energy will play an important role in transportation, industry, energy storage, and other fields. As a clean, efficient, and renewable form of energy, Hydrogen is of great importance to the conversion of energy and the environment. Though there are still some problems in the field of hydrogen power, it is expected that it will make a great contribution to building a clean, low-carbon, safe, high efficiency, and so on. This will also bring many longer-term and more sustainable development opportunities for human society.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Information Office of the State Council of the People's Republic of China. White Paper Energy in China’s New Era. (2020-12-21) [2024-05-21]. http://www.scio.gov.cn/zfbps/ndhf/2020n/202207/t20220704130663.html.

[2] Fu Guanyun. The Status and Role of Hydrogen Energy in China's Energy Transformation [J]. China Coal, 2019, 45 (10): 15-21.

[3] National Energy Administration. Medium and Long-Term Plan for Hydrogen Energy Industry Development (2021-2035). (2022-03-23) [2024-05-21]. http://zfxxgk.nea.gov.cn/2022-03/23/c-1310525630.htm.

[4] Fu Guanyun & Xiong Huawen. Hydrogen Energy Development Models in Japan, Germany and the United States and Their Enlightenment. Macroeconomic Management, 2020 (6): 84-90.

[5] International Energy Agency (IEA), 2023. World Energy Outlook. Paris: IEA.