Current Situation and Prospects of Hydrogen Energy Utilization under "Dual-Carbon" Situation

Haizhou Shi [1, †], Haoyu Wu [2, †], Hongpeng Zhang [3, †], Hongqiang Zuo [4, *, †]

[1] Electric Power Institute, North China University of Water Resources and Electric Power, Henan, China

[2.]Shanghai Shangde Experimential School, Shanghai, China

[3.]Mechanical and Electrical Engineering, China Jiliang University, Zhejiang, China

[4.]Department of Mechanical and Electrical Engineering, Wuhan City College, Hubei, China

* Corresponding Author Email: 18409480@masu.edu.cn

[†.]These authors contributed equally.

Abstract. Hydrogen energy development of high quality is critical for optimizing energy structure and guaranteeing national energy security. The hydrogen energy business has grown rapidly as a result of the continued support of government policy. The rate of industrial technology independence has been continuously improved, the construction of supporting system has been accelerated, the application fields have been expanded, and the industrial pattern has been optimized. With policy support, government promotion, large-scale action of enterprises and other measures adopted around the world, as well as cost reduction driven by continuous technological progress, hydrogen energy utilization will have broad development potential. Many governments and organizations are working hard to produce hydrogen energy in order to address current energy and environmental issues. As a result of the research into hydrogen production, this article analyzes the status of hydrogen energy use in hydrogen fuel cells, hydrogen energy vehicles, and hydrogen for aerospace, and anticipates the hydrogen energy industry's development prospects.

Keywords: hydrogen production, hydrogen fuel cells, hydrogen energy vehicles, hydrogen for aerospace, prospects

1. Introduction

The development of clean new energy and renewable energy has become the fundamental concern confronting mankind in the twenty-first century, due to the catastrophic condition of global warming and people's increasing energy demand. All countries have agreed to implement the transformation and upgrade of their energy policy by vigorously developing clean energy and renewable energy. 77 countries promised to attain zero carbon emissions by 2050 at the Conference of the Parties to the United Nations Framework Convention on Climate Change, which took place in Spain at the end of 2019. During the United Nations General Assembly's 75th session in September 2020, Chinese President Xi proposed that China aim to peak its carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. The goal of "carbon peak" and "carbon neutrality" will realize the transformation from fossil energy consuming high carbon fuel to clean energy renewable low carbon fuel, and its essence is the process of hydrogenation and decarbonization of fuel. Carbon-free green hydrogen energy may be the ultimate source of fresh energy in the future, according to the hydrogenation trend.

Hydrogen is one of the most cost-effective and efficient alternative energy sources for humanity to break free from dependence on the "three primary energy sources" (coal, oil and natural gas) since it is clean, safe, efficient, and renewable [1]. Hydrogen reserves are large. Hydrogen is the third largest element in the earth and mainly exists in the form of water. Its raw materials are very easy to obtain. Besides, hydrogen energy comes from water, and the product after use is still water. The production and use of hydrogen energy form a recyclable closed loop to achieve sustainable development. Moreover, hydrogen has a high specific energy. It has the highest calorific value

(142kJ/g), roughly 3 times that of petroleum and 4.5 times that of coal, among typical fuels. Compared with the current two highest capacity battery anode and anode materials, the specific energy is more than seven times that of lithium batteries [2]. Furthermore, hydrogen energy, as a clean energy carrier, has a high utilization rate, a high calorific value of combustion, a high energy density, a long existence, storage, and transportation, and so on. Hydrogen energy planning has risen to the top of national energy policies in China, the United States, Japan, Germany, and other countries, and the development and use of hydrogen energy has become an important aspect of each country's energy system.

Leading the way in the strategic layout of the hydrogen energy industry and technology are major developed economies that have successively produced national plans or top-level designs for hydrogen energy. And as the world's largest carbon emitter, accounting for nearly 30 per cent of global emissions, China faces a serious challenge in achieving carbon neutrality. It is critical to explain the important areas of China's hydrogen energy industry application in 2021, the first year of the “14th Five-Year Plan,” and to figure out how to further support the development of the hydrogen energy industry under the carbon neutrality target. As a result, this paper will introduce and analyze the principle of hydrogen production, storage, and transportation in the context of the dual carbon goal, with a focus on a review of the current situation and methods of hydrogen energy utilization in recent years, and on this foundation, we will look forward to hydrogen energy and make recommendations for its future development.

2. Production of hydrogen

2.1. Hydrocarbon steam reforming technology

This hydrogen production technology is currently the most widely used in the world which used by approximately 90% of industrial systems in various countries. This kind of hydrogen production technology are requires a variety of hydrocarbon-rich gases such as natural gas, liquors and so on. The raw materials need to undergo stepwise detoxification and purification, water vapor transformation, high-temperature transformation, decarbonation, and methanation to yield hydrogen. Figure 1 is Hydrocarbon steam hydrogen production process flow chart.

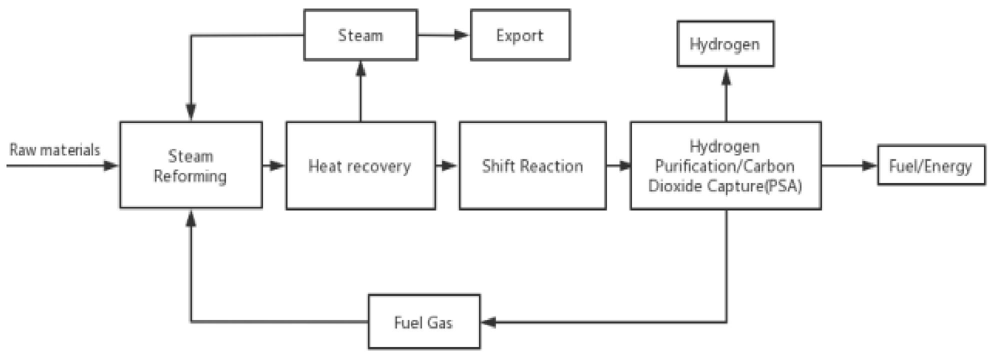

Figure 1. Hydrocarbon steam hydrogen production process flow chart.

The specific process flow is visualized by the figure above, which is the conversion of hydrocarbon compounds such as natural gas, liquefied gas into hydrogen rich synthetic gas. After cooling, it enters the reactor for CO-water-gas conversion reaction and then obtains crude hydrogen. Finally, high-quality pure hydrogen is obtained after purification by PSA separation purifier. The normal temperature of the transformation reaction of this technology is between 500℃ and 850℃. The advantages of this technique lie in the low consumption of raw materials and the high purity of hydrogen (about 95%). And the process plant often installed in refineries and petrochemical plants in industrial areas for the sake of convenience to getting plenty of raw materials.

2.2. Photocatalytic water splitting technology

Due to the huge consumption industrially for non renewable energy such as oil, coal and natural gas. Human society faces two problems, energy crisis and environmental pollution. And solar energy is an inexhaustible, renewable clean energy. So among the utilization technologies of solar energy, using solar energy to cause water splitting to produce hydrogen is a promising and emerging technology for hydrogen production. This technique primarily utilizes photocatalytic active materials to photolyze water by solar energy, i.e., photoirradiation on a semiconductor, The utilization of powerful radiant energy enables electrons within a semiconductor to activate electrons from the valence band (electrons that are in atomic orbitals and are in a bound state which are valence electrons. Many energy levels occupied by these valence electrons can be assigned and treated as a single continuous energy range) to transition to the conduction band (the energy space formed by free electrons, ie, the energy range possessed by freely moving electrons within a solid structure), and holes remain in the valence band.After that,the holes and electrons are allowed to separate, and then water is reduced to hydrogen or water is oxidized to oxygen at different locations of the semiconductor, respectively. But this hydrogen production technology has low utilization efficiency and poor stability, which until now has difficulty in meeting practical applications and needs further development research [3].

3. Storage and transportation of hydrogen

3.1 Gaseous hydrogen storage at high pressure

When hydrogen is in a gaseous state, it is known as "gaseous hydrogen," and its density is only 0.089 gL-1 at normal temperature and pressure. This characteristic determines that gaseous hydrogen has strong activity and diffusivity in natural state, and it is easy to cause leakage during storage and transportation. Despite the fact that gaseous hydrogen has a high energy density per unit mass, it has a very low energy density per unit volume. Therefore, in order to ensure that hydrogen can be stored and transported with sufficient energy and reduce the transportation cost, people usually take the method of increasing the pressure of storage and transportation containers or pipelines to increase the energy density of hydrogen per unit volume, improve the efficiency of hydrogen storage and transportation by reducing the amount of hydrogen storage containers. As a result, gaseous hydrogen is usually stored and transported by compressing the gas volume and increasing the unit gas pressure, and is stored in a specific container in the state of high pressure gas. The hydrogen storage container is usually a high pressure resistant steel gas cylinder. At the same time, gaseous hydrogen can also be transported through special transportation pipelines after being pressurized.

Gaseous hydrogen storage can be classified into two types based on the differing storage pressures of hydrogen: low-pressure storage (≤35 MPa) and high-pressure storage (≥35 MPa) [4]. The most frequent method of hydrogen energy storage and transfer is the storage and transportation of high-pressure gaseous hydrogen. A hydrogen compression device compresses the gas source before injecting it into a particular high-pressure gas storage tank or a steel pipe network for storage and delivery. When people need to use it, they can use the pressure reducing valve to adjust and directly complete the release of hydrogen.

The method of using gaseous hydrogen for pressurized storage and transportation has many obvious advantages. For example, the manufacturing difficulty of pressurized storage containers is relatively low; the hydrogen compression technology and equipment can learn from the existing air compressors and related technologies; the gaseous hydrogen transmission pipelines and supporting process equipment can also learn from the related technologies of the existing natural gas or gas transmission pipeline network and equipment; the processing cost of related equipment is low [5].

At the same time, there are numerous flaws in the pressurized storage and transportation of gaseous hydrogen. For instance, the process of hydrogen compression necessitates the consumption of a significant quantity of external energy; the container for hydrogen storage needs to use special steel cylinders or carbon brazing and other gas storage cylinders to control the material and its pressure. The strength and sealing requirements are high, so its weight and size are generally large. The weight of hydrogen stored in the high-pressure hydrogen storage cylinder only accounts for about 1% to 2% of the weight of the container, the hydrogen storage capacity is small, and the transportation cost is high; Hydrogen transportation pipelines need to be treated with special anti-corrosion, anti-hydrogen embrittlement and other processes; the safety of equipment and processes is critical in high-pressure gaseous hydrogen storage and transportation.

As a result, taking into account the physical and chemical properties of hydrogen, as well as the benefits and drawbacks of gaseous hydrogen storage and transportation, it is necessary to select hydrogen storage cylinders for transportation or lay hydrogen pipelines based on the various transportation distances of gaseous hydrogen, as well as user needs and distribution characteristics [6]. The transportation mode of hydrogen storage cylinders is suitable for occasions with short distance, small consumption and scattered users, while the hydrogen transport mode of gaseous hydrogen transportation pipeline is suitable for occasions with short distance, large consumption, stable and continuous use, and concentrated users. The total length of gaseous hydrogen pipes in use throughout the world has already surpassed 1,000 kilometers, and long trailers commonly used in China to transport hydrogen storage cylinders [7]. Figure 2 is the example diagram of gaseous hydrogen storage.

Figure 2. Example diagram of gaseous hydrogen storage.

3.2 Pipeline transportation

If hydrogen energy is to be developed on a large scale, from a long-term perspective, pipeline transportation is an inevitable trend of future development. Pipeline transportation has large transportation capacity, high efficiency, low cost, and is not affected by the climate along the way. The amount of pipeline transportation development is a critical aspect in the growth of hydrogen energy [8]. At present, pure hydrogen pipeline transportation has been applied in some developed areas, however, this type of pipeline system is costly and difficult to scale up to meet the needs of hydrogen energy's rapid development. On the other hand, using the natural gas transmission and distribution pipeline network and infrastructure that has been constructed to carry out the mixed transmission of natural gas and hydrogen, after the transformation, it can also transport pure hydrogen, which can realize low-cost, large-scale and continuous hydrogen energy supply. Therefore, using the existing mature natural gas pipeline network and supporting equipment to realize the natural gas hydrogen-blended transportation is the most ideal feasible solution in the future [9].

The findings show that lower levels of hydrogen can be blended into natural gas without major technical adjustments. Of course, the infrastructure needs to be assessed before use. For most components, 10% to 20% can be tolerated without major modifications. The incorporation of hydrogen into natural gas pipelines will cause certain hazards to the pipelines, including hydrogenium embrittlement, hydrogen blistering and hydrogen induced cracking. Among them, hydrogenium embrittlement is the most harmful, and it is formed at low temperature. Hydrogenium embrittlement of steel pipes is due to the erosion of the inner wall of the pipe by hydrogen, which reduces the plasticity and strength of the material, and thus leads to brittle fracture or delayed brittle failure. We should formulate corresponding protection methods according to different hydrogenium embrittlement mechanisms. The natural gas pipeline network includes long-distance pipelines and distribution pipelines, and its transmission pressure is relatively high, so people generally choose high-grade steel pipes.

The gas transmission pressure of China's natural gas trunk pipelines is 4 ~ 12 MPa, and the materials are metal materials, like X60 ~ X80 and R245 ~ R365. At a working pressure above 4 MPa, hydrogen may penetrate into the pipeline and cause hydrogenium embrittlement. However, due to the relatively low volume of hydrogen doping (≤ 10%), the partial pressure of hydrogen is also low (<1 MPa), the actual impact on the pipeline remains to be further verified. From the experience of European and American countries, at lower hydrogen mixing ratios and lower hydrogen partial pressures, pipeline embrittlement may be largely ignored, and the safety of using natural gas pipes to transport hydrogen-doped natural gas can be assured. The verification experiment of pipeline hydrogen embrittlement can be carried out to assure safety.

According to relevant studies, the key to developing natural gas hydrogen-mixed pipeline transportation technology in the future is to resolve hydrogen-mixing compatibility and adaptability of supporting equipment including pipes, pressure regulating stations, and flowmeter detectors. Besides, we also need to improve the safe operation guarantee technology of the pipeline network. In general, natural gas hydrogen-mixed pipeline transportation technology is one of the most effective means for large-scale and long-distance hydrogen transportation.

4. Current status of hydrogen energy utilization

4.1 Hydrogen fuel cell

A hydrogen fuel cell is a device that transforms hydrogen and oxygen chemical energy into electricity. The production of hydrogen fuel cells is an isothermal electrochemical process that does not require any heating. The Carnot cycle has no effect on the machine's operation. Without combustion, hydrogen fuel cells can turn the chemical energy in fuel into computers with a conversion efficiency of 60 percent to 80 percent. Furthermore, the device is tiny, reasonably flexible, and produces little noise or pollutants [10]. Previously, hydrogen fuel cells were expensive and only employed as a power source in the aerospace industry. The cost of hydrogen fuel cells has steadily declined as technology has progressed, and their use has become increasingly prevalent.

A fuel cell is a device that converts energy using electrochemical principles. To put it another way, the galvanic cell operates by directing the chemical energy contained in the fuel and oxidizer to be turned into electricity, resulting in the REDOX process. A cathode, an anode, an electrolyte solution, and an external circuit make up the fuel cell. Fuel gas and oxide gas are introduced into the fuel cell via the anode and cathode, respectively. Anions are formed when the anode fuel gas releases electrons, which are transmitted over the external circuit and result in an oxidation process between the cathode and oxygen, creating cations.When the cation reacts in the electric field, it passes through the electrolyte to the anode and reacts with the gas to form a loop, creating current [11].

Hydrogen fuel cells are based on the reverse reaction of electrolysis of water. The electrodes are as follows:

Negative reaction: H2+2OH- → 2H2O+2e-;

Positive reaction: 1/2O2+H2O+ 2E - → 2OH-;

Battery reaction: H2+1/2O2 → H2O.

The fuel cell system includes not only the fuel cell body, but also the auxiliary systems such as the drug supply system with anti-interference function, heat dissipation system, drainage system, electrical performance control system, and safety devices to enable the fuel cell to work properly.A common fuel cell consists of an electrolyte plate, fuel electrodes on both sides (anode) and air-composed electrodes (cathode), and airflow channels on both sides. The effect of gas inflow is to allow fuel combustion feedstock gas and air (oxidant gas) to pass through the flow channel.

The earliest fuel cell is phosphate type fuel cell, which has relatively mature process. The United States has built 4,500 kW commercial power plant, and Japan has built 11 000 kW commercial power plant. Phosphate fuel cells can achieve an operating temperature of 200℃, a power generation efficiency of 45%, and a maximum current density of 150 mA per square cm. Hydrogen and methanol are used as fuels, air is used as oxidant, and platinum series is used as catalyst. The power generation cost is relatively high, averaging 40 cents per KWH. The melt carbonate fuel cell belongs to the second generation of fuel cells, which can run at 650 degrees Celsius and generate power at 55 percent efficiency. Japanese companies have built power generation units up to 10 kilowatts. The fuel cell operates at high temperatures and uses a liquid electrolyte where carbon monoxide can be retained, as well as carbon monoxide, hydrogen and natural gas. Power generation costs less than 40 cents per kilowatt hour. Solid oxide fuel cell is considered as the third generation fuel cell. Its working temperature is about 1000 ℃ and its power generation efficiency can exceed 60%. At present, many countries are studying it; They are suitable for building large-scale power stations. Westinghouse is developing them, and the power generation cost is expected to be less than 20 cents per kilowatt hour. In addition, there are other types of fuel cells, such as alkaline fuel cells, which can work at temperatures up to 200 degrees Celsius with an efficiency of 60%. The catalyst does not use precious metals. The fuel cells developed by Sweden for submarines can reach 200 kW.The principle of hydrogen fuel cell is reciprocal with electrolysis hydrogen production, so hydrogen is the best fuel for fuel cell [12]. Fuel cells can be used to set up fixed power stations and provide energy for mobile vehicles and ships, which is the key development direction of hydrogen energy utilization in the future.

Hydrogen fuel cells typically operate without noise, at decibels similar to normal human communication. As the hydrogen fuel cell is noiseless, the hydrogen fuel cell system can be installed either indoors or outdoors without much impact on its surroundings [13]. In the process of the concepts and principles described above, it is known that under ideal conditions, hydrogen fuel cells produce only water, which is pollution-free to the environment. Hydrogen fuel cell is through electrochemical reaction, not a lot of harmful to the environment of the gas is released by burning if hydrogen is by renewable energy, such as wind, solar, etc.), so in the process of production of hydrogen fuel cells, there will be no harmful gas, the hydrogen fuel cell cycle of no pollution to the environment. Fuel cells have high efficiency, which can reach 50% power generation efficiency in the process of power generation, at a very high level in power generation facilities. Fuel cells are directly converted from chemical energy of substances into electrical energy without thermal energy to mechanical energy conversion in the production process [14].

4.2 Hydrogen-powered vehicles

Hydrogen-powered cars use hydrogen as engine fuel instead of conventional petrol, converting the chemical energy produced by the hydrogen reaction into mechanical energy to drive the car. It has been tested by the automotive industry in the USA, Japan and Germany. The energy produced by hydrogen combustion is 33.6 kW/hour per kg, which is approximately 2.8 times more efficient than the combustion of petrol. Hydrogen also has a very high calorific value, can be ignited with very low energy and the flame has a high speed of propagation, so hydrogen-powered cars have a high fuel efficiency, about 20% higher than petrol cars. Furthermore, hydrogen combustion contains almost no hydrocarbons and produces no polluting gases. The main product is water, so hydrogen vehicles are environmentally friendly and ideal for transportation [15].

There are two types of hydrogen powered vehicles. Hicev is driven by an internal combustion engine and burns hydrogen (usually by decomposing methane or electrolyzing water) and oxygen in the air. The fuel cell vehicle (FCEV) is to make hydrogen or hydrogen containing substances and oxygen in the air generate electric energy through the fuel cell, and then drive the electric energy to drive the motor, which drives the vehicle. Generators in such vehicles convert the chemical energy of hydrogen into mechanical energy. Hydrogen can be used in combustion internal combustion engines, or oxygen can react with hydrogen in fuel cells to run the engine [16]. The fuel cell has no moving parts or friction pairs like the internal combustion engine, the energy conversion is completed under static state, there is no noise or vibration, the working temperature is low (about 80 ℃), and the power response is fast. The fuel cell directly converts the chemical energy of fuel into electric energy, which is not limited by Carnot cycle, and the energy conversion efficiency is more than 60%. Compared with the lithium-ion battery carried by pure electric vehicles, hydrogen fuel cells are light in weight, take less time to supplement energy (hydrogenation takes only 3 to 5 minutes) and have a longer range (more than 600 kilometers). Fuel cells can be installed on different types of vehicles for different purposes. The power is determined by the number of cells deployed, and the range is determined by the size of the hydrogen fuel tank (hydrogen storage capacity).

Several companies are using private and government funds to develop hydrogen powered vehicles, but Ford has given up and concentrated its resources on all electric vehicles. Renault Nissan announced in 2009 that it would stop developing hydrogen powered vehicles; General Motors announced in October 2009 that it would cut hydrogen fueled vehicles because it believed that hydrogen fueled vehicles were far from practical. In 2009, Nissan launched a new FCV program in Japan. Since then, in October, Nissan, Ford Motor, general motors, Hyundai Group, Toyota, Daimler, Renault and Kia issued a joint statement, saying that they would develop fuel cell vehicles, which are expected to be completed in 2015. In 2011, Hyundai Group announced that it would launch blue fuel cell vehicle (FCEV) in 2014.

China Yangtze automobile group experimental production line in September 2016 rolled off the production line for the first time a atmospheric pressure hydrogen storage bus tiger song, the experimental car has almost reached commercial operation ability, the breakthrough of science and technology is to adopt a chemical absorbent to absorb the liquid hydrogen mixture, reoccupy catalyst reduction after release, solved the hydrogen danger or the high cost of storage transport problem, The dilemma of traditional hydrogen gas lies in that it must be stored in either low temperature or high pressure. Low temperature requires a lot of electric energy and is completely uneconomical. Although high pressure cylinders are cheap, they are also expensive products, and there are major safety risks when they are widely used in commercial and civilian use. The breakthrough technology lies in Professor Cheng hansong's world-leading and original "normal temperature and pressure hydrogen storage technology", which can make use of existing gas stations and oil transportation system and other infrastructure, greatly reducing the problem of hydrogen economy. Figure 3 is Schematic diagram of the main structure of a hydrogen-powered vehicle.

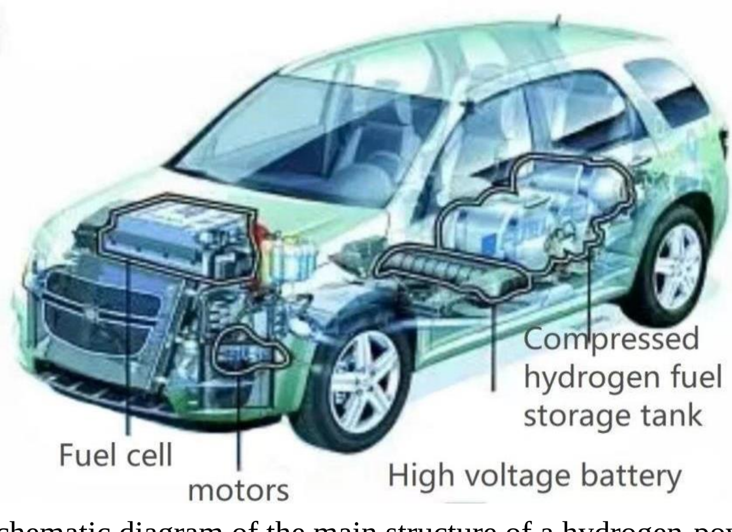

Figure 3. Schematic diagram of the main structure of a hydrogen-powered vehicle.

4.3 Hydrogen for aerospace

Hydrogen-oxygen engine is a kind of rocket engine which using liquid oxygen and hydrogen oxygen as propellants. Hydrogen-oxygen engines have many advantages such as batter power on pushing, green environmental protection, recycling and so on. Hydrogen oxygen is the best propellant at the moment which can significantly improved the transport capacity of the rocket in and out of space. Hydrogen-oxygen engine occupies an important position in the field of space delivery. Figure 4 is Physical map of various hydrogen-oxygen engines.

Figure 4. Physical map of various hydrogen-oxygen engines.

As one of the most critical subsystems of the launch vehicle, hydrogen-oxygen engines can increase the payload capacity of launch vehicles significantly, whether to master high-performance hydrogen and oxygen engine technology is one of the important indicators to measure a country's aerospace strength. The advantages of hydrogen-oxygen engines are at the following points. First of all, liquid hydrogen is the most energetic fuel in chemical propellants, the calorific value of liquid oxygen combustion is very high, when using liquid chlorine liquid hydrogen as a propellant for engines, specific impulse performance 40% to 50% higher than conventional engines; The combustion product of liquid hydrogen and liquid oxygen is water vapor without solid products' accumulation, clean and pollution-free as well, which is particularly suitable for reuse; Liquid hydrogen and liquid oxygen are easy to ignite with stable combustion and high efficiency, the critical pressure of liquid hydrogen is low, on the other hand, it has high specific heat capacity, suitable for regeneration as a thrust chamber coolant that lead a conducive to engine solution optimization and reliability design.

Hydrogen-oxygen power technology can effectively promote the development and upgrading of domestic materials, chemicals, manufacturing, machinery and other industries. China relies on professional technologies such as hydrogen-oxygen power combustion technology, high-speed rotating machinery technology, and high-pressure cryogenic valve technology to create considerable economic and social benefits, at the same time, it also provides a large number of high-quality products and engineering projects to the energy, chemical, environmental protection and other industries, these technologies are gradually expanding into the civilian field [17].

In the face of the demand for high-performance and highly reliable power units for carrier rocket in future, it is necessary to further accelerate the development speed of hydrogen-oxygen power technology to provide solid and reliable support for the development of major space activities in the future.

5. Conclusion and Prospects

As a new type of secondary energy, hydrogen energy has attracted more and more attention from major countries and enterprises around the world. Under the dual-carbon situation, the world's renewable energy industry and new energy vehicle industry will usher in a deterministic high-speed development in the next 30 years, and the hydrogen energy industry is currently on the eve of explosive growth. The commercialization of the hydrogen energy industry, according to the experience of various countries around the world, requires the resolution of a number of issues, including policy guarantees, technological breakthroughs, industrial foundations, basic facilities, cost control, and social cognition. As a result, this report makes the following recommendations for the future development of the hydrogen energy business.

(1) Strengthen top-level planning and design. China’s “14th Five-Year Plan” has clearly put forward the strategic position of hydrogen energy as the future industrial development. Facing the ever-expanding new applications of hydrogen energy, realistic medium and long-term development goals and supporting policies should be formulated on a rolling basis, and the use of hydrogen energy on a broad scale and the creation of production systems should be strongly encouraged.

(2) Establish sound laws and regulations, standards and improve the policy guarantee system. Take hydrogen energy as an important energy form to support the “dual carbon” goal as soon as possible, clarify government departments, continuously improve the standard system, formulate long-term support measures, coordinate resources from all walks of life such as government, enterprises and capital, and actively guide and encourage investment in industrialization and commercialization , to encourage the quick growth of the hydrogen energy industry.

(3) Guided by market application, strengthen technology development and exploration, demonstration and promotion. Although hydrogen fuel cell vehicles are the focus of current hydrogen energy development and application, we should also focus on the use of hydrogen energy storage in renewable energy and solving the problem of new energy grid connection, as well as the enormous hydrogen metallurgy and other fields. potential, based on the current state of development. At the same time, enterprises should be encouraged to increase hydrogen energy technology research, especially the research and development of core key materials and industrialized equipment, so as to realize the autonomy of core technology.

(4) Strengthen core technology research and improve infrastructure construction. Promote the combination of production, education and research, increase benign international cooperation, strengthen personnel training, and be problem-oriented, strengthen core technology research, in order to realize the localization of related technologies. The popularity of infrastructure and the promotion of hydrogen terminals are interdependent, but the imperfection of infrastructure and the development of hydrogen terminals hinder each other. Infrastructure such as hydrogen pipeline networks and hydrogen refueling stations must be developed ahead of time in locations where hydrogen could be used. Improving the hydrogen energy infrastructure is critical for lowering the cost of hydrogen usage and encouraging hydrogen energy application.

References

[1] L. Li, S. Fan, Q. Chen, Research status and prospect of hydrogen storage technology, Energy Storage Science and Technology. 7(2018) 586-594.

[2] L. Wang, Z. Shi, Y. Wang, Development status and prospect of hydrogen energy industry, Industrial Furnace. 44 (2022) 24-28.

[3] D. Liu, X. Su, H. Zhao, Research progress on photocatalytic water splitting catalysts for hydrogen production, Materials Review. 33 (2019) 13-19.

[4] J. Min, Technological and economic analysis of the application of coal to hydrogen in refineries, Contemporary Petroleum and Petrochemical. 18 (2010) 27-29.

[5] F. Liu, S. Zhou, The development status and trend of my country's hydrogen energy industry, Science and Technology Innovation and Application. 25 (2019) 37-38.

[6] National Research Council, The Hydrogen Economy, first ed., The National Academies Press, Washington, DC, 2004.

[7] Y. Cai, J. Xu, Hydrogen storage technology and materials, first ed., Chemical Industry Press, Beijing, 2018.

[8] C. Feng, Y. Zhou, H. Liu, Current Situation and Analysis of Hydrogen Storage and Transportation Technology, Science and Technology Information. 19 (2021) 44-46.

[9] Z. Yin, G. Yang, H. Liu, Research status and prospect analysis of key technologies for hydrogen energy storage and transportation, Modern Chemical Industry. 41 (2021) 53-57.

[10] H. Liu, L. Song, X. Liang, Current status and development direction of hydrogen fuel cell technology for vehicles, Liaoning Chemical Industry. 48 (2019) 1005-1008.

[11] P. Gao, Research on the application progress of hydrogen fuel cells, Petrochemical Technology. 6(2020) 115-116.

[12] B. Shan, Design, preparation and characterization of titanium dioxide-coated carbon nanotube/chitosan proton exchange membrane, Tianjin University of Technology, 2018.

[13] C. Dai, Y. Lei, Research status and prospect of hydrogen fuel cell vehicle technology, economy and environment, China Energy. 56 (2020) 25-31.

[14] F. Liu, H. Zhu, New progress in fuel cell technology, Progress in Materials in China. 6 (2020) 449.

[15] T. Lei, Utilization methods and development prospects of hydrogen energy, Liaoning Chemical Industry. 50(2021) 1078-1081.

[16] P. Yu, J. Wang, J. Zheng, A Review of Hydrogen Energy Utilization and Development, Automotive Practical Technology. 24 (2019) 22-25.

[17] W. Yue, D. Zheng, Y. Yan, An overview of the development of high-performance liquid oxygen and liquid hydrogen engine technology in China, China Aerospace. 10 (2021) 20-25.