

Technical Status and Prospect of Hydrogen Fuel Cell

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Abstract. The use of non-renewable energy leads to frequent ecological and climate problems, and the exploitation and utilization of clean energy has become the general trend of energy transformation and development in various countries. This article introduces the hydrogen fuel cell technology, its advantages and disadvantages, and its applications, and finally discusses the innovation and challenges. Firstly, this paper introduces the working principle of hydrogen fuel cell. Hydrogen fuel cells use hydrogen and oxygen to undergo Reduction-oxidation (REDOX) reactions under the action of a catalyst to produce electricity and water. The process is both efficient and emission-free, making it an ideal way to convert clean energy. Secondly, the composition of hydrogen fuel cell is introduced in this paper. Hydrogen fuel cell consists of hydrogen supply system, oxygen supply system, electrolyte membrane, anode, cathode and other components. The components work together to achieve the storage, delivery and reaction of hydrogen gas with oxygen into electricity. Then, this paper analyzes the advantages of hydrogen fuel cells. Compared with traditional internal combustion engines, hydrogen fuel cells have the advantages of zero emissions, high energy conversion efficiency, and fast charging. Additionally, hydrogen fuel cells are not subject to geographical restrictions, and can be flexibly applied to various transportation and energy fields. Finally, the application prospect of hydrogen fuel cell is prospected. Hydrogen fuel cells have been widely used in automobiles, public transportation, ships and aircraft, and remarkable results have been made. In the future, with the constant progress of technology and the decline of costs, hydrogen fuel cells will be further popularized and promoted, becoming an important part of the field of clean energy and making important contributions to the realization of sustainable development. In the future, if the market strengthens the top-level planning of hydrogen energy development, improves hydrogen production technology, speeds up component research, and improves metallurgical technology, hydrogen energy is expected to be greatly utilized. This paper provides a theoretical basis for hydrogen fuel cell research, and provides suggestions and measures for large-scale commercial use of hydrogen energy.

Keywords: Hydrogen energy, hydrogen fuel cell, sustainable development, environmental and ecological, energy utilization.

1. Introduction

In the 18th century, coal and fossil energy as the main energy promoted the emergence and development of the first and second industrial revolution. However, with the passage of time, the use of non-renewable energy has led to frequent ecological and climate problems, and the exploitation and utilization of clean energy has become the general trend of energy transformation and development in various countries. Hydrogen energy is considered to be the ideal choice of future energy and has attracted the attention of all countries in the world. It is a clean, efficient and sustainable form of energy and has broad application prospects. The use of hydrogen energy is not only environmentally friendly, but also could revolutionize energy supply, industrial development and transportation. On the way to achieve comprehensive well-being and modernization in China, the per capita energy demand is increasing, and biological energy such as hydrogen energy is gradually replacing fossil energy in the energy structure.

Hydrogen fuel cell technology dates back to the late 19th century, when scientists began studying how to harness the chemical energy of hydrogen to generate electricity. However, real technological development began in the 1960s and 1970s, when the United States and the former Soviet Union conducted large-scale hydrogen fuel cell research, respectively. In the 1980s, with the increasing environmental problems and energy crisis, hydrogen fuel cell technology once again attracted

people's attention. At present, hydrogen fuel cell technology has made great progress and has begun to be widely used in various applications, and countries around the world are actively promoting the development and application of hydrogen energy. Among them, Japan, South Korea, the United States and other countries have a certain lead in fuel cell technology and hydrogen energy production. China is also actively promoting the development and use of hydrogen energy technology, and several cities have carried out demonstration operations of fuel cell vehicles and rail transit.

This study aims to introduce the hydrogen fuel cell technology to the reader. This paper will focus on the following issues, what is hydrogen fuel cell technology, and related hydrogen production methods, fuel cell principles, combined with the characteristics of hydrogen to discuss the advantages and disadvantages of hydrogen fuel cells, hydrogen fuel cell applications in social life, hydrogen fuel cell technology in the development process of innovation and challenges. Based on the research of China's fuel cell vehicle development reports in recent years, this paper analyzes the development status of hydrogen fuel cell technology, considers the problems faced by China's hydrogen fuel cell technology, sorts out the future development direction of related technologies and studies support suggestions, so as to provide basic reference for the technological progress of the industry.

2. Hydrogen Fuel Cell Technology

A technique known as a hydrogen fuel cell uses hydrogen energy to transform chemical energy into electricity. One of China's current major goals is to achieve carbon neutrality by 2060 through energy saving, emission reduction, and afforestation, or "carbon peak and carbon neutrality," by 2030, when domestic carbon dioxide emissions would have peaked. The hydrogen fuel cell exerts a significant role in advancing the industrial structure's optimization and achieving the dual-carbon target as a clean and effective energy technology [1]. By employing hydrogen fuel cells, we may accomplish clean and effective energy utilization, lessen our reliance on fossil fuels, and minimize carbon emissions. The advancement and widespread use of hydrogen fuel cell technology can aid in the system's transition. It may speed up the transition of the energy structure to a cleaner, low-carbon, and sustainable direction and accomplish the aim of energy transformation in the dual-carbon plan by encouraging the research, development, as well as deployment of hydrogen energy technology.

2.1. Hydrogen Production Method

At present, hydrogen production technology with promising development prospects is hydrogen production by electrolysis of water, which can be classified into four types: hydrogen production by alkaline electrolysis of water, hydrogen production by proton exchange membrane electrolysis of water, hydrogen production by solid oxide electrolysis of water, and hydrogen production by anion exchange membrane electrolysis of water. Each of the four methods has its own advantages under different circumstances [2].

Alkaline electrolytic water hydrogen production is an important way to prepare hydrogen. Electrolytic water produces hydrogen and oxygen under the action of direct current, and the two gases are separated in the negative electrode and the anode. With the maturity of hydrogen production technology by electrolytic water, this method of hydrogen production will be used on a large scale.

Under the premise of providing external direct current, the hydrogen production method of hydrolysis into hydrogen and oxygen through membrane electrodes is called proton exchange membrane electrolysis water hydrogen production method. Proton exchange membrane electrolysis water hydrogen production technology has entered the stage of commercial application, and has been planned and applied in many renewable energy hydrogen production demonstration projects. The technology has the advantages of fast dynamic response and adaptability to the volatility of renewable energy generation, and will make a vital impact on the deep decarbonization of transportation, chemical industry, steel, energy storage and other fields in the future.

Hydrogen production by electrolysis of solid oxide water is done by heating solid oxide to a certain temperature, causing it to decompose and generate oxygen atoms and electrons. The decomposed

solid oxide reacts with water to form hydrogen and oxygen. In this process, electrons are passed through an external circuit, producing hydrogen at the cathode of the electrolyzer and oxygen at the anode. This method can improve electrolysis efficiency, reduce energy consumption and optimize hydrogen generation conditions.

Anion exchange membrane electrolysis of water for hydrogen production Anion exchange membrane electrolysis of water for hydrogen production is a technology that uses electrolysis of water to produce hydrogen. The technology uses a membrane material called an anion exchange membrane that splits water into hydrogen and oxygen. In the process of hydrogen production by electrolysis of water in anion exchange membrane, water is decomposed into hydrogen ions (H^+) and hydroxide ions (OH^-), and the anion exchange membrane only allows hydroxide ions to pass through, but prevents hydrogen ions from passing through. When a current is passed through an electrolytic cell with a small impedance, hydrogen ions are reduced to hydrogen at the cathode electrode, while hydroxide ions are oxidized to oxygen at the anode electrode. High purity hydrogen can be produced by anion exchange membrane electrolysis, which exhibits the advantages of low energy consumption and high efficiency.

2.2. Operating Principles and Advantages of Fuel Cells

The working principle of the fuel cell is to convert the chemical energy in the fuel into electrical energy through electrochemical reaction, electrolyte, fuel electrode, oxidizer electrode to form a battery. The hydrogen oxidation reaction and oxygen reduction reaction occur on both sides of the diaphragm of the electrolyte, and the electrons in the reaction do work to the external circuit to generate electric energy [3].

The fuel cell has the following advantages: (i) its power generation efficiency is high, the power generation efficiency in practical applications can reach 40%-60%, if the combined heat and power supply is realized, the power generation efficiency can reach 80%; (ii) the carbon dioxide emissions of fuel cells are 40% less than the traditional heat engine effect, and the environmental pollution is small, and the nitrogen and sulfur oxides are not emitted, so the pollution of the atmosphere is also small; (iii) The specific energy of fuel cells is much higher than that of ordinary batteries, and the specific energy of direct methanol batteries is 10 times higher than that of lithium-ion batteries [4]; (iv) Fuel cells can be adapted to multiple fuel sources. In addition to hydrogen, methanol, ethanol, natural gas and other combustible substances can also be used as fuel. This means that in different situations, the appropriate fuel can be selected to meet the needs of the fuel cell, so as to better use the existing energy resources; (v) Fuel cells have high reliability and long life. Its chemical reaction process is stable, and it can be operated under high intensity and high frequency of use. In addition, with the constant development of technology, the maintenance cost of fuel cells is also gradually reducing, further improving their reliability.

3. Advantages and Disadvantages of Hydrogen Energy

3.1. Advantages of Hydrogen Fuel Cells

There is almost no noise during the operation of hydrogen fuel cells, the running volume is almost the same as the decibels of people talking, and the installation of indoor and outdoor has no much impact on its surroundings. Water is the only byproduct of hydrogen fuel cells, which is pollution-free to the environment and is different from other electrochemical reactions. If hydrogen is generated from other renewable energy sources, it does not produce harmful gases to the environment [5]. Hydrogen fuel cells can be used for a longer period of time than conventional batteries. Only new hydrogen may be utilized since hydrogen is a very renewable fuel. Many different things may use hydrogen fuel cells, including cars, mobile devices, residential energy storage, and more. It is widely adjustable and may satisfy the needs of numerous scenarios. Hydro-electrolysis may produce hydrogen, which can be combined with renewable energy sources (such solar and wind) to provide sustainable energy. Hydrogen fuel cells offer a far better energy density than conventional batteries.

Unlike traditional batteries, which have a poor energy density, hydrogen can create a lot of energy per unit of mass.

3.2. Disadvantages of Hydrogen Fuel Cells

The downsides of frequently used hydrogen production techniques, such as electrolysis of water to produce hydrogen, water gas to produce hydrogen, oil cracking to produce hydrogen, etc., include high cost and low purity of hydrogen production. The large-scale commercial usage of hydrogen fuel cells is constrained by technological constraints related to energy density, hydrogen storage security, and other areas. The high-pressure hydrogen storage method is currently the least secure of the ways frequently used to store hydrogen, and it has additional risks such as leakage and hydrogen embrittlement. The storage of liquid hydrogen is expensive and energy-intensive. The hydrogen storage method using metal hydrides is expensive and has a low hydrogen storage density.

The hydrogen transport network system is still in its infancy compared to the developed fuel energy chain and the developed electric energy chain, which is a significant drawback for the widespread commercial application of hydrogen fuel cell technology. Additionally, there are not nearly enough hydrogen refueling stations being built, and the expansion of the hydrogen fuel cell sector is being constrained by the high cost of construction and tight technical reliance [6]. Table 1 shows the changes in the number of hydrogens refueling stations from 2020 to 2025.

Table 1. Operational planning of hydrogen refueling stations in major countries around the world [7].

Nation	The year 2020	The year 2025
America	75	100
Germany	100	400
Japan	160	320
Korea	80	210
China	20	-
Aggregate	435	1030

4. Hydrogen Fuel Cell Vehicles

China has recently implemented a number of strong regulations and initiatives for environmental preservation, with the strategic aim of "carbon peak, carbon neutrality" as one of them. Because of its nearly zero emission and low-carbon green properties, new energy vehicles have once again become a hot subject in the "dual carbon" setting. The public's desire for new energy cars is growing along with new energy vehicles' ongoing advancements in areas like battery life, wireless charging, hydrogen fuel cells, and other technologies. It is probable that new energy cars will soon overtake conventional fuel vehicles in market share and become a staple of the automotive industry [7]. They will also likely be used more often.

The hydrogen fuel cell vehicle's primary structural components are the power control unit, motor, hydrogen tank, and fuel cell stack. Despite the development and production of automobiles that run on hydrogen fuel, issues including inadequate hydrogen storage tank strength and subpar vehicle safety remain. In order to increase fuel cell longevity, increase vehicle stability, lower purchase costs, realize the industrialization of hydrogen energy vehicles, and be widely adopted in the real world to supply new power for a green lifestyle, the optimization of the structure of hydrogen fuel cell vehicles currently primarily focuses on fuel cell stacks [8]. Figure 1 presents the global progress of hydrogen vehicles as a percentage of total vehicles over the period 2010-2022 [9].

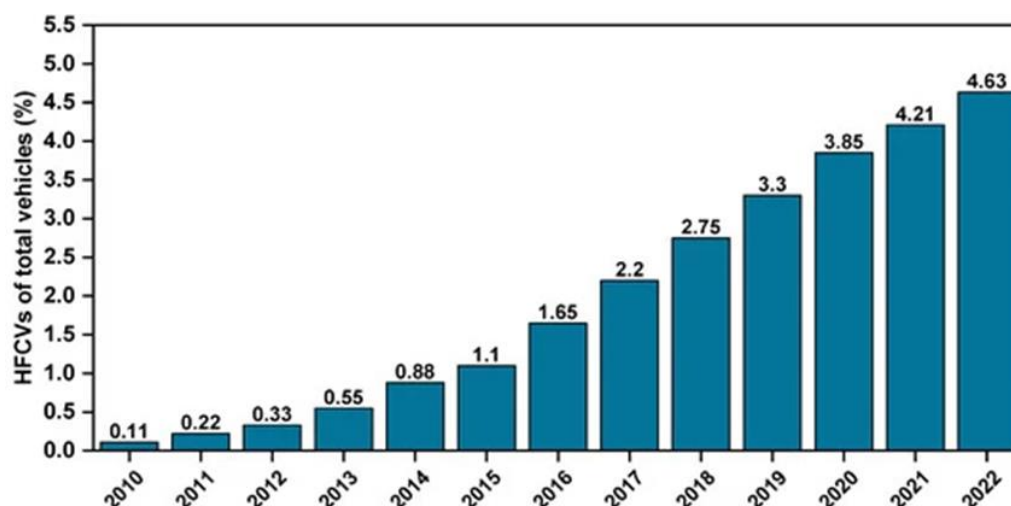


Figure 1. The global HFCVs as a percentage of the total vehicles. <https://www.mdpi.com/ethics#16>

5. Innovation and Challenge

The future development of hydrogen energy can refer to the following points: strengthen the top-level planning of hydrogen energy development, formulate the development goals of the hydrogen energy industry under the "dual carbon" goal, clarify the development tasks of hydrogen energy at each stage, and improve the industry technical standards and safety monitoring system as soon as possible to provide reference for the standardized development of hydrogen energy. Strengthen research on gray hydrogen, blue hydrogen and green hydrogen production technology, lower hydrogen production costs, enhance the competitiveness of hydrogen energy products, and improve the hydrogen supply industry chain; Strengthen the research of key materials and core technologies of fuel cells, realize independent production as soon as possible, and reduce the cost of fuel cell industry and hydrogen-powered automobile industry. Strengthen the research on the key components of hydrogenation station and accelerate the process of localization of core components; The national unified project approval process is introduced to improve the approval efficiency of construction stations. Actively explore new technologies of hydrogen rich metallurgy and pure hydrogen metallurgy, improve the economy of hydrogen metallurgy, and accelerate the pace of steel industry decarbonization [10].

6. Conclusion

Hydrogen fuel cell technology is closely related to the completion of the dual-carbon goal and the transformation and development of energy structure. Hydrogen fuel cell technology uses its advantages of no noise, no pollution and high efficiency to stand out from other clean energy sources, but hydrogen fuel cell vehicles on the basis of existing technologies if they increase the optimization of their fuel cell piles for hydrogen production by electrolytic water, hydrogen by water gas process, hydrogen production by petroleum cracking and other hydrogen production methods with high cost and low purity. The safety of hydrogen storage, energy storage density and other technical requirements are restricting the large-scale commercial use of hydrogen fuel cells. Moreover, the hydrogen transport network is not yet perfect, and the construction of hydrogen refueling stations needs to be improved. To improve vehicle stability and reduce purchase costs, hydrogen energy vehicles will be industrialized and provide new power for green life. In the near future, if the market strengthens the top-level planning of hydrogen energy development, improves hydrogen production technology, speeds up component research, and improves metallurgical technology, hydrogen energy is expected to be used in large quantities. The present study introduces the principle and application of hydrogen fuel cell technology, and provides suggestions for its further improvement.

References

- [1] Li J., Li G., Ma S., Wang H., Review on progress and prospects of key technologies for hydrogen production under carbon neutrality. *Thermal Power Generation*, 2021, 50 (06): 1 - 8. (In Chinese).
- [2] Xu S., Yu B.Y., Current situation and future prospect of hydrogen energy technology in China. *Journal of Beijing Institute of Technology (Social Sciences)*, 2021, 23 (06): 1 - 12. (In Chinese).
- [3] Shao Z.G., Yi B.L., Development status and prospect of hydrogen energy and fuel cell. *Proceedings of the Chinese Academy of Sciences*, 2019, 34 (04): 469 - 477. (In Chinese).
- [4] Liu J., Wang J.X., Xing Z.N., Li W., Research progress and development of fuel cell. *Energy Saving Technology*, 2010, 28 (04): 364 - 368. (In Chinese).
- [5] Zhang Y.D., Application and development prospect of hydrogen fuel cell. *Nanfang Agricultural Machinery*, 2020, 51 (18): 193 - 194. (In Chinese).
- [6] Chen T., Zhou Y.H., Zhang H.Z., Development status and trend of hydrogen fuel cell. *energy conservation*, 2019, 38 (06): 158 - 160. (In Chinese).
- [7] Zhang Z.L., Opportunities and challenges of new energy vehicles under the background of "dual carbon". *Special Purpose Motor Vehicle*, 2023, (03): 10 - 12. (In Chinese).
- [8] Gao Z.W., Li X.G., Liu Z.X., Research status and development trend of hydrogen fuel cell vehicle. *Material Guide*, 2022, 36 (14): 74 - 81. (In Chinese).
- [9] Hassan Q, Azzawi I.D.J., Sameen A.Z., Salman H.M., Hydrogen Fuel Cell Vehicles: Opportunities and Challenges. *Sustainability*, 2023, 15 (15): 11501.
- [10] Meng Z.X., He Q., Hu H.W., Current situation and consideration of hydrogen energy industry development in China. *Modern Chemical Industry*, 2022, 42 (01): 1 - 6. (In Chinese).