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The future of hydrogen fuel: opportunities and challenges in production, storage, and applications

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Abstract. As the world transitions towards sustainable energy solutions, hydrogen fuel has become a promising alternative to fossil fuels due to its high energy density and zero carbon emissions. However, its widespread adoption faces technological and economic challenges in production, storage, and application fields. This article provides a comprehensive review of hydrogen fuel technology, examining current production methods, storage technologies, and potential applications, while identifying key challenges and opportunities in its large-scale implementation. Research has found that although steam methane reforming remains the main method of hydrogen production, producing green hydrogen through electrolysis provides a sustainable alternative, albeit at a higher cost. With the continuous research on advanced materials such as metal organic frameworks, hydrogen storage faces challenges in terms of energy density and safety. In terms of applications, hydrogen has shown great potential in transportation, power generation, and industry, but infrastructure limitations and economic feasibility remain major obstacles. Policy interventions, including subsidies and carbon pricing, are crucial for accelerating the adoption of hydrogen. To unleash the full potential of hydrogen, further progress is needed in production efficiency, storage technology, and infrastructure development. Government policies and international cooperation will play a crucial role in promoting the hydrogen economy. With the continuous technological innovation, hydrogen fuel is expected to become the cornerstone of the global clean energy transition.

Keywords: hydrogen fuel, green hydrogen, green energy, hydrogen safety

1. Introduction

Nowadays, as the require of using the energy is increase, the using of traditional fuel is caused a serious energy danger. Crude oil, carbon, and other resources is limit so it's indeed to find another energy which can substitute it. Otherwise, as the burning of traditional fuel is the main reason which course the air pollution and global warming. This affects a lot for the local environment and the health of human being. So it's important to find a new route, to find out a new energy, which are clean and the sustainable.

As it known to all, hydrogen fuel as a clean energy it can substitute the traditional fuel. Because it's only produced what a steam when it was burning, it will not release carbon dioxide or other harmful substance to sharply decrease the pollution to the environment. And we can get the hydrogen from a lot of ways we can use such as the electrolyze of water and the transformation of biomass to get the hydrogen. Otherwise, the energy density of hydrogen fuel is very high, so it's more convenient to storage and transfer hydrogen fuel than others. These species make the hydrogen feel becomes the identical chose for the energy danger and the pollution of the environment.

Hydrogen can be produced through various methods, including steam methane reforming, which is currently the most common, but also the most carbon-intensive. Another method is electrolysis, where electricity splits water into hydrogen and oxygen. This process can be powered by renewable energy sources like wind and solar, making it a cleaner alternative. However, the efficiency of electrolyzers and the cost of renewable energy are still barriers to widespread adoption

For instance, advancements in electrolyzer technology could significantly reduce the energy required for hydrogen production, making it more cost-effective. Catalysts are also a critical component in the hydrogen production process, and finding cheaper, more abundant materials to replace expensive precious metals like platinum could be a game-changer. When it comes to the use of hydrogen fuel, one of the most promising applications is in the transportation sector. Hydrogen fuel cell vehicles emit only water vapor, making them a clean alternative to internal combustion engine vehicles. However, the current

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cost of Fuel Cell Vehicles (FCVs) is high, and there's a lack of refueling infrastructure. Automakers and energy companies are working together to build hydrogen refueling stations, but this requires significant investment and coordination.

The policies and markets are driving the development of the hydrogen economy in the following ways. Governments around the world are recognizing the importance of hydrogen in the transition to a low-carbon future. Subsidies, tax incentives, and investments in hydrogen infrastructure are becoming more common. For example, the European Union has set ambitious targets for renewable hydrogen production and is funding research and development projects to bring down costs. Markets are also playing a important role. As the world seeks to reduce greenhouse gas emissions, there is a growing demand for clean energy solutions. Hydrogen is seen as a versatile energy carrier that can be used in various sectors, from transportation to industry and even in power generation. Companies are investing in hydrogen technology, with some car manufacturers committing to bringing hydrogen-powered vehicles to the market within the next few years.

The goal of this article is to discuss the production, storage and application status of hydrogen fuels. And then this paper will analyse technical bottlenecks and economic limitations. Finally, it will propose a possible path to solve this challenge. The meaning of the research is, it's not only help to make the energy danger lower and decrease for the pollution of the environment, but also promote sustainable economic develop. Through Mac can use hydrogen fuel technique. It can create new Chance for people to get a job, promote the development of industry which related to it. so as bring more economic benefit to the society.

At last, the arrangement of the chapter of this paper is like: it will first introduce the background knowledge and the importance of research of hydrogen fuel the second step is detailedly talking about the effect of hydrogen fuel in solve energy danger, and the problem of environment pollution and analyze the challenge of that technique of hydrogen bonding faced, and the problem of the research in this period of time. Then this article will give a possible route to solve this question and the way to following research. Through the case, analyze to show the future of hydrogen technique. The final step is toconclude the result of the research and gave the suggestion of the way to research in the future.

2. Research review

2.1. Characteristics of hydrogen fuel

This research aims to fully understand the potential of hydrogen fuel through a detailed analysis. Under standard conditions, the density of hydrogen is about 0.0899g/L, which is only about 1/14 of the air density, which requires special equipment and technology for hydrogen storage and transportation to improve its density and increase the energy content per unit volume. As the boiling point of hydrogen is -252.87℃. The extremely low boiling point means that hydrogen exists in gaseous form at normal temperature and pressure. To liquify it, it requires extremely low temperature and high pressure. Liquid hydrogen is often used in aerospace and other fields with high requirements for fuel energy density. Hydrogen as an element which get a high energy density and the energy released by the complete combustion of hydrogen per unit mass is about 2.8 times that of gasoline and 4 times that of coal. This means that the same mass of fuel and hydrogen can provide more energy, which has a great advantage in the application scenarios that pursue efficient energy, such as the aerospace field. and hydrogen has a feel also environmentally friendly. Because the only product of hydrogen combustion is water, which does not produce carbon dioxide, nitrogen oxides, sulphides and other pollutants. It is very environmentally friendly and is an ideal clean energy source that helps to reduce greenhouse gas emissions and environmental pollution, and is of great significance to dealing with global climate change. Hydrogen mainly exists on the earth in the form of water and other compounds, and it is rich in resources. If renewable energy is used to electrolyse water to produce hydrogen, it is sustainable and is an ideal carrier for renewable energy. But the fossil fuels is formed from ancient biological fossils, with limited reserves, non-renewable energy, and will gradually deplete with mining and use. As we know hydrogen fuel has a high energy density so it can reach 40%-60% or higher in fuel cells [1, 2]. But the fossil fuel is half of the efficiency.

2.2. The development history of hydrogen fuel

Hydrogen, as the fuel of the internal combustion engine, is the latest invention of mankind. The use of hydrogen in internal combustion engines has a long history. The history of the first hydrogen internal combustion engine in human history can be traced back to 1807, when the Swiss Isaac Dai Livatz made a single-cylinder hydrogen internal combustion engine. He filled the cylinder with hydrogen, and the hydrogen burned in the cylinder and finally pushed the piston back and forth. The invention was patented in France on January 30, 1807, which was the first patent for automobile products. However, due to the limitation of the technical level at that time, the manufacture and use of hydrogen is much more complicated than the use of resources such as steam and gasoline, and the hydrogen internal combustion engine was "submerged" by steam engines, diesel engines and gasoline engines.

In 1960, liquid hydrogen was first used as an aerospace power fuel. In 1970, the take-off rocket used by the Apollo lunar spacecraft launched by the United States was also fuelled by liquid hydrogen. Hydrogen has become a common fuel in the field

of rockets.

For modern space shuttles, reducing fuel weight and increasing payloads have become more important. The energy density of hydrogen is very high, three times that of ordinary gasoline, which means that the space shuttle uses hydrogen as fuel, and its weight can be reduced by 2/3, which is undoubtedly extremely beneficial to the space shuttle. In addition, hydrogen can also be used for spacecraft. Scientists are working on a "solid hydrogen" spacecraft. Solid hydrogen is not only the structural material of the spacecraft, but also the power fuel of the spacecraft. During the flight, all non-important parts of the spacecraft can be converted into energy and "consumed", so that the spacecraft can fly longer in the universe.

In the late 1980s, a variety of fuel cell vehicles were publicly demonstrated. The feasibility of replacing storage batteries with small fuel cells in the late 1990s was confirmed. Entering the 21st century, in the face of crises such as environmental pollution, hydrogen fuel cells are developing rapidly, and more moulded hydrogen fuel cell vehicles are beginning to enter the market.

Hydrogen energy is an ideal clean energy source, and its application in the field of fuel cells is the key to developing the clean utilisation of hydrogen energy. Fuel cell is a device that directly converts the chemical energy of hydrogen into electrical energy. It has the characteristics of high conversion efficiency and zero emissions. It is the best hydrogen energy utilisation technology. In recent years, the continuous improvement of fuel cell technology has driven the rapid development of emerging industries with fuel cells as the core. Among them, the applications of hydrogen fuel cell vehicles, distributed power generation, hydrogen fuel cell forklifts and emergency power supplies have approached industrialization [3]. The development and utilisation of wind and solar energy is affected by intermittent and unpredictable, resulting in a large amount of waste of energy and seriously restricting their development. Hydrogen energy is a good energy carrier. Converting wind power and photovoltaic electricity into hydrogen through electrolysis can improve the usage and utilisation efficiency of wind and solar energy. The hydrogen obtained can be directly utilised and can be mixed into the existing natural gas pipeline network to realise large-scale transportation and utilization [3]. There are many forms of utilisation of hydrogen energy. It cannot only generate thermal energy through combustion, generate mechanical work in thermal engines, but also be used as energy materials for fuel cells, or converted into solid hydrogen for structural materials. Using hydrogen to replace coal and oil does not require major modifications to the existing technical equipment. The current internal combustion engine can be used with a slight modification. Of all gases, hydrogen has the best thermal conductivity, which is 10 times higher than that of most gases. Hydrogen is an excellent heat transfer carrier in the energy industry. Therefore, the research on the utilisation of hydrogen energy has become a hot topic for scholars at home and abroad [4].

3. Discussion

3.1. Production

The main technical processes for hydrogen preparation are thermochemical hydrogen production and water electrolysis hydrogen production. Among them, thermochemical hydrogen production technology mainly includes fossil energy hydrogen production and chemical raw material hydrogen production. Fossil energy hydrogen production includes water and gas hydrogen production, natural gas reformulation hydrogen production.

Steam Methane Reforming is currently the most widely used hydrogen production technology in the world, accounting for about 80-85% of the global hydrogen supply [5]. This technology uses high-temperature water vapour to react with methane to produce hydrogen and carbon monoxide:

$$CH_4 + H_2O \rightarrow CO + 3H_2 \tag{1}$$

Carbon monoxide is then further converted into hydrogen and carbon dioxide through the water-gas transformation reaction:

$$CO + H_2O \rightarrow CO_2 + H_2 \tag{2}$$

Steam Methane Reforming is a mature and efficient hydrogen production technology that can produce a large amount of hydrogen at a high yield to meet a wide range of industrial needs, especially in the fields of petroleum refining and chemical synthesis. Due to the low cost of natural gas as a raw material and the optimisation of the process over the years, Steam Methane Reforming is highly economical and has become one of the most cost-effective hydrogen production methods at present. With mature technology, reliable equipment and rich operating experience, it can carry out stable large-scale production. The existing natural gas infrastructure also facilitates this technology, reducing additional transportation and storage costs. However, Steam Methane Reforming (SMR) also has some disadvantages. First of all, the SMR process will release a large amount of carbon dioxide. In the context of the current global response to climate change, this high-carbon emission is contrary to the goal of sustainable development and exacerbates the greenhouse effect. Secondly, SMR is an energy-intensive process that requires a large amount of energy consumption, which not only leads to excessive resource consumption, but also may have a negative

impact on environmental sustainability. During the reorganisation process, if there are no proper exhaust gas treatment facilities, it may also pollute the surrounding environment and further aggravate the environmental burden. Finally, current technology makes SMR more dependent on traditional fossil fuels and lacks effective utilisation and investment in renewable resources, limiting its potential in future energy transformation.

Hydrogen production technology of electrolysed water. Electrolysed water to produce hydrogen is a process of using electricity to decompose water into hydrogen and oxygen. This technology is considered one of the most promising green ways to produce hydrogen because of its low dependence on fossil fuels and clean emissions. At present, electrolysed water technology mainly includes four types of electrolys: alkaline water electrolysed cell, proton exchange membrane electrolys, solid oxide electrolys and anion exchange membrane electrolys.

Alkaline Water Electrolyzer (AWE). Alkaline water electrolysis tank is the most traditional and mature electrolytic water technology, using liquid alkali solution (usually potassium hydroxide or sodium hydroxide) as the electrolyte. Its main advantages are mature technology, relatively low cost, and the catalyst used does not require rare or expensive materials. However, the main disadvantages of AWE are its low current density and energy efficiency, as well as low operating pressure, which limits its hydrogen production rate. At the same time, because the load range of the alkaline electrolytic cell is 20%~100% of the rated power, for the off-network renewable energy electrolysed water hydrogen production system, the fluctuation of the landscape power output may cause AWE to start and stop frequently, while the cold start time of AWE is relatively long, resulting in a huge waste of energy [6].

Proton Exchange Membrane Water Electrolyser (PEMWE). The proton exchange membrane electrolyser uses solid polymer electrolyte and works at a high current density, which can provide high energy efficiency and hydrogen production rate. The main advantage of PEMWE is its ability to start and stop quickly, which is suitable for integrated use with intermittent renewable energy such as wind and solar energy. The disadvantages include the high demand for catalysts (especially platinum metals) and the relatively high cost of the system [7].

Solid Oxide Electrolysis Cell (SOEC). The solid oxide electrolysis tank is a high-temperature electrolysis technology that can operate at temperatures from 800℃ to 1000℃. The high-temperature operation of SOEC allows it to directly use thermal energy, improving the overall energy efficiency. At the same time, it can be integrated with the co-heat and power system or the industrial waste heat recovery system. Although SOEC provides high energy efficiency, its technical complexity, durability and long-term stability are still the main challenges [8].

Anion Exchange Membrane Water Electrolyzer (AEMWE). The anion exchange membrane electrolytic tank is an emerging technology characterised by the movement of hydroxide (OH-) on the anion exchange membrane. At present, AEMWE's industrial application is low, there are few commercial products, and the technology is still in the research and development stage. These electrolysed water hydrogen production technologies have their own advantages and limitations. The selection of appropriate technologies needs to be comprehensively considered according to specific application scenarios and needs [8].

These technologies have been industrialised at present. The technology is relatively mature, but the output of energy is greater than the input. If this method of hydrogen power generation is used, the energy conversion efficiency is low and the economy is poor. Therefore, traditional energy hydrogen production is not an ideal hydrogen production technology. The production of hydrogen from chemical raw materials mainly includes alcohol cracking hydrogen production and alcohol reforming hydrogen production, such as methanol water vapour reforming hydrogen production [9]. Water electrolysis hydrogen production method is the use of photovoltaics, wind power and other new energy power sources to electrolyse water to produce hydrogen. This hydrogen production method has almost zero carbon emissions. It can make full use of the "three wastes" (discarding wind, abandoning light, abandoning water) energy to hydrolyse hydrogen production, and can also greatly reduce the cost of hydrogen production. It is an important technical link to realise "green hydrogen" production, and it is also a key area of investment in the field of hydrogen energy. The hydrogen production raw materials and hydrogen production processes used in different hydrogen production technologies are very different [10].

3.2. Storage

The storage of hydrogen is also a difficult problem face to people. The way, totally being used is storage the hydrogen in physical way. It can usually be divided into three categories: compressed hydrogen storage (at room temperature, 35~70 MPa); liquified hydrogen storage (-253 ℃, 0.1~1 MPa); material adsorption hydrogen storage (193 ℃, 0.2~0.5 MPa). Physical hydrogen storage does not involve the chemical bond interaction between H_2 and the medium. At present, high-pressure gaseous hydrogen storage and liquified hydrogen storage are the most mature technologies, and the hydrogen energy systems on fuel cell vehicles mostly use these two. Several physical hydrogen storage techniques [11]. Since the density of hydrogen under natural conditions does not meet the conditions of the energy carrier, the pressure must be increased before it can be applied in practice. To achieve the goal of fuel cell vehicles travelling 500 km, on-board hydrogen storage requires about 5 to 6 kg of hydrogen. Due to space limitations, steel cylinders (pressure of 35~70 MPa) are usually used as containers. Almost all hydrogen fuel cell vehicles adopt a high-pressure hydrogen storage system. Increasing the internal pressure can improve the hydrogen storage density, but when the pressure is stronger than 70 MPa, the hydrogen storage amount and the pressure are no longer linear. Continuing to increase the

pressure, more compression work and thickening of the cylinder wall lead to a decrease in hydrogen storage efficiency, and there are problems such as leakage and explosion. According to the study, the cost efficiency is when the pressure is 55~60 MPa. In addition, hydrogen can be stored in a lightweight high-pressure container wrapped with a fully composite fibre structure to give full play to its quality advantages. Finally, the addition of auxiliary hydrogen storage substances can further improve the material of the hydrogen storage container. The technology of composite lightweight hydrogen storage tanks is expected to become the most common storage in the future with its characteristics of low energy consumption, fast speed and simplicity [11].

At present, China's hydrogen energy preparation and storage technology is not mature compared with most developed countries, and most of the hydrogen storage materials are still in the laboratory stage. However, through the above analysis, it can be seen that the future research direction should focus on biological hydrogen production, and strive to achieve a major breakthrough in biomass hydrogen production technology, while the development of hydrogen energy storage technology focusses on the synthesis of new energy storage materials. In order to realise the comprehensive utilisation and development of hydrogen energy in China, it is necessary to increase investment in hydrogen energy development, accelerate the research progress of major research aspects such as biomass hydrogen production and solar hydrogen production; formulate policies conducive to the development of hydrogen economy, and give preferential treatment to enterprises and research institutions to encourage their development. It is also necessary to formulate industry market standards to put enterprises in an advantageous position when competing with foreign enterprises; formulate development plans and implementation directions to ensure the smooth development of the industry. Finally, we should widely publicise the importance of hydrogen energy and strengthen people's awareness of new energy in order to gain more support and help [12].

3.3. Application

According to the different ways of using hydrogen, hydrogen-powered vehicles can be divided into two categories, namely hydrogen fuel cell vehicles and hydrogen internal combustion engine vehicles.

Hydrogen fuel cell cars convert the chemical energy generated by the reaction of hydrogen and oxygen under the action of catalysts into electrical energy through hydrogen fuel cells, and then drive the vehicle through the motor. The most critical core component is hydrogen fuel cell. Hydrogen fuel cells are mainly composed of two parts: the electric stack and the electric control system. The electric stack also includes parts such as bipolar plates, proton exchange membranes, gas diffusion layers and catalysts [13].

Bipolar plates are an important part of electric stacks. In hydrogen fuel cells, the mass ratio is 60% to 80%, and the cost is about 29% to 45%. It is one of the important factors affecting the commercial application of hydrogen fuel cells. It can support electric stacks, distribute fuel and oxygen aids, collect and export current, and block reaction gas. Body and so on. The function of the proton exchange membrane is to isolate the oxidiser and fuel, and transport protons from the anode to the cathode in a targeted manner. Its performance directly affects the stability and service life of the battery. The gas diffusion layer has the functions of transmitting current, guiding gas and draining, and is located on the outermost side of the membrane electrode. The electric control system optimises the control of fuel consumption, reaction temperature and other variables, so that the hydrogen fuel cell supplies power continuously and stably [14].

Hydrogen internal combustion engine cars use hydrogen as fuel, and the heat energy generated by hydrogen combustion is converted into the kinetic energy of the vehicle through the internal combustion engine. The basic structure of the whole vehicle is similar to that of traditional fuel vehicles. The main changes are in the hydrogen fuel supply system, ignition system, exhaust system, crankcase ventilation system and filtration system [15, 16].

According to the different hydrogen injection positions, the hydrogen fuel supply system can be divided into out-cylinder injection type and in-cylinder direct injection type: the out-cylinder injection type is similar to the internal combustion engine structure of traditional fuel vehicles, but the power per unit working volume is relatively low; the in-cylinder direct injection type injects hydrogen into the combustion chamber in the compression stroke, effectively avoiding premature combustion. The problem is the current mainstream research direction. The ignition system should consider the use of cold spark plugs to reduce the probability of premature combustion and tempering. Stainless steel drain pipes need to be designed in the exhaust system, because hydrogen combustion will produce a large amount of water, which is easy to rust the pipes or accumulate in the cylinder, and may freeze in cold areas and cause malfunctions. In addition, the hydrogen internal combustion engine also needs to be equipped with a crankcase ventilation and filtration system to avoid carbon or oil in the cylinder from igniting hydrogen [14-16].

From the technical perspective of hydrogen-containing exhaust gas-coupled hydrogen fuel cell power generation, the advantages of hydrogen fuel cell power generation technology are obvious, which are manifested in the following aspects.

(1) The domestic mature technologies of lyanalky dehydrogenation, chlor-alkali hydrogen production, refinery gas hydrogen production, methanol gas hydrogen production and coke oven gas hydrogen production are coupled with gas purification technology and hydrogen fuel cell power generation technology to form a new power generation process route. The technical means of the process route are mature and stable, and the technical risk is low.

(2) The process route is safe and reliable. Gas purification and power generation facilities are all static equipment. There are no large-scale dynamic equipment and hazardous sources in the system, which can achieve zero-duty operation, avoiding the

high maintenance cost of large steam turbines and ultra-high-pressure steam safety hazards in the traditional power generation industry.

(3) The energy conversion rate of hydrogen-containing exhaust-coupled fuel cells is high, and the power generation efficiency is about 56%. The power generation system is flexible, and medium-voltage synthetic gas can be stored at low cost. By storing gas for peak adjustment, the electric stack can increase or decrease the load according to the amount of incoming gas to achieve peak adjustment operation.

(4) After hydrogen fuel cells generate electricity, they can directly enter enterprises, restaurants, hotels or families to realise the combined use of heat and power. There is almost no loss of power transmission and heat in the process, and the comprehensive utilisation rate of energy can reach 80%.

Hydrogen-containing exhaust gas coupled fuel cell power generation technology can change the current situation of China's chemical waste gas disposal, avoid the disadvantages of high energy consumption, high emissions, negative income and other disadvantages brought about by traditional exhaust gas incineration and disposal technology, realise the resource utilisation and economic output of hydrogen-containing exhaust gas, mobilise the enthusiasm of petrochemical enterprises for environmental protection management, and promote The sustainable development of the environmental protection industry also has a great industrial promotion effect on the power generation and disposal industry, and the application prospect is very broad [17].

4. Conclusion

Hydrogen is a clean source of energy. When burned, it only produces water and does not pollute the air. Therefore, it is considered an important alternative to oil and coal. However, from production to use, each link faces difficulties, and future development must overcome challenges such as technology, cost, and infrastructure.

Currently, most hydrogen comes from natural gas and carbon (gray hydrogen). Despite the low cost, a large amount of carbon dioxide is released during the production process. A more environmentally friendly method is to generate hydrogen (green hydrogen) using electrolysed water from wind and solar energy, which is very expensive because the electrolysed water system relies mainly on precious metal materials (such as platinum). In the future, in order for green hydrogen to be really popular, we will have to look for cheaper materials or improve their technical properties.

Hydrogen is very light and requires high pressure or low temperature for storage. For example, for a hydrogen tank to become liquid, it must be pressurised 100 times the atmospheric pressure or cooled at minus 250 degrees or more. These two methods are expensive and not very convenient to carry. Scientists are studying the use of specialised substances (such as sponges) to "capture" hydrogen, but these techniques are still in the experimental stage and are far from being actually applied.

Hydrogen-fuelled cell vehicles such as Toyota Mirai and Hyundai Nexo were running on the road, but they could travel more than 600 km in a few minutes of hydrogenation, which is much faster than electric cars. However, the problem is that there is not enough hydrogen filling material. There are only about 1,000 in the world (30 in China). This is not much more convenient than a gas station. In addition, hydrogen fuel cell vehicles are twice as expensive as conventional fuel vehicles that are difficult for the general public. If hydrogen gas stations become as popular as gas stations in the future, the advantages of hydrogen vehicles can actually be realised.

Looking ahead, the development of hydrogen fuel will rely on continuous technological innovation, effective policy support, and cross disciplinary collaborative efforts. In terms of technology, replacing expensive precious metals with cheaper materials, developing lighter and safer hydrogen storage tanks, and improving the conversion efficiency of fuel cells will be key to promoting the widespread application of hydrogen fuel. At the same time, the government plays an important role in infrastructure construction, such as investing in hydrogen refueling station networks, providing incentive policies for scientific research and industrial development, and formulating unified safety standards to achieve effective connection between policies and technology. In addition, cross industry collaboration between energy companies, automobile manufacturers, and even household users is equally important—by converting excess wind energy into hydrogen, which can be used for heating or power generation, to build a green energy cycle system. These measures will collectively accelerate the transformation of hydrogen energy towards scale and sustainability.

Simply put, hydrogen fuels have great potential to protect the environment, but it takes time, technology, and money to truly replace traditional energy. Since it took more than 10 years for electric cars to become popular, hydrogen energy may last longer, but the "pollution-free" property will be an integral part of the future energy map.

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