

Technology And Prospect of Hydrogen Energy

Zimo Wu¹, Yuanning Yang², Caixin Yin^{3, *}

¹Rosedale Academy, Shenyang, China

²Jinan Xinhang Experimental Foreign Language School, Jinan, China

³Qingdao West Coast District No.2 Senior high school, Qingdao, China

* Corresponding Author Email: ycx13210177330@outlook.com

Abstract. This article summarizes the development trend of the hydrogen energy industry, the technical difficulties faced by the production of hydrogen, the problems encountered in the storage and transportation of hydrogen energy, and the potential and development trend of hydrogen energy in the future application. The paper emphasizes that the hydrogen production through hydroelectrolysis and biomass resources can effectively utilize renewable resources and may solve the environmental problem of producing "gray hydrogen" in the conversion process of fossil fuels and methanol, which is in line with the concept of clean energy development. Therefore, improving the efficiency of hydrogen production and realizing its large-scale commercial production has become the focus of the current scientific research work. The core challenge of storing high-pressure gaseous hydrogen and low-temperature liquid hydrogen is to optimize container materials, develop new substances that can adsorb hydrogen, and reduce energy consumption and spending. Whether hydrogen is transmitted by compression, liquefaction, or pipeline means, the cost-effectiveness and safety issues need to be addressed urgently. In general, the large-scale use of hydrogen as an energy source still needs to overcome many difficulties.

Keywords: Hydrogen; energy; hydrogen storage; new energy.

1. Introduction

Hydrogen energy development began in the middle of the 20th century. In 1923, British biologist J.B.S. Haldane first proposed the establishment of an energy system driven by hydrogen energy, he foresighted the eventual exhaustion of coal resources, so proposed the development of wind power to produce hydrogen technology. With the decline of traditional energy sources such as oil and coal and the increasingly serious problem of environmental pollution, the world is paying more attention to environmental protection and energy transformation. Hydrogen energy, as a clean, efficient and ideal secondary energy source, has gradually attracted global attention and become an important direction of future energy development. "Hydrogen will be successful in all areas, but it won't be easy," said Michael Liebreich, founder of Bloomberg New Energy Finance. Therefore, the development of hydrogen energy still needs to face various challenges, such as preparation technology problems, cost problems, transportation problems, and storage problems. In this paper, by comparing various hydrogen production technologies, the advantages and technical barriers of hydrogen energy are understood, and the future application direction of hydrogen energy is explored. In China, with the strengthening of environmental protection policies and the adjustment of energy structure, the hydrogen energy industry has also been rapidly developing. Driven by the goal of "double carbon", In addition, China participates in hydrogen production under the slogan "hydrogen drive" into 10,000". This article will explore the current progress in the hydrogen energy industry, the current technical difficulties in hydrogen production, the problems encountered in hydrogen storage and transportation, the potential opportunities to use hydrogen energy, and the expected future trends in the development direction and application areas.

2. Hydrogen Energy Develop

Hydrogen is the most common component in the universe, especially in water and organic substances such as hydrocarbons, accounting for about 75 percent of all organic matter on earth. Coal, industrial waste and natural gas are all rich in hydrogen, which currently is the source of China's primary access to hydrogen energy. Considering water as a huge hydrogen reservoir, estimates suggest that if all the hydrogen can be extracted from the ocean and used for energy, it could generate more than 9,000 times the combined heat of all existing fossil fuels on Earth [1].

3. Hydrogen Production Technology

3.1. Water Decomposes to Produce Hydrogen

The water decomposition process of hydrogen production is mainly realized by two technologies: electrolysis method and photoelectrolysis. In electrolysis, water molecules are used to be separated into hydrogen and oxygen; in photoelectrolysis, light energy is used to separate water.

Through the process of water electrolysis, that is, the water molecules are divided into hydrogen and oxygen gases under the action of direct current, in which the direct current is connected with the positive and negative electrodes in the electrolysis device. According to the different diaphragm materials of the electrolytic pool used, this hydrogen production method can be mainly divided into four categories: alkaline water electrolysis, proton exchange membrane (PEM) hydroelectrolysis, high temperature solid oxide (SOEC) hydroelectrolysis, and solid anion exchange membrane (AEM) hydroelectrolysis. China's electrolytic water hydrogen production technology route has gradually matured, among which, alkaline electrolytic water technology equipment has achieved domestic production, has been able to achieve large-scale hydrogen production applications, and has achieved megawatt-level hydrogen production applications. Rapid breakthroughs have been made in proton exchange membrane electrolysis of water to produce hydrogen, and the cost of catalyst and membrane electrode has been significantly reduced. At the same time, China has mastered the technology of proton exchange, carbon and other land, membrane electrode anode disk, processing, manufacturing engineering, hydrogen fuel cell complete control of the combination of design and production technology, independent intellectual property and combined fuel cell propulsion platform" [2].

Photocatalytic reactions can be divided into two types: "down hill" and "up hill" reactions. Photocatalytic oxidative degradation of organic matter belongs to the energy barrier reduction reaction, and the $\Delta G < 0$ of this kind of reaction is irreversible. In this kind of reaction, O_2^- , HO_2 , $OH\cdot$, H^+ , and other active groups are generated under the action of the photocatalyst. The decomposition of water to H_2 and O_2 is a high-energy barrier reaction, with $\Delta G > 0$ ($\Delta G = 237$ kJ/mol), which converts light energy into chemical energy.

In a semiconductor material, if the energy of the incident radiation reaches or exceeds the band gap width of the material, the electrons in the valence band will transition to the conduction band. This process leads to the separation of electrons from holes, and at different positions, these free carriers can promote water decomposition reactions: on the one hand, electrons participate in the reduction reaction to produce hydrogen; on the other hand, in other areas of the semiconductor surface, holes can catalyze the oxidation of water to produce oxygen.

3.2. Hydrogen Production from Fossil Fuels

3.2.1 Carbon to hydrogen

Coal is a fossil raw material with a high carbon content. Coal is a high-quality reducing agent to reacts with H_2O to generate H_2 . The principle of the coal water slurry process is generally adopted, namely:

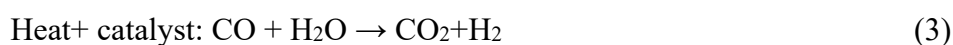


The hydrogen production process involves several steps, including gasification, CO sulfur resistance transformation, acid gas removal, and H₂ purification.

3.2.2 Hydrogen production from natural gas

In natural gas hydrogen production technology, steam reforming hydrogen production is relatively mature and is the mainstream hydrogen production method abroad [3]. First, natural gas is pretreated, and methane and water vapor react in the reformer to produce carbon monoxide and hydrogen. The conversion tower is filled with carbon dioxide and hydrogen, the result of carbon monoxide reacting with water vapor after the waste heat is recovered.

The technology is based on the natural gas steam conversion technology. In the case of a reformer, a catalyst converts carbon monoxide and water into hydrogen and carbon dioxide. The main reaction formula is:



3.3. Hydrogen Production from Biomass

Biomass hydrogen production technology is a technology that uses biomass for hydrogen production. Its basic principle is to prepare biomass hydrogen through biological reaction (biomass through gasification and microbial catalytic deoxygenation method) and to produce molecular hydrogen in the process of physiological metabolism. The technique usually involves the following steps:

(1) Biomass pretreatment: pretreatment of biomass (such as cellulose, lignin, oil, etc.), such as crushing, screening, dehydration, and drying, etc., to improve its reactivity.

(2) Preparation of biomass hydrogen: the pre-treated biomass is mixed with water, and the biological reaction is carried out under the action of microorganisms to generate hydrogen and carbon dioxide. This process usually requires specific microbial strains and suitable reaction conditions, such as temperature, pH, and nutrients.

(3) Separation and purification of hydrogen: The generated hydrogen may contain other impurities, which need to be separated and purified to obtain high-purity hydrogen. This process usually requires the use of physical or chemical methods such as adsorption, distillation, and electrolysis.

3.3.1 Photolytic water to produce hydrogen

Hydrogen production by photolysis water is a process in which microalgae and cyanobacteria use solar energy and water as raw materials to decompose water into hydrogen and oxygen through photosynthesis and its unique hydrogen-producing enzyme system. This hydrogen production process does not produce CO₂. Both cyanobacteria and green algae can photocrack water to produce hydrogen, but their hydrogen production mechanisms are different. The hydrogen production of cyanobacteria is divided into two categories: one is hydrogen production catalyzed by nitrogenase and hydrogen production catalyzed by hydrogenase; The other is that the hydrogen production of green algae under light and anaerobic conditions is catalyzed by hydrogenase.

3.3.2 Hydrogen production by light fermentation

Microalgae and cyanobacteria, through their unique hydrogenase systems, are able to use sunlight and water to break down water into hydrogen and oxygen. The process is called biopolysis of water to produce hydrogen and does not emit carbon dioxide. In the process, both green microalgae and some types of cyanobacteria can produce hydrogen but take different paths. For the latter, there are two main ways: relying on the direct use of sunlight or on using a specific enzyme, —, which is called "hydrogenase". In contrast, hydrogen production can also be produced in the absence of external light sources and anaerobic conditions, which is usually catalytic by the "hydrogenase" mentioned above.

3.3.3 Hydrogen production by dark fermentation

The process of hydrogen production by dark fermentation involves the use of heterotrophic anaerobic microorganisms to convert organic matter into hydrogen, such as carbohydrates. This method can not only reduce environmental pollution, but also effectively treat and recycle industrial and agricultural waste (including paper wastewater, food processing residue, straw and livestock manure, etc.). In these waste resources contain a large number of carbon sources available for microbial decomposition, such as glucose, starch and cellulose. Among them, polymer complex carbohydrates such as starch can be transformed into glucose or other simple sugars after degradation, which is an ideal raw material easily accessible and suitable for microbial metabolism. Through oxygen-free dark fermentation treatment of these industrial and agricultural byproducts, clean energy — hydrogen can be extracted, and a large number of potential pollutants can be reduced.

3.4. Methanol conversion to hydrogen process

Under certain temperature and pressure conditions, methanol triggers a series of reactions when it passes water vapor through the catalyst. These reactions, which include the lysis of methanol and the conversion of carbon monoxide, are facilitated by the catalyst, eventually resulting in hydrogen and carbon dioxide. The whole process is a complex gas-solid catalytic system involving the interaction of multiple components and many reactions in parallel. The relevant chemical equations describe these transformations.



By using pressure swing adsorption (PSA) technology, carbon dioxide and hydrogen can be effectively separated from the mixture produced in the methanol water vapor reforming process to prepare high purity hydrogen. In methanol steam reforming, the usual operating conditions are temperatures between 250 and 300 degrees Celsius, pressure range between 1 to 5 mpa, and maintain a water to methanol molar ratio between 1.0 and 5.0. The reformed product gas can be purified by pressure swing adsorption and other purification processes to obtain hydrogen products of different specifications. Both isothermal reaction systems and adiabatic reaction systems can be used in the methanol steam reforming process. The isothermal reaction system adopts a tubular reactor, the tube shell is filled with a heat carrier for heat exchange, and the reaction is maintained at a constant temperature. In an adiabatic reaction system, a mixture of steam and methanol passes through a series of adiabatic catalyst beds with heat exchangers between the beds.

4. Storage Technology

Hydrogen is light, volatile, and easy to leak, so the storage technology of hydrogen is very important. At present, the most common methods of hydrogen storage include compression, liquefaction, and adsorption with materials. However, these three methods have some problems, such as low storage density, poor safety factors, and difficult detection. To solve these problems, it is necessary to strengthen material research and development and technological innovation and explore more and more reliable safe storage methods.

4.1. Compressed Hydrogen Storage Technology

The technology for storing compressed hydrogen involves storing hydrogen in specially designed containers at high pressure. This is currently the most commonly used method of storing hydrogen fuel. Its core concept is the use of high-pressure equipment to turn hydrogen into liquid or in its gaseous form and safely packaged in pressure containers. This technology is widely used because of its excellent energy storage efficiency and reliability and is suitable for the needs of many fields.

According to the different storage status, it is divided into two categories: one is the common and widely used high-pressure gas storage method, which is directly converted by high pressure and placed in a special high strength container, and the second is the liquid storage method, which condenses hydrogen into a liquid form and stored in tanks specially designed with heat-insulated vacuum layer. Although this method can achieve higher density storage effect, it faces more technical challenges due to the need for extremely low temperature conditions to maintain the liquid.

4.2. Liquid Hydrogen Storage Technology

Liquid hydrogen storage technology is a technology in which hydrogen is liquefied and stored in an adiabatic vessel. At low temperatures, hydrogen can be liquefied, and liquid hydrogen is much denser than gaseous hydrogen, so this technique can provide a higher density of hydrogen storage. The principle of liquid hydrogen storage technology is to compress hydrogen gas and cool it to extremely low temperatures through a series of complex thermodynamic processes to liquefy it.

4.3. Adsorption Hydrogen Storage Technology

The technology for storing hydrogen involves fixing it inside a solid material so that it can subsequently be released on demand. Hydrogen reserves in the physical form mainly accumulate hydrogen in solid-state media through physical and chemical pathways. The physical adsorption process involves using van der Waals forces to reversibly trap hydrogen molecules on porous structural materials with a large specific surface area. Chemical adsorption occurs when hydrogen atoms bind to other elements through ions or covalent bonds to form complexes such as metal hydrides, and this binding can be reversed under certain conditions to absorb or release hydrogen. Physical adsorption hydrogen storage materials include carbon-based materials (such as graphite, activated carbon, and carbon nanotubes), inorganic porous materials (such as zeolite), and metal-organic skeleton compounds (MOFs). Because most physical adsorption materials can reach a certain hydrogen storage density at a lower temperature, the hydrogen absorption amount at normal temperature and pressure is very low, so its application is limited.

Chemical adsorption hydrogen storage materials mainly include metal hydrides (such as LaNiH , MgH), coordination hydrides (such as NaAlH), chemical hydrides (such as NHBH), etc. At present, metal hydrides are the most mature. At the same time, metal hydride hydrogen storage materials are extremely rich, including magnesium series, titanium series, vanadium series, rare earth series, and zirconium series.

5. Transportation Technology

Hydrogen is very leaky and requires technology to protect it during transmission. At present, hydrogen transmission technology mainly includes compressed hydrogen transmission, liquefied hydrogen transmission, and pipeline transmission. It is of great significance to improve the safety and reliability of hydrogen transmission. Therefore, it is necessary to strengthen safety management, improve safety awareness and technical level, and carry out more perfect research on hydrogen transmission technology.

5.1. Compressed Hydrogen Transmission

The transportation of compressed hydrogen is the transportation of hydrogen after compression into high-pressure gas, which is suitable for the transportation of hydrogen to the hydrogen hydrogenation station. The characteristic of this method is that no phase change occurs in the process of transportation, storage, and consumption, and the energy loss is small, but the amount of transport is also relatively small, so it is suitable for occasions where the distance is relatively close and the amount of transport is small. If it is a small-scale occasion such as a laboratory, hydrogen cylinders can generally be used to transport compressed hydrogen, and the occasion of hydrogenation stations

requires large-scale transportation methods, for which a tractor with a large high-pressure vessel has been developed.

5.2. Transmission of Liquefied Hydrogen

The transfer of liquefied hydrogen usually involves cooling the hydrogen to extremely low temperatures to liquefy it. Liquefied hydrogen can be stored and transported more efficiently because it has a smaller volume and higher density in the liquid state. Liquefied hydrogen is loaded into specialized transport containers or vehicles and transported by road, rail, or pipeline. Since the volume of hydrogen is greatly reduced after liquefaction, it can be transported over long distances more economically and efficiently. The transmission of liquefied hydrogen has many advantages, including higher energy density, less volume, faster charging speed, and better safety. However, this process also requires a lot of energy and special equipment, so its cost is relatively high.

5.3. Pipeline for Hydrogen Transportation

Pipeline hydrogen transport is an efficient way of hydrogen transport, which mainly involves long-distance and large-scale hydrogen transport. This model has the advantages of large transport volume, long distance, low energy loss, economic efficiency and so on. According to the transmission distance, pipeline hydrogen transmission can be divided into long-distance pipelines and short-distance pipelines. Long-distance pipelines are mainly used for long-distance transportation between hydrogen production plants and hydrogen stations, with high hydrogen delivery pressure and large pipeline diameters. The short-distance pipeline is mainly used for hydrogen distribution between the hydrogen station and each user, with low hydrogen transmission pressure and a small pipeline diameter. According to the purity of hydrogen, pipeline hydrogen transport can be divided into natural gas hydrogen doped pipelines and pure hydrogen pipelines. Natural gas hydrogen-mixing pipeline refers to the method of using the existing natural gas pipeline to pressurize hydrogen and input it to make hydrogen and natural gas mixed transport. A pure hydrogen pipeline refers to a pipeline specially used for pure hydrogen transport, but it is difficult to lay and the investment cost is high.

6. Technology Utilization

As a clean energy source, hydrogen can be used in many fields such as fuel cell power generation, combustion power generation, and hydrogen refueling stations. Compared with traditional thermal power generation, hydrogen fuel cell has the advantages of high efficiency, cleanliness, and flexibility. Among them, fuel cell is one of the ideal utilization methods, but there are bottlenecks in the efficiency and durability of fuel cells. In the process of enhancing the commercial application of hydrogen energy, it is necessary to carry out technological innovation and promotion for these problems and improve the efficiency of hydrogen utilization.

The field of hydrogen power can also be applied to the field of transportation, especially heavy vehicles and public transport. Hydrogen fuel cell vehicle (HFCV) is an environmentally friendly means of transportation with a long driving range, fast hydrogenation speed, and friendly to the environment. In addition, hydrogen energy can also be used as an energy source for transportation such as aviation, railways, and ships.

In the industrial sector, hydrogen electricity can be used in the production process of industries such as steel, chemicals, electronics, and aerospace, reducing dependence on fossil fuels and reducing carbon emissions.

At present, the cost of the hydrogen energy industry is relatively high, especially in hydrogen production and fuel cells. Therefore, it is necessary to further reduce costs and improve the economy to better promote application.

At present, the infrastructure of the hydrogen industry is not perfect, especially when it comes to hydrogen refueling stations. Therefore, it is necessary to strengthen the infrastructure construction and improve the coverage and convenience of hydrogen refueling stations.

7. Future Outlook

At present, China has made some progress in the field of hydrogen energy, built the world's largest hydrogen refueling station, and carried out a series of hydrogen energy application pilots in public transportation, logistics, power and other fields. In China, hydrogen into 10,000 demonstration projects have been launched in some cities. For example, the "hydrogen into 10,000" demonstration project in Qingdao, the main content includes hydrogen green preparation and purification, pure hydrogen pipeline network construction, hydrogen energy transportation application, etc., and gradually apply hydrogen energy to residents' lives. In addition to cities, hydrogen energy is also being used in some specific areas. For example, in the Intelligent Manufacturing Park of the International Academician Port in Shandong Province, hydrogen production by photovoltaic power generation is the main source of hydrogen supply, and comprehensive demonstrations of various types of hydrogen energy applications such as fuel cell cogeneration system, backup (emergency) power supply, and hydrogen energy vehicles have been carried out. In addition, Weifang City has also actively promoted the development of hydrogen energy industry, introduced the hydrogen energy industry development plan, and vigorously promoted the construction of hydrogen refueling stations.

The National Fuel Cell Technology Innovation Center is also promoting the development of hydrogen energy and fuel cell industries. As the only national technological innovation center in the field of fuel cells in China, it can play a greater role in the China-Japan-ROK Forum to help the cooperation and development of the China-Japan-ROK hydrogen energy industry.

China's future development of hydrogen potential is huge, the market is huge, commercial vehicles, port trucks, logistics vehicles, and passenger cars, the number is very large, and the application scenario will be more and more. [4] "In 2024, green methanol and green ammonia as hydrogen energy derivatives will play an important role in petrochemical, transportation, building energy supply and other application scenarios." Xiong Jian, president of the Shanghai Pudong New Area New Energy Industry Association, told reporters that to produce green methanol, the two main paths currently feasible are biomass conversion and "green hydrogen combined with renewable carbon dioxide." In the entire production process, both methods show extremely low emission levels, almost reaching the standard of net zero emissions. [5]

In short, hydrogen energy into the 10,000 is a challenging and promising field, which requires joint efforts from all sides to promote the progress and application of hydrogen energy technology. Relying on major projects such as "Hydrogen into 10,000 households" and the Winter Olympics, hydrogen energy has been promoted in multiple scenarios. Contribute to the sustainable development of mankind. [6]

8. Conclusion

Hydrogen into the 10,000 is a grand vision. "Hydrogen into thousands" refers to the process of promoting hydrogen energy to thousands of households, aiming to apply hydrogen technology to daily life and provide people with cleaner and more efficient energy options. In this process, hydrogen energy, as a clean, efficient and safe energy, will be widely used in transportation, power, industry and other fields, bringing more convenience and benefits to people's production and life. In order to realize the vision of "hydrogen into 10,000", it is necessary to strengthen the research and development and production of hydrogen energy, improve the supply capacity and stability of hydrogen energy, but also need to strengthen the promotion and application of hydrogen energy, solve a series of technical and market problems, including hydrogen production technology, storage and transportation, hydrogen station construction, hydrogen energy application scenarios, and improve the public's awareness and acceptance of hydrogen energy. In this process, the joint efforts of the government, enterprises and all sectors of society are needed to form a joint force to promote the popularization and application of hydrogen energy.

In order to realize the vision of hydrogen energy into the 10,000, it needs the cooperation and support of the government, enterprises and scientific research institutions. The government can

introduce relevant policies to encourage the development and application of hydrogen energy industry; Enterprises can strengthen technological innovation and business model innovation, reduce the cost of hydrogen energy, and expand application scenarios; Scientific research institutions can strengthen basic research and applied research to provide strong support for the development of hydrogen energy technology.

As a clean and efficient energy source, hydrogen has great development potential and future prospects. Further exploration of hydrogen energy preparation, storage, transport and use technologies will enable it to play a central role in the future energy system. At the same time, promoting the progress of hydrogen energy has a positive impact on environmental protection and sustainability, and contributes to social development. Achieving these goals requires us to continuously research and innovate related technologies to enhance the efficiency and safety of hydrogen energy utilization. In addition, strengthening international cooperation is key, which will help to jointly promote the development and application of hydrogen technologies and more effectively meet global future energy needs. At the same time, the public needs to improve the popularity of scientific knowledge, and make more people realize the benefits and possibilities of hydrogen energy, so as to support its rapid development.

Authors Contribution

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

References

- [1] Ni Yaoqi, Zhu Hengkai. Opportunities, difficulties and path selection of hydrogen energy development under the goal of "double carbon". Modern chemical industry, 2024.
- [2] Qiu Lijing. Effectively explore the potential of multiple application of hydrogen energy. China Electric Power News, 2023.
- [3] Li Jianlin, Li Guanghui, Ma Suliang, Wang Han, et al. Overview of the key technology progress and development prospects of hydrogen production under the carbon neutral target. Thermal power generation, 2021, (9): 1-8.
- [4] Gan Yong. How the hydrogen energy will change our future. Smart China, 2023, (12): 18-20.
- [5] Deng Zhen. Policies have helped to accelerate the growth of the hydrogen energy industry. Shanghai Securities News, 2004, 4.
- [6] Qiu Lijing. Effectively explore the potential of multiple application of hydrogen energy. China Electric Power News, 2004, 4.