# State of the Arts of Hydrogen Fuel Cell Vehicles

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**Abstract.** With the rapid development and progress of science and technology, people are doing more and more serious damage to the earth. Hydrogen energy, a pollution-free energy, has naturally become the main research object. Hydrogen energy is a kind of secondary energy, which needs to be produced by some specific methods. Hydrogen fuel cell vehicles becomes one of the key new energy automations in both academia and industry, considering the eco-friendly capability. In this paper, the development of hydrogen fuel cell vehicles is comprehensively introduced, and the related characteristics of hydrogen energy, hydrogen fuel cells work are discussed. Meanwhile, the use of hydrogen fuel cell car and challenges, analysis of the cases of several existing hydrogen fuel-cell cars and hydrogen fuel cell vehicles in China in the future are given in this paper. Finally, a personal vision of the future of hydrogen fuel electric vehicles is conclusion in the end of this paper.

**Keywords:** Electric vehicle, Hydrogen Fuel Cell, Hydrogen energy storage.

## 1. Introduction

With the rapid development and progress of science and technology, people are doing more and more serious damage to the earth. Fossil energy is a kind of non-renewable energy and fossil energy consumed by a traffic area there are quite a few parts of, and in the field of traffic and nearly 70% of fossil energy is used as in the car, but now can use the oil on earth is running out, so people began to look for a new environmental protection energy to replace the existing fossil fuels. Hydrogen energy, a pollution-free energy, has naturally become the main research object. Hydrogen energy is a kind of secondary energy, which needs to be produced by some specific methods. The general methods of hydrogen production include electrolysis of water to produce hydrogen, production of hydrogen from coal, production of hydrogen from natural gas or light oil, and so on... The hydrogen has many advantages, such as its loss, when converted to other energy can save a lot of energy, followed by its thermal conductivity is very good, can adapt to the heat inside the car use, not only that it is abundant, according to experts' calculations, hydrogen accounts for about 76% of the universe. On the earth, hydrogen is mostly stored in water, and then water is the most material on the earth, accounting for about 71%, so hydrogen is the most element.

**Table 1.** Energy density of some energy carriers

| Energy carrier | Way of storage | Energy density by weight [kWh/kg] | Energy density by volume [kWh/l] |
|---|---|---|---|
| Hydrogen | Gas (20 MPa) | 33.3 | 0.53 |
| | Gas (24.8 MPa) | 33.3 | 0.64 |
| | Gas (30 MPa) | 33.3 | 0.75 |
| | Liquid (253°C) | 33.3 | 2.36 |
| Diesel | Liquid | 11.6 | 9.7 |
| Methanol | Liquid | 5.6 | 4.4 |
| Gasoline | Liquid | 12.7 | 8.7 |

Generally, as listed Table 1, the hydrogen is the best energy such requisites compared with other energy. The main reason is that hydrogen combustion products are pollution-free (only water) and hydrogen is a renewable energy source. Replacing coal and oil with hydrogen can be used without major transformation of existing technical equipment and minor modification of existing internal combustion engines. Except hydrogen energy, there are many other renewable energy sources, such as solar energy, wind energy, hydrogen power and geothermal energy, if we want to realize the concept of low-carbon and environmental protection, it is very necessary to use these low-carbon

energy widely and correctly. However, except for water energy, there are still many problems in these renewable energies, such as uneven distribution of time and space, poor grid connection ability, etc., which cause a great waste of energy. In order to improve the grid connection ability of renewable energy, reduce the phenomenon of abandoning wind and light, and at the same time, in order to adjust the power grid transmission and distribution, the development of appropriate energy storage technology is particularly important. The traditional energy storage method is difficult to conveniently store energy for a long time. These are the reason why we should choose hydrogen as the energy of the car.

China is still in a critical period of industrialization and modernization. Its industrial structure is heavy, its energy structure is carbon biased, and its energy efficiency is low. As a result, China's emissions of traditional pollutants and greenhouse gases are in sync and at a high level. We must make comprehensive innovations in the whole process of green and low-carbon transformation and in all fields, extensively promote innovation in science and technology, products and institutions, and achieve deep integration of innovation chains and industrial chains. Just as climate change is a challenge for all of us, achieving a "double carbon" goal will require broad collaboration from all of us. It is necessary to make systematic and comprehensive planning, formulate a comprehensive and clear "double carbon" roadmap, properly handle the relationship between industries, urban and rural areas, regions, domestic and international, man and nature, handle the relationship between current and long-term, local and global, low carbon and people's livelihood. It is necessary to introduce laws, regulations and industrial policies to encourage enterprises to eliminate backward production capacity and technologies and actively adopt energy-saving, green and low-carbon technologies. Encourage private capital to invest in green emerging industries and low-carbon technologies; We will resolutely crack down on illegal high-polluting and high-emission enterprises. At the same time, do a good job of public opinion publicity, guide the whole society to cultivate a green development culture atmosphere, consciously save energy in life, avoid waste, take the initiative to try a more green and low-carbon lifestyle. Achieving the "double carbon" goal will entail long-term adjustment across all sectors, but not at the expense of people's growing need for a better life. In all reforms to achieve the "double carbon" goals, we must always put people at the center of our efforts, take people's aspirations for a better life as our goal, and enable the whole society to enjoy the benefits of green and low-carbon development. The production of hydrogen fuel cell vehicles in China increased year by year from 2016 to 2020, but the production dropped to 1,199 units in 2020 due to the impact of the pandemic. This shows that the hydrogen fuel cell vehicle market in China is growing, and the increase in production to some extent represents the increase in market demand. In the future, the development prospect of hydrogen fuel cell vehicles is good.

This article mainly introduced the development of hydrogen fuel cell vehicles, and discusses some related characteristics of hydrogen energy, hydrogen fuel cells work, and discusses the use of hydrogen fuel cell car and now meet some obstacles, analyses the cases of several existing hydrogen fuel-cell cars and hydrogen fuel cell vehicles in China in the future, Finally, there is a personal vision of the future of hydrogen fuel electric vehicles.

## 2. Hydrogen energy storage

### 2.1. Hydrogen Fuel Cell Vehicles Basics

Basically, the operation of the hydrogen fuel cell vehicles is relied on the chemical reaction between the hydrogen and oxygen. The system diagram of the hydrogen fuel cell vehicles is as demonstrated in Figure 1.

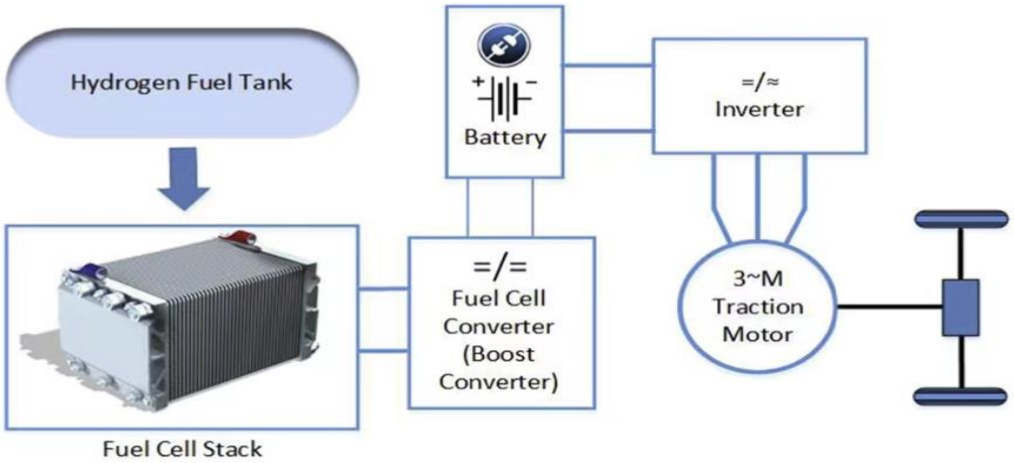


**Figure 1.** System diagram of the hydrogen fuel cell vehicles

The reaction of the hydrogen fuel cell operation is expressed as,

$$\begin{cases} Cathode: H_2 + 2OH^- = 2H_2O + 2e^- \\ Anode: \frac{1}{2}O_2 + H_2O + 2e^- \ 2OH^- \\ Reaction: H_2 + \frac{1}{2}O_2 = H_2O \end{cases} \quad (1)$$

## 2.2. Toyota Mirai


**Figure 2.** Toyota Mirai [1].

At present, the existing hydrogen fuel cell vehicles are Chase MAXUS FCV80, Toyota Mirai, Honda Clarity and Hyundai NEXO, etc., of which Toyota and Modern Nexo are the most representative. In terms of the development of hydrogen fuel cell vehicles, Japan, South Korea, Europe and the United States are currently leading the industry. For example, as demonstrated in Figure 2, Toyota's new development of fuel cells, and reduce the dynamic properties of the battery size and weight to achieve world-class, Toyota's new compact fuel-cell cars, enough to hold the car chassis, thereby reduce the body's centre of gravity, thus improve the driving performance of the bend, mirai automobile comprehensive evaluation is a great fun to drive and environmental performance of a new car. Fuel battery pack is composed of 370 cells, produced by cells of current drive cars, hydrogen into the fuel cell anode catalyst catalytic reaction, he will be separated into electrons and

protons, proton electrolyte and electronics to the cathode, water and oxygen reaction, released from the reaction of the flow of electrons, to produce electric power and electric motor. Compared with the conventional fuel cell, Toyota's new fuel battery pack with catalysts with higher activity and more thin electrolyte film brings improvement of proton conductivity, diffusion layer is more thin, density is small, enhanced diffusion, electrode reactant significantly improve the innovation, the new fuel cell stack has adopted the world's first 3 d mesh magritte that helps to improve the power performance, With the traditional direct way to summarize the generated water can inhibit the accumulation in the batteries, power generation, 3 d mesh low sense provides a supply air onto the surface of the batteries, who so as to prevent the accumulation of the spread of the high-performance electrode and three fine screen lead a world-class power performance, mirai electric vehicles very environmental protection, not only because of its revolutionary fuel cell technology, This is also a user-friendly design of driving fun. And unlike electric cars, it takes only five minutes to fuel the mirai at a hydrogen station, just like filling up a conventional car, but hydrogen is more expensive. According to a report released by South Korean market research firm SNE Researchon Oct. 6, the global sales of hydrogen fuel cell vehicles totaled about 11,200 units as of August this year, compared with 5,900 units in August last year, an increase of 91.7 percent year-on-year. Hyundai Nexo's sales accounted for 52.2 percent of the total hydrogen fuel cell vehicle sales worldwide, ranking first. The first-generation Hyundai Nexo and Toyota Mirai are the two hydrogen-powered models leading sales this year. Through August, Hyundai Nexo sold about 5,900 units worldwide, up 34.2% from 4,400 last year. Global sales of the Toyota Mirai were 4,400 units, a 7.3-fold increase from 600 units sold in the same period last year. Toyota Mirai remained in second place with 39.2 percent of the market. In the first August of this year, 7.03 million hydrogen fuel cell vehicles were sold in China.

## 3. Hydrogen energy storage

There is no hydrogen production in hydrogen consuming areas, and the cost of hydrogen energy storage and conveyance remains high. Hydrogen energy storage and conveyance is the current bottleneck restricting the development of hydrogen energy in China. " Han Difei, told China Energy News. In the upstream of the hydrogen energy production and utilization industry chain, the hydrogen production and hydrogenation ends are relatively mature, and the storage and transportation links (hereinafter referred to as "storage and transportation") have become the main constraints on the high price of hydrogen energy.

In fact, hydrogen energy storage is mainly to store unstable hydrogen energy in a stable form. Under the condition of economy and safety, improving the efficiency of hydrogen storage, reducing the cost and improving the utilization efficiency of hydrogen energy are the development priorities of hydrogen energy storage technology. Hydrogen storage technology can be roughly divided into physical hydrogen storage and chemical hydrogen storage.

### 3.1. Liquid ammonia hydrogen storage

Hydrogen and nitrogen react to form liquid ammonia under the help of high temperature, high pressure and catalyst, and then hydrogen energy is stored and transported in the form of liquid ammonia. Under normal atmospheric pressure, liquid ammonia needs to be decomposed below 400℃ and release hydrogen.

Compared with the extremely low hydrogen liquefaction temperature of - 253℃ required by the low-temperature liquid hydrogen storage technology, the liquefaction temperature of ammonia at one atmospheric pressure is much higher than - 33℃, and the "hydrogen ammonia hydrogen" mode consumes less energy, has lower difficulty in realization and transportation. At the same time, the volume hydrogen storage density of liquid ammonia hydrogen storage is 1.7 times higher than that of liquid hydrogen, which is much higher than that of long tube trailer type gaseous hydrogen storage technology. This technology has certain advantages in long-distance hydrogen energy storage and transportation. However, liquid ammonia hydrogen storage also has many disadvantages. Liquid

ammonia is highly corrosive and toxic, and there are potential hazards to equipment, human body and environment during storage and transportation; Synthetic ammonia process is relatively mature in China, but there is a certain proportion of loss in process conversion; The equipment for synthetic ammonia and ammonia decomposition and the equipment for terminal industry still need to be integrated.

### 3.2. High pressure gaseous hydrogen storage

Hydrogen can be transported in gas cylinders. At present, the high-pressure gas hydrogen storage technology can directly release gas through the pressure reducing valve, which is very convenient and stable. It is the most widely used hydrogen storage technology. This method uses high pressure to compress hydrogen into a high-pressure cylinder made of carbon fiber and aluminum composite materials [2]. The metal high-pressure hydrogen storage container has certain hydrogen embrittlement resistance, because they will not be hydrogen embrittlement and react with hydrogen under normal temperature and high pressure [3,4].

The cost of hydrogen storage in high-pressure gas is relatively cheap compared with other energy storage methods. The hydrogen energy consumed in the compression process is also relatively small, and the release method is also very simple, just open the gas valve. High pressure hydrogen storage is a relatively mature hydrogen storage technology at present, but it also has some problems, such as low density of hydrogen storage. In addition, high pressure gaseous hydrogen storage may lead to the risk of leakage and even explosion under specific circumstances. In the future, high pressure gaseous hydrogen storage needs light weight, high pressure, low cost and stable quality.

The operating temperature of the air tank is 40~60℃, and the storage pressure is 45-95MPa. Austenitic stainless steel, which is resistant to hydrogen embrittlement and hydrogen corrosion, has the advantages of explosion suppression and explosion resistance, defect dispersion, online diagnosis of operation status, etc. Safety valves, pressure sensors, temperature sensors, hydrogen leakage probes are installed in the gas tank, and the safety status of the tank can be monitored from time to time through remote online monitoring of the gas tank.

In general, 35MPa gaseous hydrogen storage is mainly used in urban vehicles, such as urban buses, logistics vehicles and group buses; 70MPa has been successfully developed and mainly used in passenger cars; The liquid hydrogen storage technology is mature and mainly used in the military field in China [5,6]. After the realization of civil promotion, it can meet the hydrogen demand of long-distance, heavy haul and high-power commercial vehicles; After the breakthrough of organic liquid hydrogen storage technology, it can be used in most hydrogen use fields; Solid hydrogen storage is suitable for areas insensitive to weight.

### 3.3. Low temperature liquid hydrogen storage

Organic liquid hydrogen storage technology is based on the hydrogenation of unsaturated liquid organics under the action of catalyst to generate stable compounds, and then dehydrogenation reaction is carried out when hydrogen is needed. The volume hydrogen storage density of liquid ammonia hydrogen storage is 1.7 times higher than that of liquid hydrogen, which is much higher than that of long tube trailer type gaseous hydrogen storage technology [7-9]. This technology has certain advantages in long-distance hydrogen energy storage and transportation. However, liquid ammonia hydrogen storage also has many disadvantages. Liquid ammonia is highly corrosive and toxic, and there are potential hazards to equipment, human body and environment during storage and transportation; Synthetic ammonia process is relatively mature in China, but there is a certain proportion of loss in process conversion; The equipment for synthetic ammonia and ammonia decomposition and the equipment for terminal industry still need to be integrated.

However, the liquid hydrogen plants in China only serve the space rocket launch, which cannot be used in the civil field due to the limitation of regulations and technical costs. However, relevant enterprises have started to develop corresponding liquid hydrogen storage tanks and liquid hydrogen tankers, such as Aerospace 101 Institute, Guofu Hydrogen Energy, Hongda Xingye, CIMC

Shengdayin and other companies are developing domestic liquid hydrogen storage and transportation products. Relevant departments are studying and formulating civil standards for liquid hydrogen. In the future, liquid hydrogen transportation will become the main artery of hydrogen energy development in China.

### 3.4. Metal hydrides

This technology stores hydrogen in the form of metal hydride in hydrogen storage alloy materials. At a certain temperature and pressure, hydrogen storage alloy first forms hydrogen containing solid solution in contact with hydrogen (α Phase), and then the solid solution continues to react with hydrogen to produce phase transition, forming metal hydride (β Phase). Under heating conditions, metal hydride releases hydrogen. Early discovered alloys include LaNi5, Mg2Ni, TiFe, etc. Later, researchers found that this kind of alloy is composed of one hydrogen absorbing element A and another non-hydrogen absorbing element B. The two elements control hydrogen storage and reversibility of hydrogen absorption and desorption respectively [10].

This kind of solid based hydrogen storage technology often has the advantages of high hydrogen storage density, low hydrogen storage pressure, good safety, high hydrogen release purity, and its volume hydrogen storage density is higher than that of liquid hydrogen. At present, the research achievements of hydrogen storage metal materials at home and abroad are continuous and have been applied in some fields. Solid hydrogen storage technology has been commercially applied in battery warships abroad, and has been demonstrated in distributed power generation and wind power hydrogen generation scale hydrogen storage; Solid state hydrogen storage has been demonstrated in distributed power generation in China.

However, the weight hydrogen storage rate of metal hydrogen storage materials in mature systems is low, and the highest reversible hydrogen storage capacity of TiV materials is 2.6 wt%. In order to improve the weight hydrogen storage rate, new materials such as coordination hydrides and metal ammonia boranes have been developed. However, these materials are still in the process of laboratory technology research and development due to their slow hydrogen absorption and desorption speed and poor reversible cycle performance. In addition, the cost of hydrogen storage metal materials is affected by the price fluctuation of non-ferrous metal raw materials, and the high cost is another factor restricting the development.

## 4. Sales comparison of hyundai NEXO and toyota mirai over the years

According to the statistics of orange Club hydrogen energy database, the total global sales of Hyundai NEXO in 2020 was 6781, including 5786 in South Korea and 995 overseas. Hyundai NEXO's total global sales in 2019 were 4987, 4194 in South Korea and 793 overseas. In 2018, 2019 and 2020, Hyundai NEXO's sales continued to grow, and the compound growth rate of global sales in the three years was about 92.6%. According to the data of orange Club Research Institute, the total global sales of Toyota Mirai in 2020 was 1770, including 789 in Japan and 981 overseas. 2017 was the sales peak of Toyota Mirai, with a total global sales of 2741 vehicles, including 768 in Japan and 1973 overseas. In addition, unlike Hyundai, the overseas sales of Toyota Mirai have exceeded the domestic sales since 2016, and overseas has become the main sales market of Toyota Mirai. Since its launch in 2018, Hyundai NEXO's sales in South Korea have always been ahead of overseas sales. Since then, South Korea has surpassed Japan to become the world's No. 1 hydrogen passenger vehicle sales.

## 5. Domestic status of fuel cell vehicles

The relevant technology and market are still immature Hydrogen fuel cells have the highest fuel energy density, higher than lithium-ion electric vehicles and fuel vehicles, and occupy an advantage in energy efficiency ratio. After considering the whole life cycle, the energy efficiency is about 29%,

which is higher than 28% for lithium-ion electric vehicles and 14% for fuel vehicles. In terms of endurance, hydrogen fuel cell vehicles are similar to traditional fuel vehicles, with a range of about 600 kilometers, which is better than lithium-ion electric vehicles; In addition, hydrogen fuel cell vehicles also have the advantages of no noise, short charging time, low temperature resistance, and low accident severity. However, at present, hydrogen fuel cell vehicles have just started in the Chinese market, and the technology and market are still immature, in a naive period, and there is huge room for development in the future; And the application field of hydrogen fuel cell vehicles is not universal, which is also where the technology of hydrogen fuel cell vehicles needs innovation and research in the future.

## 6. Conclusion

In this paper, the development of hydrogen fuel cell vehicles is comprehensively introduced, and the related characteristics of hydrogen energy, hydrogen fuel cells work are discussed. Meanwhile, the use of hydrogen fuel cell car and challenges, analysis of the cases of several existing hydrogen fuel-cell cars and hydrogen fuel cell vehicles in China in the future are given in this paper. In China, hydrogen fuel cell vehicles have not reached the leading level in the industry. In this regard, we hope that we can learn more from other countries and accumulate experience. Once hydrogen fuel cell vehicles are popularized, we can not only achieve our "double carbon" goal, but also greatly improve our ecological development.

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