

Working principle and application of hydrogen fuel cells

Kefeng Ke¹, Siyuan Pang^{2, *}

¹Beijing Chaoyang Foreign Language School, Beijing, China

²Shanghai Foreign Language School Affiliated to SISU Hangzhou, Hangzhou, China

* Corresponding Author Email: dujiang@ldy.edu.rs

Abstract. With the increasing number of people on the earth, technology continues to improve. People enjoy a convenient life at the same time, the ecological pollution and energy consumption problems are constantly aggravating, in the environment is caused by irreversible damage to the fact in front of before waking up, and then began to develop and research a not only meet the energy needs but also minimize the damage to the environment of a new type of clean energy-fuel cells. Fuel cell is one of the most promising energy sources. At present, hydrogen-fueled automobile is one of the most widely used tools of fuel cell in transportation law, and the production of automobiles is increasing year by year, and the production technology is also improving. National governments have issued relevant policies to support the development and research of fuel cells. However, fuel cells still have problems such as high production cost, high energy consumption, and imperfect hydrogen energy industry chain. This article uses the literature to analyze the working principle, development status and future prospects of hydrogen fuel cells. In addition, it also includes the problems of the current use and puts forward some suggestions to solve the problems, such as improving the hydrogen industry chain and reducing the energy consumption of the battery. It helps people to recognize and understand the fuel cell, and also provides some suggestions for the future direction of fuel cell research.

Keywords: hydrogen fuel cells, application, limitations.

1. Introduction

In the past fifty years, the global economy has grown nearly five times as much, so that people's quality of life has more than one rapid improvement. With the standard of living and the number of people, people's demand for energy continues to increase, while the traditional non-renewable fossil fuels are depleting, and people enjoy the convenience of today's high-tech high-development era. The world's environment and energy problems have become imminent. Energy problems have been imminent, therefore, scientists have studied the new energy batteries are used in our lives, and this time we are studying the new energy batteries in the very promising fuel cells, fuel cells, as the name suggests, is the presence of chemical energy in the fuel is directly converted into electrical energy we utilize. The theory of electrochemistry, is generally made up of three parts-electrodes (divided into anode and cathode), electrolyte membrane and external, an electrolyte diaphragm, and an external circuit. The reason why it is heavily utilized is that compared to conventional batteries, it is not only significantly less harmful to the environment, but it is also far more efficient than devices such as thermoelectric power generation.

In addition to the two most notable advantages, fuel cells also have the advantages of low radiation and high reliability, and are highly economical products [1]. The earliest technology development of fuel cell was applied in aerospace technology, and with continuous improvement and updating, it is now mainly used in transportation in the market, for example, the hydrogen fuel cell vehicle (FCEV) which is the closest to our life. The principle is that in the presence of electrolyte, hydrogen ions, that is, fuel ions, and oxygen ions react to generate electricity, which drives the electric motor and moves the wheels of the vehicle. Although the use of fuel cells greatly reduces the amount of carbon emissions into the atmosphere compared to conventional petroleum and diesel vehicles, there are some drawbacks. Hydrogen fuel is required to power the vehicle, and when manufacturing hydrogen fuel, factories generally consume fossil fuels to obtain hydrogen as a raw material, which can cause environmental pollution, so there is still room for improvement.

Taking the hydrogen fuel cell as an example, the most widely used hydrogen-powered cars, as the name suggests, use hydrogen fuel as the main energy supply to replace the old version of cars that use fuel such as petroleum and diesel as power. And compared with ordinary chemical batteries, hydrogen fuel cells can be directly replenished with fuel for range, and compared with cars using conventional batteries, there is no need to wait overnight for a full charge before starting the car, and can be directly added to the hydrogen as fuel replenishment [2]. Therefore, this is a vehicle that not only eliminates the disadvantage of high pollution and high emissions of conventional fuel, but also has the advantage of being able to complete the range process in a short period of time. It can be said that it is a highly economical product that can hardly be criticized.

There are generally two kinds of hydrogen-powered vehicles-hydrogen internal combustion vehicles and hydrogen fuel vehicles. The main research of this time is the hydrogen fuel cell vehicle, and for this type of vehicle, the main technology used is the proton exchange membrane fuel cell technology, the main working principle of the fuel used is also known as hydrogen, which is fed into the anode of the battery, under the action of the catalyst through the reaction is broken down into positively charged protons and negatively charged molecules, and then protons through the proton exchange membrane to the large battery cathode, and electrons with the external circuit to form a circuit. The protons then pass through the proton exchange membrane to the cathode of the large battery, while the electrons form a circuit with the external circuit. At the same time, oxygen is fed into the battery, and under the action of a catalyst, hydrogen protons and hydrogen electrons react with oxygen in a redox reaction to produce water and the electricity we need. And the efficiency is very high, up to 50% and more. In simple terms, this reaction can be recorded as an inverse reaction of water electrolysis. In the application, because the final product of the reaction is only water and the use of electricity, and water in the case of heat generated by the reaction can be eliminated in the form of water vapor, which greatly reduces the pollution of the environment, and really realizes the substantial protection of the natural environment pollution. This research will analyze the working principle and application of hydrogen fuel cells.

2. Principle and application of hydrogen fuel cell

2.1. Composition and principle of hydrogen fuel cell

The system of hydrogen fuel cell is more complex compared with lithium battery, which is mainly composed of electric stack and system components. For the battery system, the core part is the electric stack, which includes the battery cell and the collector plate, end plate, sealing ring and other components, among which, the battery cell is the main one, which consists of the membrane electrode and the bipolar plate. Membrane electrode is the core component for hydrogen fuel cell, which generally consists of anode gas diffusion layer, anode catalyst layer, proton exchange membrane, cathode catalyst layer, and cathode gas diffusion layer, and the membrane electrode is the determinant of power density, durability as well as lifetime of the cell. A hydrogen fuel cell is a combustion situation where hydrogen and oxygen are allowed to react to convert hydrogen energy into electricity. The reaction process is shown in Fig. 1 [3]. Before the reaction starts, hydrogen (H_2) passes through the collector plate and arrives at the gas diffusion layer, at which time the catalyst causes H_2 to lose electrons and become wandering hydrogen ions (H^+), and during the wandering process, H^+ passes through the proton-exchange membrane and eventually arrives at the cathode of the cell. The lost electrons flow into the external circuit, which creates the electric current that we want. At the cathode of the battery, there is an external inflow of oxygen (O_2), through the collector plate to arrive at the diffusion, and then finally with the inflow of hydrogen ions into the cathode to form water, and release a certain amount of heat layer after the catalyst will make it to receive the electrons of the external circuit flow into the cathode, the formation of negatively charged oxygen ions. The reaction has no pollution and no carbon emissions, and no Carnot cycle, high energy conversion rate [3], so the hydrogen fuel cell is the future of the battery Hydrogen fuel cell, only hydrogen reacts with oxygen, and only water is generated after the reaction, which is the focus of the direction of the research.

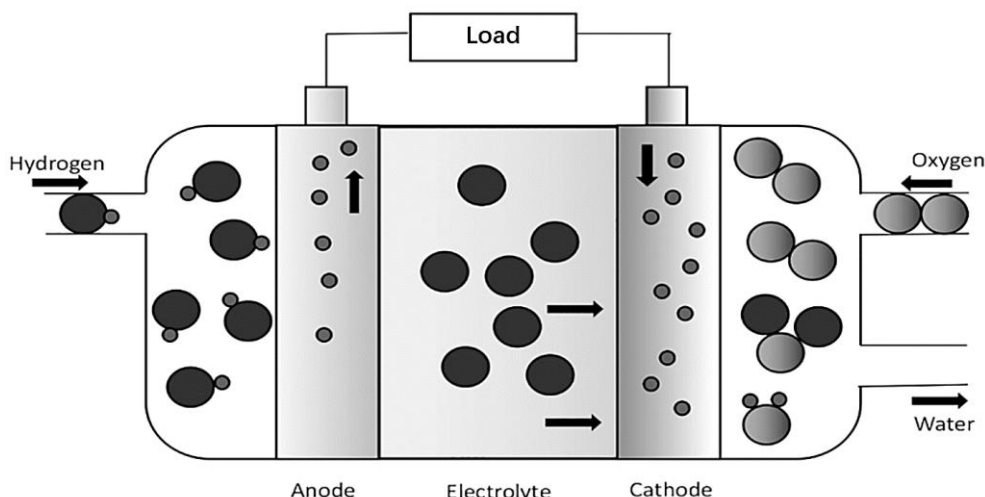


Fig. 1 Reaction process for hydrogen fuel cell [3].

2.2. Hydrogen-fueled vehicles

At present, hydrogen-fueled vehicles occupy an influential position in the market, as shown in Fig. 2, the domestic production of hydrogen-fueled vehicles has been increasing since 2015, and the overall trend is showing an upward trend [4]. In 2019, the year with the highest data, the production reached 3018 units. And arriving in 2020, the global outbreak of large-scale health and wellness issues, the national government mobilized to focus on attacking the looming health alarms first, reducing subsidies for hydrogen-fueled vehicles. As a result, hydrogen-fueled vehicle production was dramatically affected, with production plummeting to 1,199 units. As shown in the chart only 10 hydrogen fueled vehicles were produced in 2015, 628 in 2016, 1,612 in 2017, 3,018 in 2019 and 1,199 in 2020. The data continues to be recorded. Moreover, hydrogen-fueled buses account for a not-insignificant proportion of such vehicles in the market, with production rising gradually with increasing years, technological innovations, and improved equipment.

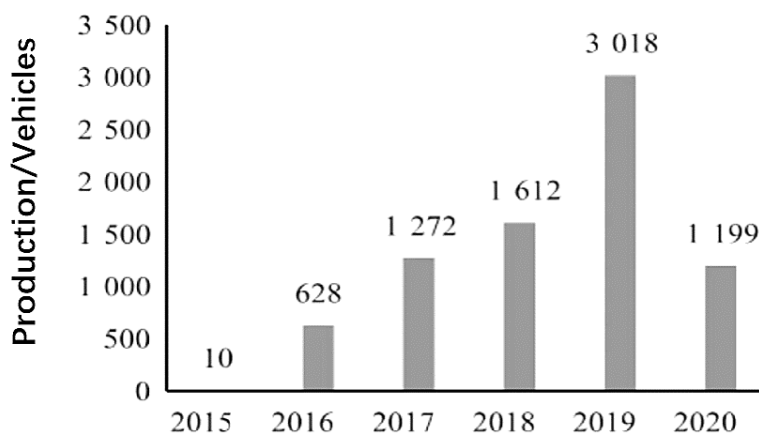


Fig. 2 2015-2020 hydrogen-fueled vehicle production [4].

As shown in Fig. 3, it is in an upward trend and accounts for a large share of the total hydrogen fuel vehicle production data [4]. A total of 28 buses were produced in 2016, 189 buses in 2017, 710 cars in 2018, 1,345 cars in 2019, and production plummeted to 549 in 2020 due to global health concerns. The good news is that most of the health and hygiene issues have now been resolved almost globally and do not have a massive impact on the hydrogen fuel vehicle side of production. As a result, the hydrogen fuel industry has been able to resume production and the national government is supporting the production and research of hydrogen fuels. The government has shown great importance to this. In fact, we can be seen that from 2016 to 2020, the state has a great supportive role in the research on the production of hydrogen fuels, and puts forward and publishes the

corresponding problem-solving policies at different times of the production of hydrogen fuels. It makes a great contribution to support the high-speed development of hydrogen fuel and strongly promotes the results of applied research on hydrogen fuel [4].

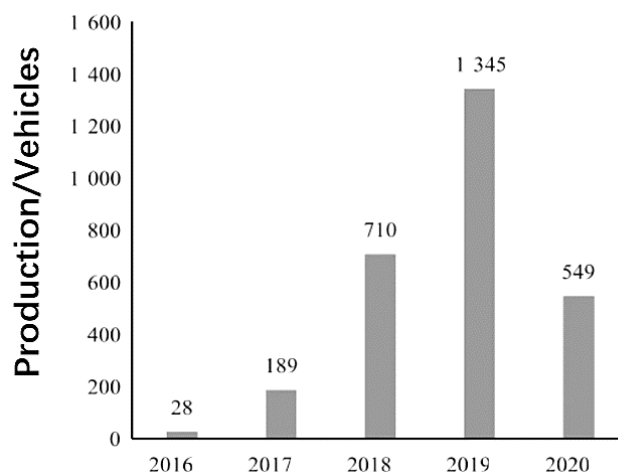


Fig. 3 The production volume of buses among hydrogen fuel vehicles in recent years [4].

Why is it that such an efficient, low-polluting, ultra-high-economy commodity has not yet been widely used around the globe for the benefit of mankind. It can be explained that there are still some difficulties that we can't solve at present. First of all, hydrogen fuel, as the name suggests, requires the use of hydrogen as a raw material for the reaction to produce electricity, but the production, transportation and storage of hydrogen are all parts of the process that we can't control and utilize properly nowadays. Let's take the process of hydrogen production as an example. At present, in China, there are generally natural gas hydrogen production, refinery hydrogen production, and natural gas hydrogen production. The most traditional use of refinery hydrogen production, the process is to add hydrogen to the petroleum refinery for cracking, and then to carry out processes such as thermal cracking, coking, and catalytic cracking. The catalytic cracking is one of such methods. Catalytic cracking is an important source of hydrogen for this type of method. The advantages of hydrogen production in refineries are not only the abundance of resources, which can be made from a wide variety of materials such as the familiar crude oil, natural gas, or petroleum brains, but also the extremely high hydrogen production rate, which can theoretically be as high as 99%. The other more convenient is the electrolysis of water to produce hydrogen, this kind of technology is more mature, and we have learned in junior high school in the science textbook electrolysis of water, seems to be closer to our lives. It works by passing direct current into an electrolyzer filled with electrolyte, where an electrochemical reaction occurs at the electrodes, and water molecules are reacted and decomposed to produce hydrogen and oxygen. The electrolyzer in the water electrolysis device is very conducive to hydrogen cell phones due to its physical characteristics. This type of reaction is simple and easy to operate for industrial production, and because there are no harmful substances in the final reaction result, there is only oxygen and water after the hydrogen is purified. Can really realize "zero emission". However, one unavoidable disadvantage of both types of hydrogen production is that it is very expensive. If the cost of hydrogen production is too expensive, then the price of hydrogen-fueled cars will not be reduced, not only the car itself, in the process of use, the need to use hydrogen for fuel replenishment, the cost of which may be the average family is not willing to bear, so there is a certain impediment to the promotion of hydrogen-fueled vehicles.

Hydrogen is the first element in the periodic table and therefore the lightest. Under standard atmospheric pressure, the density of hydrogen is 0.0899g/L, which is much smaller than that of water, so storing hydrogen is quite a difficult problem, and if hydrogen storage cannot be solved, transportation also becomes a tricky problem. Moreover, hydrogen is extremely prone to explosions and other safety incidents, such as the world's first hydrogen production and storage explosion, which occurred at 6:20 p.m. (5:20 p.m. BST) on May 23, 2019, at a factory in Gangneung City, Gangwon

Province, South Korea, where workers were conducting a safety test on hydrogen tanks when a serious explosion accidentally occurred. The result was two deaths and six injuries. We also need to learn a lesson, be more careful about the use of hydrogen, and establish and improve the industrial chain of hydrogen production, storage and transportation. In the use of hydrogen fuel cells, the catalyst is a very important device. Therefore, the same problem will arise, the catalyst will use platinum, and platinum as a rare metal is also a very high cost of raw materials. Not only the price of hydrogen is high, but also the cost of catalyst production is high, resulting in the high price of hydrogen fuel cells, which cannot really realize the civilianization [5].

Whether we have a certain solution to this is still a question we need to explore. Hydrogen production from electrolyzed water, even with its high efficiency and zero-emission characteristics, its high cost will still be a problem on the way to development, according to our research, breakthroughs in large-scale electrolysis of water costs, there are mainly three ways to alleviate the problem. First, reduce energy consumption, that is, the energy consumed in the electrolysis process. According to the data research, electrolysis of water at room temperature, 101kpa under atmospheric pressure to prepare 1 cubic meter of hydrogen at least 2.95k W h. But in the actual reaction process, the energy consumption is much larger than the theory. As early as 2009, Japan has developed a breakthrough technology to reduce the actual energy consumption, but it still requires 3.8kWh to produce one cubic meter of hydrogen at normal temperature and pressure, and we are still working on it. We can utilize more renewable energy sources such as wind, solar and tidal energy for the reaction. For example, solar hydrogen production is actually an ideal technology for hydrogen production, which works by utilizing solar energy to break down water molecules with the help of a photocatalyst to produce hydrogen. Not only is solar energy a renewable energy source that reduces energy consumption, but it can also be reused, and there is no problem of impurities and wastage due to the disruption of other energy sources. However, the disadvantage is that it is not very efficient, and if it is used in large quantities, even if the consumption of traditional fossil energy sources is greatly reduced and the environment is greatly improved, there is no guarantee that it will be able to supply enough for global human use [6].

For the future development of hydrogen fuel cells, the most supported area should be the transportation sector, because of the high energy conversion rate, low emission pollution, long range and other characteristics of hydrogen fuel cells, the market outlook in the transportation is bright. Toyota MIRAI brand, for example, as early as 1992, Toyota has developed the fuel cell vehicle market area, until December 2014, the world's first mass-produced fuel cell trolley Toyota MIRAI officially listed, the car not only has low emissions - carbon dioxide emissions of 0, but also almost the range of the problem and the charging time problem overcome, as of now, in the world on the As of today, about 8,000 units of this fuel cell tram have been sold globally. Toyota is looking farther ahead, and in order to improve and strengthen this technology, it is promoting and selling it on a large scale in regions around the world, such as Canada, Japan, and Australia. In China, Toyota established a hydrogen refueling station at its research center in Jiangsu Province in October 2017 to test the technology. The future of hydrogen fuel cell trams should not be underestimated [7].

The advantages of hydrogen fuel cells are obvious, and we should widely popularize them after strengthening the technology, but again, before that, we need to strengthen the improvement and enhance the reliability of its use as well as its lifespan. Currently, there is a gap between the level of domestic research on batteries and the international state-of-the-art technology. We may need to research new equipment and other methods to improve the device. As for the hydrogen industry chain, we need to improve the core technology of hydrogen refueling stations, in addition to the support of national government policies. I believe that in the future we can see the large-scale use of hydrogen fuel cells in the global aspect and good performance.

2.3. Challenges and developemnt

Over the past 20 years, BAIC Foton's hydrogen industry has created a number of industry firsts, and is laying out a new track and developing a new platform in 2023. BAIC Foton's hydrogen energy products have been well applied in major events as well as bus cold chain transportation, medium and heavy duty, and medium and long-distance transportation scenarios. Hydrogen energy, as a green energy, is a strategic emerging industry and a key development direction for future industries. As early as 2003, BAIC Foton set up the first new energy vehicle industrial base in China and became the first vehicle enterprise in the field of new energy vehicles; in 2006, BAIC Foton pre-empted the layout of the hydrogen energy field and completed the first fuel cell bus and truck announcement in China, and in recent years, the 70 MPa hydrogen-fueled bus successfully passed the world's first case of basic collision test, and was honored with the title of "State-level Green Factory". In recent years, the company has successfully passed the world's first base crash test for 70 MPa hydrogen-fueled buses, won the title of "National Green Factory", and set the record of serving the largest scale and the largest number of models of hydrogen-fueled buses in international sports events in the Beijing Winter Olympics. From new energy to green manufacturing, from low-carbon supply chain to green industrial ecosystem, BAIC Motor Foton is at the forefront.

Since the beginning of this year, BAIC Foton has actively adjusted its strategic deployment, released its new energy strategy and ecological layout plan, and accelerated its green transformation with its leading technology, diversified product portfolio, and continuous improvement of new energy logistics and transportation solutions. In the company's new cultural concept system, BAIC Foton takes "providing green solutions for the energy revolution" as its mission, and aspires to become a "green technology and market-leading international enterprise". In the future, BAIC-Foton will continue to accelerate innovation and new energy layout, and the penetration rate of new energy vehicle products will reach 20% in 2025 and 50% in 2030 [8].

The development of hydrogen fuel cells still needs to solve a variety of problems, including cost reduction, increase power, improve efficiency and extend life. At the same time, the cost of on-board hydrogen storage bottles also needs to be significantly reduced. In terms of power, fuel cell part-load efficiency is higher than the rated load efficiency, so increasing the power can move the common operating point to the high-efficiency zone. And the current fuel cell heavy truck hydrogen consumption is still high, so the rated efficiency also needs to be improved. In terms of life, the current hydrogen fuel cell life is about 18,000 hours. By 2025, it needs to be improved to 25,000 hours, and by 2030 to do 30,000 ~ 35,000 hours, to meet the driving range of 1.2 million to 1.5 million kilometers. The hydrogen fuel cell system mainly includes the electric stack, proton exchange membrane, membrane electrode, bipolar plate, catalyst, and the hydrogen storage system mainly includes the hydrogen storage bottles, bottle valves and pressure-reducing valves and other core components. Among them, the valve is heavily dependent on imports, and the proton exchange membrane and catalyst have not made substantial breakthroughs.

There are two aspects to consider, one is the source of hydrogen, from the cost point of view, the current cost of electrolysis of water is the highest, the impurities are relatively small, there are a large number of cheap industrial reforming hydrogen, by-products of hydrogen, due to the presence of toxicity species cannot be used, and therefore we need to develop the anode anti-toxicity catalysts, only to let the hydrogen to reach the reaction interface, blocking the other substances. There are two directions for hydrogen, one is to construct molecularly selective channels, so that effective antitoxicization can be achieved by allowing only hydrogen to reach the reaction site for reaction. The second is to develop catalysts with higher catalytic activity and stability. A research report released by Tianfeng Securities shows that China's hydrogen fuel cell industry is now extremely similar to the lithium battery in 2012, the policy is supported from the top down, the technology has reached the conditions for industrialization, enterprises to accelerate the speed of the layout, the industrial chain localization process is opened, and the capital market continues to rise in the heat of investment and financing. Similar to Japan, the United States, China's hydrogen fuel cell industry has

a large incremental, in the industry's rising stage, the trillion-dollar industry mining curtain has been opened [9].

To summarize, hydrogen energy is a comprehensive industrial chain system. In the hydrogen production link, coal hydrogen production with cost advantage is still the main method, which is the basis for promoting the development of other links in the hydrogen energy industry chain. At the same time, it is necessary to reduce the technical cost of hydrogen production from electrolyzed water through the combination of production and research, and hydrogen production from renewable energy sources will become the mainstream hydrogen production method in the future. In the hydrogen transportation link, it is necessary to choose a suitable hydrogen transmission method according to the actual situation of hydrogen transmission distance and volume. The research and development of solid-state hydrogen storage and organic solution hydrogen storage technology should be strengthened to obtain a more convenient and lower-cost hydrogen transportation method. Hydrogen has a wide range of application prospects in multiple industries, but the penetration rate of hydrogen energy in each industry basically relies on the cost of hydrogen use. In the transportation industry, priority can be given to promoting the use of hydrogen power in heavy truck and bus applications, and then in passenger car applications when the cost of hydrogen use is reduced to less than RMB 35 yuan/kg.

In the industrial sector, the application of hydrogen energy as a chemical raw material is mature, and the next step needs to implement green hydrogen to replace gray hydrogen, and prioritize the demonstration application of hydrogen steelmaking in areas with conditions. In the construction industry, hydrogen energy is not economical, but is still a good choice for backup power. In this paper, hydrogen energy technology foresight study was carried out through bibliometric analysis, which shows that China's hydrogen energy R&D started late but is growing rapidly. Research related to hydrogen energy storage and transportation technology and hydrogen fuel cell technology will enter the saturation period around 2027, and research related to hydrogen energy production technology will enter the saturation period around 2031. In order to ensure the balanced development of the industrial chain, it is necessary to accelerate the breakthrough of hydrogen energy production technology, with a view to realizing affordable green hydrogen production at an early date. China's hydrogen fuel cell technology development is lagging behind the global average level, and it needs to accelerate the technological research in order to avoid technical barriers created by developed countries. In addition, this paper analyzes the competitive relationship between hydrogen energy and alternative technologies in different fields, and the time when they may form competitiveness. Overall, the development trend of hydrogen energy in China is positive, local governments and enterprises are highly motivated, and the level of technology localization is gradually improving, with large resources and market potential, which is an important part of building a modern energy system. However, in the process of development, resources are scattered, and the phenomenon of duplicated construction is emerging. In order to promote the high-level and orderly development of China's hydrogen energy industry, we put forward the following two suggestions.

First, it needs to establish and improve the relevant top-level design and standard system. Establishing a national hydrogen energy development roadmap can guide the orderly development of the hydrogen energy industry, and avoid duplicated construction and blind competition. Improving the production, storage, transportation and management standards for hydrogen as an energy product, can improve the intrinsic safety, active safety and passive safety measures of hydrogen-related systems, and ensure the maturity and integrity of the hydrogen energy safety system.

Second, it also needs to strengthen core technology research and improve infrastructure construction. The popularization of infrastructure and the promotion of hydrogen-using terminals are interdependent, but the inadequacy of infrastructure and the development of hydrogen-using terminals constrain each other. In areas with potential for hydrogen use, infrastructure such as hydrogen pipeline networks and hydrogen refueling stations need to be deployed in advance. Realizing the localization of core technology and affordability, and sound hydrogen infrastructure play an important role in reducing the cost of hydrogen use and promoting hydrogen application [10].

3. Conclusion

This research mainly analyzes the working principle of fuel cells, the current development situation (taking the most widely used hydrogen-fueled vehicles as an example, using data to show the total number of vehicles developed and produced at present, and analyzing the level of development technology), shortcomings in the use of fuel cells, the future development, and the shortcomings of fuel cells and provides some suggestions, such as perfecting the hydrogen industry chain, reducing the use of batteries in the use of energy and other methods. Support from national policies was also mentioned. It helps people to recognize and understand the working principle, development field and future prospect of fuel cell. It provides some suggestions for the development direction of fuel cells.

Authors Contribution

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

References

- [1] Abdelkareem M A, Elsaid K, Wilberforce T, et al. Environmental aspects of fuel cells: A review. *Science of The Total Environment*, 2021, 752: 141803.
- [2] Singla M K, Nijhawan P, Oberoi A S. Hydrogen fuel and fuel cell technology for cleaner future: a review. *Environmental Science and Pollution Research*, 2021, 28: 15607-15626.
- [3] Lu Guoqiang. Structural Principles and Development Status of Hydrogen Fuel Cells. *Internal Combustion Engine and Accessories*, 2023 (15): 106-108.
- [4] Li Zhiqiang, Wang Kan, Wang Huijie. The Current Situation and Development Strategy of Hydrogen Fuel Cell Vehicles in China. *Automotive Practical Technology*, 2023, 48(2): 200-204.
- [5] Liu Haili. Current Status and Development Trends of Hydrogen Production and Storage Technology for Fuel Cell Vehicles. *Oil Depot and Gas Station*, 2019, 28(5): 24-27+4-5.
- [6] Zhu Mingyuan, Liu Wenbo, Liu Yang et al. Key Science and Technology of Hydrogen Energy and Fuel Cells: Challenges and Prospects. *Journal of Shanghai University (Natural Science Edition)*, 2021,27(3): 411-443.
- [7] Yu Qinghua. Current Status and Development of Toyota Hydrogen Fuel Cell Vehicles. *Automotive Parts*, 2019 (04): 58.
- [8] Duran Beiqi Foton plays a "long chain" role in the hydrogen energy industry Capital Construction Report, 2023-11-07 (002) DOI: 10.28681/n.cnki.nsdjs.2023.001536.
- [9] Wu Ziyue There are still challenges in accelerating the commercialization layout of hydrogen fuel cell vehicles in China's technological breakthroughs *First Financial Daily*, April 4, 2023 (A10) DOI: 10.28207/n.cnki.ndycj.2023.001469.
- [10] Xu Shuo, Yu Biying. Current Status and Future Prospects of Hydrogen Energy Technology Development in China. *Journal of Beijing Institute of Technology (Social Sciences Edition)*, 2021,23 (06): 1-12.