ISSN 2616-5880 Vol. 4, Issue 2: 52-58, DOI: 10.25236/AJMC.2023.040209

Research on application of hydrogen production through water electrolysis

Jiarui Miao*

College of Mechanical and Transportation Engineering, China University of Petroleum, Beijing, Beijing, 100100, China
**Corresponding author: a1930298263@163.com*

Abstract: *Hydrogen is widely used in the field of energy and power technology, and has many advantages, such as strong thermal conductivity, good combustion performance, cleanness, multiple available forms, recyclability, etc. Hydrogen production by electrolysis of water is widely used as an efficient method to produce hydrogen. This paper introduces three widely used ways and principles of hydrogen production through water electrolysis, and summarizes the current application status of hydrogen production through water electrolysis in various scientific research fields in China. The application of hydrogen production from electrolytic water in new energy, transportation, construction and other fields is analyzed, and the future application of hydrogen production from electrolytic water is prospected.*

Keywords: *Hydrogen production through water electrolysis; New energy; Hydrogen preparation; Hydrogen utilization*

1. Introduction

Hydrogen is the most widely distributed substance in the universe, constituting 75% of the mass of the universe. Hydrogen energy is an important secondary energy, which has many advantages, such as strong thermal conductivity, good combustion performance, cleanness, multiple available forms, recyclability, etc. As an efficient and clean energy in the new era, hydrogen energy is in line with the current world energy security and the future energy development goal of reducing emissions and carbon. Hydrogen energy is an important energy on the world energy stage in the 21st century. Hydrogen production, storage, transportation and application technologies are also the focus of research in the field of energy around the world.[1,2]

The research on hydrogen energy has been carried out since the 19th century, but it is the 20th century that all countries in the world really started large-scale research on hydrogen energy.The United States is the first country to develop hydrogen energy. In order to cope with the energy crisis in the 1970s, the United States first began to study the use of hydrogen, and maintained a leading position in the field of hydrogen energy research for a long time. Japan and western countries also began to study hydrogen energy in the 1980s. Among them, Japan was the first to raise hydrogen to the level of national energy strategy. In 1981, it introduced the "Moonlight Plan" for fuel cell technology research. The development of hydrogen energy in South Korea was relatively late, but the development and popularization of hydrogen energy vehicles were promoted by fully drawing on the research in relevant fields in Japan.[5]

In China, hydrogen is also an important exploration direction of the energy revolution. In recent years, as the country has increased its scientific research investment and supported relevant research, hydrogen energy has been widely used in various fields in China, with huge market scale and development potential. However, China is currently constrained by the bottleneck of core technology and key technology facilities. At present, China's hydrogen preparation industry is still in the primary stage of development, and there is still a gap with developed countries such as the United States and the West.

In order to further develop and utilize hydrogen energy and improve its application level, the Chinese government has introduced a series of policies to support the development of hydrogen energy in recent years. In 2019, the Chinese government first mentioned the policies related to new hydrogen energy in its report, and also proposed the policies related to the development of hydrogen energy in the "Fourteenth Five Year Plan", including but not limited to the implementation of the hydrogen energy industry incubation and acceleration plan, the planning and layout of a number of hydrogen energy industries, and the development of low-carbon energy should respond to climate change and other

ISSN 2616-5880 Vol. 4, Issue 2: 52-58, DOI: 10.25236/AJMC.2023.040209

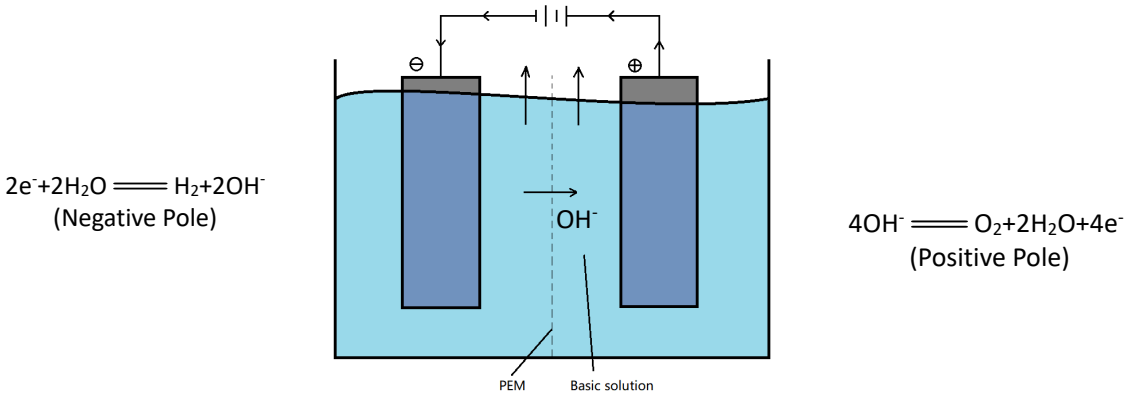
important measures.[5]

This paper briefly describes the development of hydrogen energy research in the world and China, and introduces the principle and basic form of hydrogen production by electrolysis of water. This paper describes the application of electrolytic water hydrogen production in new energy fields, automobile fields, wind power and other fields around the world, and forecasts the existing problems and possible future development of electrolytic water hydrogen production. This article will play a role of science popularization and introduction for readers who are relatively unable to understand the field of hydrogen energy and hydrogen production by electrolysis of water. Through this article, readers can have a basic understanding of the basic methods and principles of electrolytic water hydrogen production, and have a basic understanding of the development and application of electrolytic water hydrogen production in energy and other fields.

2. Principle and form of hydrogen production through water electrolysis

The extensive application and research of hydrogen energy makes the demand for hydrogen in various countries rise continuously, so to the way to improve the hydrogen production efficiency and innovate the hydrogen production technology has become the focus of scientific research in various countries. Alkaline water electrolysis hydrogen production technology is the most mature and highly commercialized hydrogen production method. Its electrode manufacturing does not use precious metal resources, and its cost is low. It is an important part of the electrolytic water market. The basic principle of hydrogen production is to electrolyze water, which makes ions in water flow directionally. The hydrogen ion moves to the cathode under the action of direct current and is reduced to hydrogen. The anion moves to the anode, where it loses electrons and is oxidized to oxygen. Since water itself is a weak electrolyte, it is necessary to add electrolyte in the actual operation process to increase the conductivity of the liquid.

At present, there are three main industrial hydrogen production methods by electrolysis of water, namely, Alkaline water electrolysis (AWE), proton exchange membrane hydrolysis (PEM) and high-temperature Solid oxide electrolysis (SOEC). The AEL method is mature, and the cost is relatively low, which has basically realized industrial large-scale application. Although the PEM method is more suitable for renewable energy, the cost of the proton exchange membrane is high, and the catalyst also needs heavy metals, so this method has not been commercialized due to cost reasons. The SOEC method has the advantage of high efficiency, but it has not been commercialized because of the strict requirements for the selection of high temperature materials. To sum up, hydrogen production through water electrolysis is a relatively low-cost and widely used method among several hydrogen production methods at present, which is a suitable choice for hydrogen production.



AEL	PEM	SOEC
Anode: $4OH^-=O_2+2H_2O+4e^-$	Anode: $2H_2O=O_2+4H^++4e^-$	Anode: $2O^{2-}=O_2+4e^-$
Cathode: $2H_2O+2e^-=2HO^-+H_2$	Cathode: $2H^++2e^-=H_2$	Cathode: $H_2O+2e^-=H_2+O^{2-}$

Figure 1: Basic Reaction Equations of Three Methods of Hydrogen Production from Electrolytic Water [1,2]

Hydrogen production through water electrolysis also has different use of membrane, mainly including asbestos membrane, PPS and inorganic membrane. The basic principle of hydrogen production through

ISSN 2616-5880 Vol. 4, Issue 2: 52-58, DOI: 10.25236/AJMC.2023.040209

water electrolysis is shown in the figure 1. The center of alkaline solution is separated by proton exchange membrane, and the electronic anode flows to the cathode. The cathode on the left side generates hydrogen and hydroxyl radicals, which move from left to right through the proton exchange membrane and react at the anode to generate oxygen. In different application fields, hydrogen production devices based on this principle are different.[2]

The manufacturing process of hydrogen production through water electrolysis does not use precious metal resources, has low cost, and also has the advantage of long working life, which makes alkaline water hydrogen production become the most important technical route in the hydrogen production market.[3,6]

3. Prospect of hydrogen production through water electrolysis

Hydrogen energy plays an irreplaceable role in various domestic industries and plays a pivotal role. According to the statistics of China Hydrogen Energy Industry Alliance and Petroleum and Chemical Planning Institute, in 2019, China's hydrogen production capacity will be about 41 million tons/year, and the output will be about 33.42 million tons. According to energy management, the share of converted calorific value in total terminal energy is only 2.7%. By 2050, hydrogen energy can be widely used in transportation, energy storage, industry, construction and other fields, and the annual demand for hydrogen will increase to 60 million tons, accounting for 10% of China's terminal energy system; To achieve the goal of carbon neutrality by 2060, the annual demand for hydrogen will increase to about 130 million tons, accounting for 20% of China's terminal energy system. By 2050, the annual demand for hydrogen energy will reach 60 million tons, and 700 million tons of carbon dioxide can be reduced. Under the national "double carbon target" of "carbon peaking" and "carbon neutralization", the demand for hydrogen energy is growing day by day. In this paper, the utilization of electrolyzed water for hydrogen production in China is prospected from four aspects: hydrogen production from electrolyzed water and new energy, transportation, construction and other utilization.

3.1 Combination of hydrogen production from electrolytic water and new energy

The hydrogen production through water electrolysis is combined with new energy sources such as wind energy and solar energy to achieve a truly environment-friendly and green hydrogen production technology. Compared with the traditional hydrogen production technology and process by electrolysis of water, the combination with new energy avoids large-scale carbon emissions and saves the use of fossil energy.

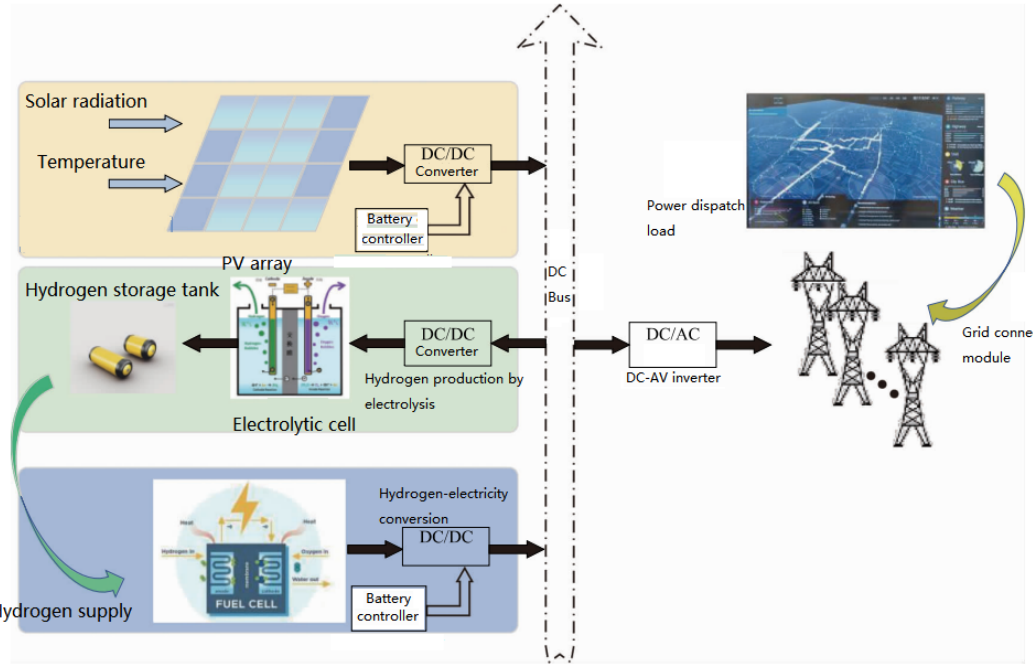


Figure 2: Structure diagram of photovoltaic hydrogen generation system [1]

ISSN 2616-5880 Vol. 4, Issue 2: 52-58, DOI: 10.25236/AJMC.2023.040209

The combination principle of solar energy and hydrogen production technology by electrolysis of water is to use the electric energy converted by solar panels for hydrogen production by electrolysis of water, which is also the hydrogen production technology by photovoltaic (PV) power generation. In the whole process, devices and components such as solar photovoltaic power generation controller are added on the basis of hydrogen production by electrolyzing water in the electrolytic cell. The principle of PV power generation is mainly based on the semiconductor photoelectric effect, which requires the conversion of photons into electrons, and the conversion of optical energy into electrical energy. Under the background of strong support of relevant policies in China and rapid development of renewable energy technology, China's photovoltaic power generation technology has significantly improved, greatly reducing power generation costs, and both technology and scale have reached the world's leading level. The figure 2 is the main flow chart of photovoltaic power generation.

The combination principle of wind and hydrogen production through water electrolysis is to convert wind energy into electric energy, that is, wind power hydrogen production technology. The main principle is that the wind drives the wind wheel to rotate, and converts the wind energy into the mechanical energy for the wheel to rotate. The mechanical energy rotating through the wind wheel is converted into electrical energy, realizing the conversion from wind energy to electrical energy. The electric is input into the electrolytic water device to realize hydrogen production. The wind power generator is mainly divided into three parts, namely turbine, turbine engine room and lower wind turbine. At present, grid connected wind power hydrogen generation system is widely used in China, while off grid wind power hydrogen generation system is still in its infancy. The whole process of hydrogen production from wind power is almost zero emission and zero pollution, with extremely high economic benefits. With abundant wind resources, distant ocean has the ability to develop super large wind farms.

The combination of hydrogen production through water electrolysis with wind and solar energy is not single, but mixed. Wind solar complementation also has two main advantages, that is, it can obtain more stable output and greatly reduce the capacity of energy storage batteries under the same power supply conditions. Some of the hydrogen energy produced by wind power has been used and developed locally, while others have been transported to other lands or stored locally, greatly increasing the utilization value and reserves of hydrogen energy. It is of great significance for China's energy cleaning and related energy research. On the road of China's "double carbon target", hydrogen production from wind power and photovoltaic power generation will continue to play a crucial role.

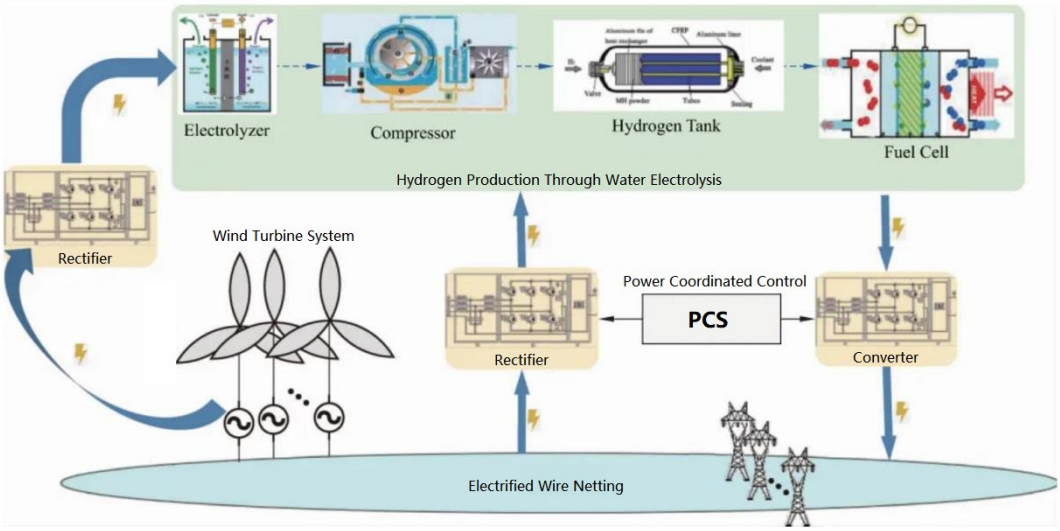


Figure 3: Structure diagram of wind power grid connected hydrogen production system [1]

As shown in the figure 3, this figure is the main flow chart of hydrogen production from wind power. According to relevant data and information in China, in recent years, with the support of national policies, a large number of wind power hydrogen production projects at home and abroad have been implemented, providing engineering support for wind power hydrogen production technology. The representative one is the 2014 863 project "Research and Demonstration of Direct Hydrogen Production from Wind Power and Fuel Cell Power Generation System Technology", in which the hydrogen production power is 100kW and the fuel cell power generation is 30kW. There is also the new energy Sino-German cooperation project "Guyuan Wind Power Hydrogen Production Project" invested by Hebei Construction and

ISSN 2616-5880 Vol. 4, Issue 2: 52-58, DOI: 10.25236/AJMC.2023.040209

Investment in 2015. According to relevant data, the project has an annual hydrogen production capacity of 17.52 million cubic meters with a 10MW electrolytic water hydrogen production system and a 200MW wind power plant hydrogen production. It can replace the use of a large number of fossil energy, which is conducive to the improvement of the environment and the realization of the "double carbon target" of new energy.[3,7]

3.2 Combination of hydrogen production through water electrolysis and transportation

According to the prediction of China Hydrogen Energy Alliance, the hydrogen demand in 2060 will reach 130 million tons, of which 40.51 million tons will be used in transportation (about 31% of the total hydrogen demand).[1]It can be seen that the demand for hydrogen in the transportation field is very large. In the field of transportation, one of the most widely used areas of hydrogen production technology is hydrogen fuel cell vehicles, as shown in Figure 4.

Hydrogen fuel cell is the main power source of fuel cell vehicles, and its role is to convert hydrogen chemical energy into electrical energy. Compared with ordinary fuel cells, hydrogen fuel cells are less affected by the environment, more environmentally friendly and maintenance free. Among them, proton exchange membrane fuel cells are based on the basic principle of hydrogen production by electrolysis of water. However, for a long time, China's hydrogen fuel cell vehicles have been plagued by technical and cost problems, and are in the stage of small-scale launch. Due to the high cost, even if a major breakthrough has been made in technology, but also because of the long industrial chain and other issues, there has been no large-scale application conditions. Nevertheless, hydrogen fuel cell vehicles still have great development potential, and have shown great value as a driving force of green energy. A typical case is the widespread application of hydrogen fuel cell vehicles in the Beijing Winter Olympics.[6]

At the 2008 Beijing Olympic Games, hydrogen fuel cell vehicles have already appeared and been piloted. "Green" is the distinctive background of the 2022 Beijing Winter Olympics. With the support of more than 30 hydrogen refueling stations, thousands of hydrogen fuel cell vehicles have been widely operated in all major competition areas, undertaking more than 80% of the transport capacity of the Winter Olympics. As the "ultimate environment-friendly vehicle", hydrogen fuel cell vehicle, with its low carbon, environment-friendly, cold resistant and durable characteristics, has perfectly overcome the difficulties of steep slope terrain and low temperature environment in the mountainous area of the competition area. He is competent to transport materials, pick up and send off staff and volunteers, and ensure the smooth operation of the Winter Olympic Games. The picture 4 below shows the operation of hydrogen fuel cell vehicles in the 2022 Beijing Winter Olympics.[4,6,9]

Figure 4: Hydrogen fuel cell vehicles in the 2022 Beijing Winter Olympics[6]

As hydrogen fuel cell vehicles have not been popularized, there is not enough data statistics on various emission data and indicators of hydrogen energy in China. However, by comparing the data of fuel

ISSN 2616-5880 Vol. 4, Issue 2: 52-58, DOI: 10.25236/AJMC.2023.040209

vehicles, the application of hydrogen fuel cell vehicles in the future can be compared and prospected. Motor vehicles and fuel vehicles are a major source of air pollutant emissions. According to the statistics of relevant national data in China, the total emission of four pollutants from motor vehicles in China in 2020 will be 15.93 million tons. The emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter (PM) are 7.697 million tons, 1.902 million tons, 6.263 million tons and 68000 tons respectively. Among them, the nitrogen oxides (NOx) emitted by diesel vehicles account for more than 80% of the total vehicle emissions, and particulate matter (PM) accounts for more than 90%; The carbon monoxide (CO) emitted by gasoline vehicles accounts for more than 80% of the total vehicle emissions, and hydrocarbons (HC) account for more than 70%. It can be found from the above data that China's automobile pollutant emissions are huge. If new fuel cell vehicles with hydrogen energy gradually replace fuel vehicles, the emissions of various greenhouse gases and pollutants such as carbon monoxide (CO), nitrogen oxides (NOx) and particulate matter can be reduced by millions or even tens of millions every year, which plays an important role in national environmental governance and air pollution protection.[1,4]

3.3 Utilization and Existing Problems of Hydrogen Production from Electrolytic Water in Other Fields

The more stable power generation system formed by the combination of hydrogen production from electrolytic water and new energy is applied to the electric power industry. Photovoltaic power generation has the characteristics of green environmental protection and sustainable efficiency. The first ten thousand ton photovoltaic green hydrogen project in China will be constructed in Xinjiang in 2021, which is also the largest photovoltaic green hydrogen production project under construction in the world. Hydrogen production by electrolysis of water has become an important part of the project. The project is the first large-scale direct hydrogen production project using photovoltaic power generation in China. In the field of transportation, hydrogen fuel cell vehicles directly promote the progress of the automobile industry and promote the research on hydrogen energy vehicles. The application of hydrogen production from electrolyzed water in automobiles has also stimulated the research of hydrogen engine, driver and other drive systems in the field of power engineering. Due to the increasing use of hydrogen driven vehicles, the number of hydrogen refueling stations built by provinces across the country to provide hydrogen for vehicles is increasing, and the extensive construction of hydrogen refueling stations has also greatly promoted the commercialization of hydrogen driven vehicles. The basic power generation principle of hydrogen production from electrolytic water is not only applied to automobiles, but also applied to air conditioners, electrical appliances and other electronic equipment, promoting the use of green energy, improving people's livelihood and increasing people's well-being.[13]

China's renewable energy hydrogen production technology has been in the stage of rapid development, but there are still big bottlenecks in some major design structures and technological breakthroughs, and there is still a big gap compared with Japan and other western countries. There are still many problems in a series of technologies and design fields, such as fan structure design, photovoltaic panel conversion efficiency, technical breakthrough and safety improvement of electrolyzer against large-scale wind power disturbance in photovoltaic wind power hydrogen generation system. In some key technology, design and production fields, there are still problems to be solved. Therefore, solving these problems and narrowing the gap with developed countries is still the top priority of hydrogen energy development.[11]

4. Conclusions and suggestions

The utilization of electrolytic water for hydrogen production in various fields and the room for improvement of its own efficiency. With the gradual reduction of fossil energy, the demand for hydrogen energy is increasing, which will also promote more extensive and in-depth research and exploration of hydrogen in China. As one of the most basic principles and methods of hydrogen production, hydrogen production by electrolysis of water has been applied in various science and technology and related industrial fields. In the field of transportation, hydrogen fuel cell vehicles based on the principle of hydrogen production by electrolysis of water have met the conditions for commercial promotion. The successful use of hydrogen fuel cell vehicles in the Winter Olympics has also tested the performance of hydrogen fuel cell vehicles, proving the advantages of hydrogen fuel cell vehicles. It will take several years for hydrogen fuel cell vehicles to be used in a real scale. If the industrial chain is further improved, improved and piloted in more fields in a few years, the use of hydrogen fuel cell vehicles will enter a stage of exponential benign growth. In the field of electric power industry, hydrogen energy is one of the green energy alternatives to fossil energy. Green hydrogen power plants will continue to be built on a large scale to achieve universal application nationwide and boost the economy. The application of clean

ISSN 2616-5880 Vol. 4, Issue 2: 52-58, DOI: 10.25236/AJMC.2023.040209

energy cells provided by fuel cells in other fields, such as mining and construction, can provide feasible solutions to reduce pollution and facility costs.[10,12]

The research and application of hydrogen energy based on hydrogen production from electrolyzed water is in rapid development. The effective measures to promote the effective research and utilization of hydrogen energy are to increase the research efforts in various application fields, strengthen the supervision of various application fields, and promote the coordinated development of research and application in various fields.

References

[1] LI Jianlin, LI Guanghui, Etc. Review and Prospect of Hydrogen Production Technology from Renewable Energy under Targets of Carbon Peak and Carbon Neutrality. [J].2021, 6(05):1-9
[2] Liu Haili, Song Lijun, etc. Technology and Development of Hydrogen Fuel Cell for Vehicles [J].2019, 48(10):1005-1008
[3] You Shi, Huang Chunjun, etc. Concerting green electricity to green hydrogen: the status and prospects of water electrolyser development and applications in Denmark [J]. Distribution&Utilization, 2022, 39(1):2-7.
[4] Lu Qixiu, Zhong Rui. Serving the Winter Olympics to boost the confidence of the hydrogen fuel cell vehicle industry. China Energy News/2022. 2. 14 001
[5] Zhao Meimei, Wu Yongguo. The status quo of hydrogen preparation field and application prospect[J] 2021(12):53-57
[6] Liu Xiaomeng. How Hydrogen Fuel Cell Vehicles Guarantee Green Winter Olympics. Beijing Business Today 2022. 2. 17. 004
[7] Zhong Rui. Accelerated upgrading of China's electrolytic water hydrogen production equipment[N]. China Energy News, 2022-10-17(011)
[8] Qu Xiaoguang, Chen Bo, Yang Xinglin, Shen Shengji. Design of Integrated Power Supply System for Photovoltaics —hydrogen Fuel Cells[J]. 2022, 51(04):184-187.
[9] Rahman S , Masdar M S , Rosli M I , et al. Overview of Biohydrogen Production Technologies and Application in Fuel Cell. 2015.
[10] Purnami P, Hamidi N, Sasongko M N , et al. Enhancement of hydrogen production using dynamic magnetic field through water electrolysis[J]. International journal of energy research, 2022(6):46.
[11] Ji Xu, Zhou Buxiang, He Ge, Qiu Yiwei, Bi Kexin, Zhou Li, Dai Yiyang. Research Review of the Key Technology and Application of Large-scale Water Electrolysis Powered by Renewable Energy to Hydrogen and Ammonia Production [J]. 2022, 54(05):1-11.
[12] Yan Xiangzhou. Research Progress of Hydrogen Production Technology and Catalyst from Renewable Energy Electrolysis. [J]. 2022, (23):77-79.
[13] Gao Yang, Guo Kaikai, Li Qi, Zhang Kangxin, Tong Xiaofan, Ma Qinhui, Qian Bin, Ma Weichen. Research on the cost of hydrogen production from renewable energy in coastal areas of Zhejiang, [J]. 2022, 42(03):45-49.