Application Progress of Hydrogen Fuel Cells in Transportation Field

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Abstract. In recent years, China's environmental pollution problem has become increasingly serious, and pollutants produced by traditional fossil fuels have seriously affected China's air quality. China urgently needs to find clean energy that can replace traditional energy. As a consequence, there is now a lot of impetus thanks to the development of hydrogen energy. The development of hydrogen fuel cell automobiles has recently been one of the most popular topics of discussion in modern culture. The cost of hydrogen production and the penetration rate of hydrogen filling stations, which are now the most difficult problems to address, are still obstacles to the broad marketing of hydrogen fuel cell vehicles. The development of hydrogen fuel cells in the sector of transportation is the topic of this research. By analyzing the current existing energy consumption problems and environmental pollution problems, the paper provides insights into the development status of hydrogen fuel cell vehicles and the advantages of hydrogen energy compared to other energy media. Extensive research has revealed that while hydrogen fuel cells have been implemented and utilized in various transportation applications, their widespread adoption has not yet been achieved. Several challenges, including technical limitations, high costs, and refueling convenience, have emerged as key constraints impeding the advancement of hydrogen fuel cell technology in the transportation sector. It is believed that with the development and progress of technology and the support of national policies, China's hydrogen fuel cell technology will be vigorously developed in the field of transportation.

1 Introduction

China promised in the "Paris Agreement" that by 2030, its carbon dioxide emissions per unit of GDP will decline by 60% to 65% compared to 2005, the share of non-fossil energy in total energy will rise to about 20%, and China's carbon dioxide emissions will peak and work to peak as soon as possible[1]. This was done in response to the increasingly serious global pollution problem and the "dual carbon" policy. Energy serves as the backbone of the economy as a whole and is essential to economic growth. China today has issues with excessive resource use, severe environmental degradation, a clear supply and demand imbalance, an irrational consumption pattern, and outdated energy resource utilization technologies. The most pressing issue that needs to be resolved is the widespread usage of clean energy. It can decrease environmental pollutants in addition to increasing energy efficiency. The best option for using clean energy is hydrogen energy. The benefits of hydrogen energy include efficient burning, an abundance of reserves, a high calorific value during combustion, low energy consumption, zero emissions and no pollution, a high utilization rate, easy transportation, and the reduction of the greenhouse effect. The current application status of hydrogen energy in the sector of transportation will be analyzed and forecasted in this article, along with a comparison of the benefits and drawbacks of using hydrogen energy vs conventional energy sources. Further, this article will take the application of hydrogen fuel cells in automobiles, passenger cars, ships and heavy trucks as examples and compare the advantages and disadvantages with traditional energy sources. National policies currently support the use and advancement of hydrogen energy in the sphere of transportation aggressively. Numerous beneficial policies in the area show how committed the country is to the advancement of hydrogen energy, whether they are vigorously promoting the development of hydrogen fuel cell vehicles or supporting top companies in the hydrogen energy value chain.

2 Current Energy Consumption and Environmental Issues in the Transportation Sector

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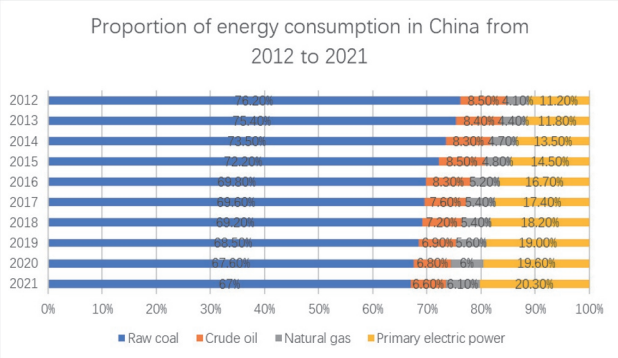

Fig. 1. Proportion of energy consumption in China from 2012 to 2021 (picture credit original)

The issue of energy consumption in the transportation sector has recently become more evident as China's transportation industry has grown. The third-largest energy consumer after industry and living consumption is the transportation sector. The energy consumption of the transportation sector needs to be adjusted immediately given the growth of the economy and the frequent exchanges of economic activities between areas.

First of all, as shown in Figure 1, the main energy consumption in China is still coal, but in the field of transportation, oil consumption also occupies a large proportion, among which gasoline, diesel and kerosene use a relatively high proportion, occupying a large proportion of society. About 70% of fuel consumption. It is clear that China's transportation sector continues to consume a significant amount of fuel energy, which will have a negative impact on the environment. For example, automobile exhaust emissions are a kind of pollution that considerably impacts the environment. Due to China's rapid economic development in the past two decades, the number of urban motor vehicles has increased rapidly, and the pollutants emitted by automobiles have greatly impacted the environment. Carbon monoxide, hydrocarbons, nitrogen oxides, Sulfur dioxide, etc., will pollute the environment and may also react to generate secondary pollution. As shown in Figure 2, among the 339 cities in China in 2021, 12.6% of them will suffer from varying degrees of air pollution.

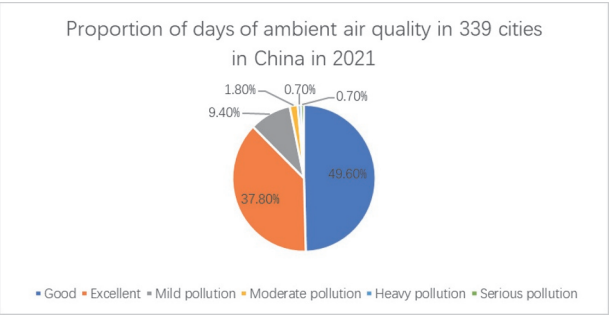

Fig. 2. Proportion of days of ambient air quality in 339 cities in China in 2021(picture credit original)

Therefore, from the standpoint of energy saving and environmental preservation, boosting the use of clean energy is a very essential step. Among the clean energy, hydrogen is undoubtedly the clean energy that has attracted the most attention in recent years. Hydrogen energy utilization and development have commenced across various modes of transportation, encompassing automobiles, city buses, marine vessels, heavy-duty trucks etc.

3 Application Status of Hydrogen Energy in Automobiles

A fuel cell vehicle is an electric car that uses a fuel cell system as either its primary power source or a fuel cell system with a rechargeable energy storage system as a hybrid power source [2]. Despite the relatively late start of the development of hydrogen fuel cell vehicles in China, thanks to national policies and funding, this technology is now ushering in a blowout development, and the supply chain for hydrogen fuel cell vehicles on the market has already been established[3]. However, it cannot be denied that there are still significant issues with the adoption of hydrogen fuel cell automobiles.

3.1 Fuel Cell Technology Level

China's hydrogen fuel cell technology is currently not among the best in the world. The next stage for Chinese automakers is to carry out more research and analysis on hydrogen fuel cell technology because the output energy of fuel cells is still the key to the development of fuel cell vehicles.

According to the kind of electrolyte, fuel cells can currently be classified as phosphoric acid fuel cells, solid oxide fuel cells, alkaline fuel cells, molten carbonate fuel cells, and proton exchange membrane fuel cells. batteries-powered [5]. Figure 3 illustrates how it operates.

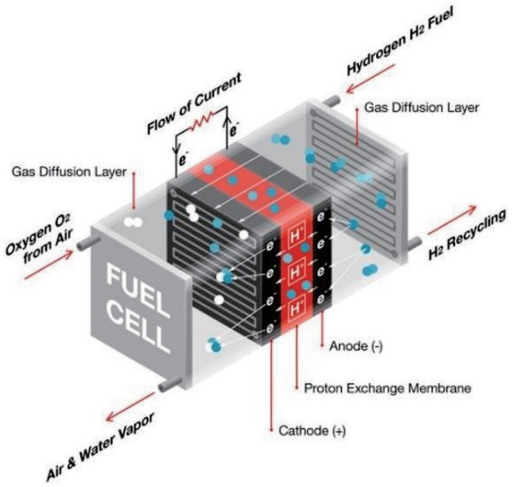

Fig. 3. Working principle diagram of hydrogen fuel cell [4]

Proton exchange membrane fuel cells have the advantages of excellent energy consumption, rapid starting, longer life, etc. at relatively low temperatures [5]. The primary focus of current research and development for hydrogen fuel cells is the proton exchange membrane fuel cell. The proton exchange membrane serves as the central element of the fuel cell, and its primary job is to separate hydrogen from the oxidant so that hydrogen protons can travel through the membrane and interact with the oxidant to produce water

[5]. As a result, the exchange membrane needs to be highly conductive to hydrogen ions as well as possess a number of other qualities, including great mechanical stability, good chemical characteristics, and cheap cost [5].

3.2 Structure of a hydrogen fuel cell vehicle

As shown in Figure 4, the primary components of a hydrogen fuel cell car are as follows: (1) fuel cell stack, which undergoes internal redox reactions to continuously output electric energy for the vehicle; (2) Electric motor: Uses the fuel cell's electric energy to power the vehicle. (3) Hydrogen tank: store hydrogen to supply the battery stack with energy continuously; (4) Power control unit: This component receives and processes operating instructions from the driver and uses the appropriate controller to give control instructions so that the driver can properly perform the driving. the driver's purpose, which causes the vehicle to operate and drive as desired [5].

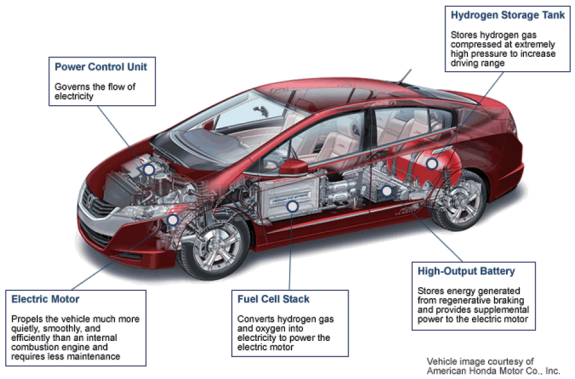

Fig. 4. Structure of hydrogen fuel cell vehicle [6]

3.3 Supply of hydrogen energy

Simply increasing output won't be sufficient for the development of hydrogen energy cars. A solid energy source is required if hydrogen energy vehicles are to become commonplace on the road. Today, the creation of hydrogen refueling stations is a crucial issue. The hydrogen fuel cell vehicle sector is severely hampered by the small scale, poor quality hydrogen that does not fulfill the needs of automobiles, high cost of hydrogen manufacturing, and difficulty in storing hydrogen. However, the cost of building hydrogen refueling stations can be further decreased by enhancing the localization of critical materials, fundamental components, and technology. The cost of hydrogen storage and transportation can be reduced by developing new technologies such as liquid hydrogen storage and transportation, hydrogen pipeline transportation, and new hydrogen storage materials like organic liquid hydrogen storage [7].

3.4 Production costs of hydrogen fuel cell vehicles

At present, the production cost of hydrogen fuel cell vehicles independently produced in China is close to 65% of the total cost, which is still relatively high [3]. In addition, the cost of hydrogen production is also high, and the cost problem will also hinder the large-scale development of hydrogen fuel cell vehicles. At present, the industrial large-scale hydrogen production method is mainly fossil fuel hydrogen production, including three methods: natural gas endothermic reforming hydrogen production, coal hydrogen production and light oil steam reforming hydrogen production [8]. The hydrogen produced by them accounts for the current hydrogen production in China is about 96% [8]. However, the production process of these three hydrogen production methods is complicated, the hydrogen production process will pollute the environment, the hydrogen produced is low in purity, and effective separation technology is needed to purify hydrogen [8], so the cost is also high.

4 Application Status of Hydrogen Energy in Passenger Cars

Since 2003, China has been implementing the usage of hydrogen fuel cell buses. More than ten cities had hydrogen refueling stations completed and operational as of July 2018. More than ten additional cities have already started building hydrogen refueling stations [9].

4.1 System structure of hydrogen fuel cell bus

Hydrogen fuel cells have the characteristics of voltage and current output characteristics and dynamic response lag, while the operation of urban public transport buses has high driving and braking power fluctuation frequency, large amplitude, and long driving range. The total driving and braking energy are relatively large, so the hydrogen fuel cell bus power system generally adopts the hybrid power system scheme of fuel cell plus power battery [9].

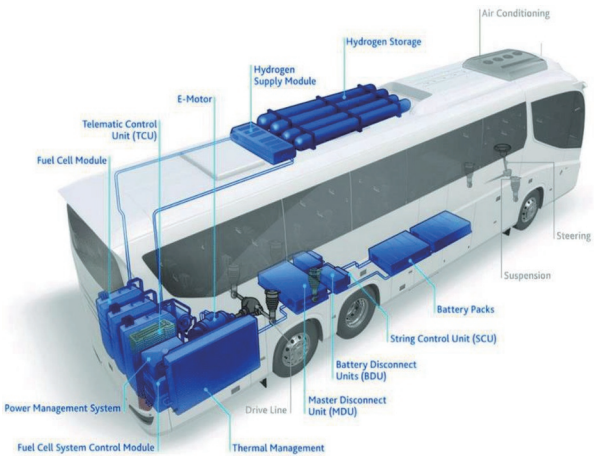

Fig. 5. structure of hydrogen fuel cell bus [10]

As shown in Figure 5, the fuel cell reactor and motor are located behind the bus, while the hydrogen tank for the fuel cell bus is mounted on the roof. Usually, a fuel cell bus adopts a hybrid power system combining a fuel

cell system of no less than 60kw and a power type power battery, and is equipped with 8 to 10 35Mpa hydrogen storage bottles, and the driving range can exceed 300 kilometers [9].

4.2 The problem with hydrogen fuel cell buses

First of all, as a means of public transportation, its applicability must be achieved, including in high-altitude plateau areas and extremely cold northern areas. Secondly, energy replenishment must be convenient, and hydrogen refueling stations along urban bus lines must be added to ensure sufficient energy to maintain operations. Finally, there is the issue of cost. The cost of hydrogen production and hydrogen refueling must be controlled, otherwise as a public transportation tool, once the cost too high and it will be difficult to maintain operations.

5 Application Status of Hydrogen Energy in Ships

At present, domestic hydrogen fuel cell ships are still in the theoretical stage as a whole, and few have been put into practical application (Figure 6) [11]. In 2002, Beijing Fuyuan Company developed the first domestic fuel cell yacht "Fuyuan No. 1", with a rated power of 400w and a speed of 7km/h; in 2005, Shanghai Maritime University developed the "Tianxiang No. 1" hydrogen fuel cell test ship, the battery The power is 2000w, the speed is about 13km/h, and the battery life is 3h. It can carry two people; It is a 2100-ton inland self-unloading cargo ship with a length of 70.5m and a design draft of 3.1m. It uses 4*135kw hydrogen fuel cells as the main power and lithium battery packs for peak-shaving compensation. It carries 35Mpa high-pressure hydrogen cylinders and a 13km/h speed. It will be used in the special project of "Green Pearl River" in Guangdong Province [11].

Fig. 6. Hydrogen fuel-powered inland self-unloader vessel[12]

5.1 Advantages of Hydrogen Fuel Cell Ships

After hydrogen combustion, only water is produced without any pollutants. Especially compared to other energy media, hydrogen fuel does not emit greenhouse gases. It has unique advantages and can truly achieve zero carbon emissions [11].

Table 1. Calorific Values of different fuels

Fuel	Calorific Value(kJ/kg)
Cow dung cake	6000-8000
Wood	17000-22000
Coal	25000-33000
Petrol	45000
Kerosene	45000
Diesel	45000
Methane	50000
CNG	50000
LPG	55000
Biogas	35000-40000
Hydrogen	150000

As shown in Table 1, in terms of combustion efficiency, the combustion calorific value of hydrogen fuel ranks first among all fuels. Each kilogram of hydrogen can produce 150,000KJ of heat after combustion, which is about 6.5 times that of ammonia and 3 times that of heavy fuel oil and 2.5 times that of LNG. Moreover, hydrogen has a wide range of energy sources, small vibration, and low noise, which is another advantage over other traditional energy media [11].

5.2 Problems with Hydrogen Fuel Cell Ships

The primary issue is the safety of hydrogen fuel cell ships. Hydrogen fuel cells are currently in urgent need of improvement in terms of stability and service life. Hydrogen is a flammable and explosive energy source, and ships usually need to carry a large amount of cargo and fuel, and the working environment of the ship is mostly in the sea with high humidity, strong wind and waves, and high salt content. Safety must be the primary issue for hydrogen fuel cell ships.

The development of hydrogen fuel cell ships is also being hampered by the high cost of building hydrogen recharging stations, and the lack of infrastructure will have a significant impact on the acceptance of transportation.

6 Application status of hydrogen energy in heavy trucks

Up to now, there are five types of fuel cell heavy-duty trucks in the Ministry of Industry and Information Technology's "Recommended Catalog of New Energy Vehicles", namely China FAW Group, Dongfeng Motor Group, Jiangling Heavy Truck, Chengdu Dayun Automobile, and Nantong Gaokai Automobile. In addition, Shaanxi Automobile, Sinotruk, Mercedes-Benz, Xugong and other enterprises have also successfully developed hydrogen-fueled heavy trucks [12].

Among them, according to the announcement information of the Ministry of Industry and Information Technology, among the best-selling models of hydrogen fuel cell heavy trucks in 2022, Foshan Feichi fuel cell semi-trailer tractor FSQ4250SFFCEV has sold a total of 444 units, accounting for 18.01% of the market, ranking first among the 10 best-selling models of fuel cell heavy trucks. This model is a 6*4 model with a total mass of 25 tons, a wheelbase of 3850+1350mm, a length of 7565mm, a width of 2550mm, a height of 3780mm, and a maximum speed of 89km/h [13]. The fuel cell system equipped on this model is Guohong Hydrogen 110kw high-power hydrogen fuel engine and permanent magnet synchronous motor + 4-speed AMT gearbox. The driving motor is a permanent magnet synchronous motor from Suzhou Green Control, with a peak power of 355kW. Compared with traditional fuel heavy trucks, its power generation efficiency can reach more than 50%, and it is mainly used for short-distance transportation of raw coal between coal chemical companies and major coal mines. In addition, this model is also equipped with a hydrogen leak detection and alarm device, which can ensure that the hydrogen will not leak out and ensure driving safety. The automatic shutdown protection can easily cope with various transportation environments, and the cruising range can reach more than 500km.

6.1 Advantages of hydrogen fuel heavy trucks

The advantages of hydrogen fuel heavy trucks are as below: (1) No pollution, zero emission, only water is produced after the chemical reaction of the fuel cell, and no harmful gas is produced. (2) Low noise and small vibration, only 55 dB. (3) The power generation efficiency is high, up to over 50%. This is due to the fuel cell's ability to produce electric energy directly after the chemical reaction, which minimizes energy loss. (4) The filling rate is fast. At present, hydrogen fuel is filled at high pressure, and the problem of rising filling temperature has been overcome to ensure the filling rate [12].

6.2 Problems with hydrogen fuel cell heavy trucks

The problems of hydrogen fuel heavy trucks are as below: (1) The cost of the fuel cell system is high: the platinum catalyst used in the reactor is an expensive metal material. With the development of technology, reducing the content of platinum or using other catalysts for catalysis will effectively reduce the cost of the entire vehicle. (2) The cruising range is short. The hydrogen fuel cell heavy truck currently uses a 35Mpa hydrogen supply system. Due to the layout of the vehicle, the hydrogen supply system is arranged behind the cab, and the cruising range is only 300-500km, which cannot meet the long-term requirements mileage requirements, subsequent improvements can be made through liquid hydrogen or solid-state hydrogen storage [12].

7 The current national policy direction for the hydrogen energy industry

China's related policies started paying more attention to the hydrogen energy sector from 2005. It is clear that China is paying an increasing amount of attention to the hydrogen energy sector. Among them, the release volume of the three periods of 2007, 2012, and 2016-17 is relatively large. Corresponding to the introduction of the general policy of the five-year plan [14].

There are five main categories of policies: (1) Hydrogen fuel cells (2) New energy vehicles (3) Regulatory regulations (4) Hydrogen production technology (5) Hydrogen energy [14]. The main trend is to vigorously encourage the development of hydrogen energy, and explore the application form and feasibility in transportation. Shandong and Jiangsu in East China, Guangdong in South China, Beijing-Tianjin-Hebei in North China, Henan in Central China, and Liaoning in Northeast China are the key regions where policies are distributed. [14].

8 Conclusion

The analysis in this article suggests that it is the catalyst for the rapid advancement of hydrogen energy, particularly in the energy-intensive industry of transportation. The main objective is the development of hydrogen energy. Efficiency is a huge plus. Among the means of transportation in the field of transportation, hydrogen fuel cell vehicles are developing rapidly and are in a period of accelerated development. However, the technical bottlenecks that need to be broken through are still: power, battery life, high cost, hydrogen production, hydrogen storage and popularization and construction of hydrogen refueling stations; hydrogen fuel cell buses also have the problem of high cost and insufficient popularity of hydrogen refueling stations, but compared with cars, the requirements for the convenience of hydrogen refueling for buses are not as high as those for family cars; Most of the hydrogen fuel cell ships are still in the theoretical stage at present, and there is still a certain period of time before large-scale application, and the life of hydrogen fuel cells immersed in high-salt and highly corrosive seawater for a long time is also a big problem that needs to be solved. The limited battery life and high battery production costs, which are essentially constant issues with hydrogen fuel cell vehicles, are the key issues with heavy duty hydrogen fuel cell trucks. In conclusion, the development of hydrogen refueling stations, the production and storage of hydrogen energy, the high cost, safety, and stability are all issues that are challenging to resolve at the moment, and China is still in the early stages of this process. In the next few decades, with the help of national policies and scientific and technological progress, China's hydrogen energy industry will surely usher in a major change.

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