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Views & Comments

Fuel Cell Heavy-Duty Trucks: Application and Prospect

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1. The strategic significance of fuel cell application in heavy-duty trucks

Heavy-duty trucks play an important role in the global transportation industry. In 2019, 1.174 million heavy-duty trucks were sold in China, and the cumulative number of heavy-duty truck sales from January to October 2020 reached 1.3737 million. The sales increment of heavy-duty trucks has also resulted in significant energy consumption and high levels of pollutant emissions. According to statistics, about 50% of total petroleum consumption in China comes from the transportation industry [1]. In 2019, the NO_x emissions of heavy-duty trucks made up more than 74% of total vehicle emissions, and their particulate matter (PM) emissions exceeded 52.4% of total vehicle emissions [2]. Therefore, the application and promotion of hydrogen fuel cells in heavy-duty trucks will significantly contribute to energy conservation and emission reductions.

Low-carbon and clean energy consumption has become mainstream in China with the changes in the national energy structure and the comprehensive construction of an ecological civilization. Carbon-free, widely sourced, and renewable hydrogen energy, along with its large-scale application in transportation, can be an important measure to relieve the pressure in energy security and environmental protection; it can also be an effective way to achieve China's goal of carbon neutrality by 2060. In November 2020, the "New Energy Automobile Industry Development Plan (2021–2035)" was released by General Office of the State Council of the People's Republic of China. The plan states that, after 15 years of continuous efforts, fuel cell vehicles will be commercialized and the construction of a hydrogen fuel supply system will be steadily promoted, effectively fostering energy conservation, emission reduction, and efficient social operation [3]. In comparison with battery electric vehicles, hydrogen fuel cell vehicles have obvious advantages in terms of fuel filling time and continuous mileage. For heavy-duty trucks, therefore, which require a long driving distance, high power, and the ability to transport heavy loads, fuel cells can provide a zero-emission power solution with competitive advantages. In comparison with passenger cars, the operation routes of heavy-duty trucks are more fixed, and the requirements for the layout of a hydrogen filling infrastructure are lower. Therefore, in the early stage of the development of the fuel cell industry, the strategic guiding role of the development of fuel-cell-powered heavy-duty trucks is higher than that of passenger cars.

2. The domestic and international development status of hydrogen fuel cell heavy-duty trucks

Throughout the world, hydrogen fuel cell heavy-duty trucks are still in the stage of key technology upgrades and small-scale pilot applications, mainly in city buses and logistics freight vehicles. As yet, there has been no application breakthrough of fuel cells in heavy-duty trucks. In July 2017, the China National Heavy Duty Truck Co., Ltd. (CNHTC) launched the first hydrogen fuel cell heavy-duty truck in China, for application in port freight transportation. In November 2019, Shaanxi Heavy Duty Automobile Co., Ltd. (Shacman) launched the X5000 49-tonne heavy-duty truck, which is equipped with Weichai Power Co., Ltd. (Weichai)'s fuel cell power system; the truck has been operating in the Handan Plant of the HBIS Group Co., Ltd. (HBIS) in Hebei, China and has achieved a remarkable demonstration effect.

Japan, Republic of Korea, the United States, the European Union, and other developed countries and regions have invested heavily in the research and industrialization of fuel cells, with in-depth basic and cutting-edge research. Significant progress has been made in durability, power density, and cost, and these countries and regions have established technology leadership in this field. The US Department of Energy (DOE) released the Class 8 long-haul truck development goal in December 2019, aiming at the goal of a fuel cell system lifetime of 25 000 h and a peak efficiency of 68% by 2030 [4]. Volvo and Daimler announced in April 2020 that they would jointly fund a new venture to develop and produce fuel cell systems for heavy-duty trucks. Hyundai delivered 10 XCIENT fuel cell heavy-duty trucks in July 2020, which promoted structural transformation and upgrading in the global environmentally friendly commercial vehicle market. Toyota and Hino have jointly developed fuel cell heavy-duty truck prototypes, and plan to launch products in 2025.

3. Challenges and key technical difficulties of fuel cell applications in heavy-duty trucks

Drivers and customers focus on the total cost of ownership (TCO; includes the cost of purchase, fuel, maintenance, etc.), driving distance, lifetime, and durability. As shown in Table 1, there is still a large gap between the level of hydrogen fuel cell heavy-duty truck technology and the goals of the US DOE [5]. Hydrogen

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Table 1
A comparison of diesel heavy-duty trucks and fuel cell heavy-duty trucks with US DOE targets [5].

Item	Diesel heavy-duty trucks	Current status of fuel cell heavy-duty trucks	US DOE targets
Fuel cost	0.28 ($USD\cdot mi^{-1}$)	1.50 ($USD\cdot mi^{-1}$)	$\leq$ 0.28 ($USD\cdot mi^{-1}$)
Purchase cost	0.13 ($USD\cdot mi^{-1}$)	0.27 ($USD\cdot mi^{-1}$)	$\leq$ 0.13
Operation cost	0.17 ($USD\cdot mi^{-1}$)	0.25 ($USD\cdot mi^{-1}$)	$\leq$ 0.17 ($USD\cdot mi^{-1}$)
Fuel	Diesel	Hydrogen	Hydrogen
Fuel carrying capacity	800–1000 L	30–40 kg	> 60 kg
Refueling time	6–10 min	10–30 min	< 6 min
Driving mileage	1200 km	300–500 km	> 1200 km
Lifetime and durability	10 years or 1.2×10^6 km	8000–10 000 h	> 30 000 h

1 mi = 1.6093 km.

fuel cell heavy-duty trucks can only win consumers' trust if breakthroughs are achieved in the above aspects.

With the continuous improvement of fuel cell technology and the gradual improvement of infrastructure, global governments and enterprises continue to increase their demonstration and promotion efforts and investment. At the same time, traditional-fuel vehicles are facing more serious environmental protection pressure. Through demonstration and verification in specific areas in the future, continuous breakthroughs will be achieved in the durability, cost, driving mileage, and refueling efficiency of hydrogen fuel cell heavy-duty trucks.

3.1. Breakthroughs in key technologies for high-power and long-lasting fuel cells

Fuel cell heavy-duty trucks can only meet the needs of large-scale commercial application by realizing a power system of at least 300 kW, a lifetime of 30 000 h, a system drive efficiency of more than 60%, and a vehicle range of not less than 1000 km. According to "the catalogue of recommended models for new energy vehicles popularization and application" [6], the current domestic fuel cell power rating range is between 80 and 120 kW and the lifetime is between 8000 and 10000 h.

In order to achieve the goal of replacing traditional energy applications as soon as possible, it is necessary to gather our national strength. In this way, breakthroughs can be achieved in key fuel cell technology, such as high power, a long lifetime, quick low-temperature start-up, and the performance degradation mechanism; fuel cell environmental adaptability can be improved; and the multi-operational requirements of the fuel cell system can be met.

The operating conditions of fuel cell heavy-duty trucks are complex and changeable. In order to improve the dynamic response characteristics of the power system under complex work conditions, the technological route followed during the initial promotion and application of fuel cell heavy-duty trucks is still the hydrogen-electric hybrid route. With the fast response characteristics and braking energy recovery contributed by the lithium battery system, the range and driving experience of fuel cell heavy-duty trucks can be improved through the development of a safety strategy for the hydrogen-electric hybrid model, along with energy distribution, energy coupling, and the systematic conservation of hydrogen and electricity.

3.2. Promote the supply chain to reduce the whole life-cycle cost of fuel cell heavy-duty trucks

As shown in the TCO comparison chart of heavy-duty trucks (Fig. 1) [6], fuel costs and purchase costs are the main increments in the total cost of a fuel cell heavy-duty truck, and are also at the core of cost reduction.

At present, China's fuel cell industry is in its initial stage, and its core materials and key components are highly dependent on foreign products. Furthermore, the fuel cell vehicle market has not yet formed at this stage, and stack and system components cannot be massively produced at low manufacturing costs. Product reliability has not been fully verified by the market, resulting in a high purchase cost and subsequent operation costs.

Considering China's hydrogen energy situation and national support policies, we should make full use of existing chemical byproduct hydrogen, coke oven gas, and other resources; actively explore diversified fuel cell vehicle application scenarios; and promote the application of fuel cell vehicles, driving the demand for hydrogen in order to reduce high fuel costs. At present, the price of hydrogen in some regions has reached 40–50 $CNY\cdot kg^{-1}$. Furthermore, renewable hydrogen energy production methods should be developed to expand hydrogen sources and reduce the cost of hydrogen to 30 $CNY\cdot kg^{-1}$.

3.3. Breakthroughs in advanced hydrogen storage technology to increase vehicle driving distance

Hydrogen energy heavy-duty trucks have high driving distance requirements, but are limited by the physical characteristics of hydrogen. At present, a mature on-board high-pressure gaseous hydrogen storage solution of 35 MPa (Type III tank) has a hydrogen storage capacity of 20–30 kg and a driving distance of 150–300 km, which would only be suitable for short-distance operation (Fig. 2). It is necessary to upgrade hydrogen storage pressure levels, develop advanced hydrogen storage solutions, and optimize the layout of hydrogen storage systems for vehicles in order to increase hydrogen storage capacity and achieve a long vehicle driving distance. For example, a high hydrogen storage density and ultra-light 70 MPa Type IV hydrogen storage tank is currently being developed in China, which would meet the needs of city buses and other operational scenarios with a driving distance of more than 500 km. In the future, as liquid hydrogen storage technology or other advanced hydrogen storage technologies continue to mature, the driving distance of heavy-duty trucks can be increased to 1000 km, which would completely solve the issue of driving distance and promote the application of fuel cell heavy-duty trucks.

3.4. Development of a high-speed and large-capacity hydrogen refueling protocol to speed up refueling

At present, the protocol specified in the SAE J2601 standard [7] is mainly used for vehicle hydrogen filling, and the maximum

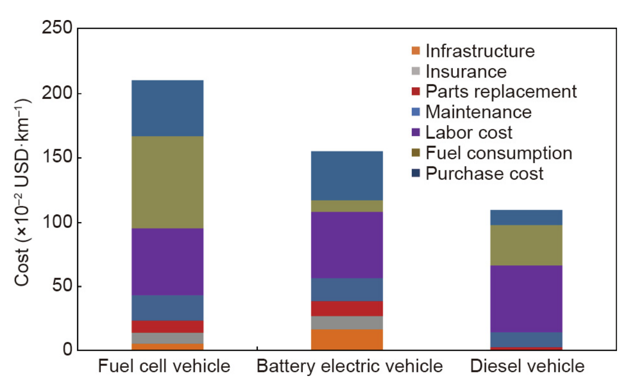

Fig. 1. A comparison of the costs of fuel cell, battery electric, and diesel heavy-duty trucks [6].

Fig. 2. A typical hydrogen storage system layout of a fuel cell heavy-duty truck.

filling speed is 60 $g \cdot s^{-1}$. For heavy-duty hydrogen trucks with a large hydrogen storage capacity, this filling time is too long to meet operational efficiency. For example, Nikola proposes to achieve a filling target of 80 kg within 15 min, and the US DOE aims to achieve a filling rate of 8 $kg \cdot min^{-1}$ by 2030. As hydrogen storage technology continues to mature and the means of process monitoring improve, filling speed will increase significantly.

Related Chinese enterprises are actively carrying out research on fast filling technology, but have not yet established a universal standard. It is urgent to establish a fast filling protocol through technological advancement, following China's laws and regulations (including the liquid hydrogen or cryogenic filling protocol), which will increase the hydrogen filling rate to more than 175 $g \cdot s^{-1}$ (10.5 $kg \cdot min^{-1}$) in order to maximize the operational efficiency of heavy-duty trucks.

4. Prospects

With their achieved and planned advantages of energy conservation, environmental protection, a long driving distance, and convenient use, fuel cell heavy-duty trucks are an important measure for China to transform and upgrade its commercial vehicles. The large-scale market application of fuel cell heavy-duty trucks can provide strong support for China to reduce its petroleum consumption and pollutant emissions, and thus achieve the goal of carbon neutrality by 2060. Moreover, fuel cell heavy-duty trucks have several potential applications and markets in China, so they can be popularized on a large scale and have promising application prospects.

China is currently committed to the core technology research and industrialization of hydrogen and fuel cells. A hydrogen fuel cell vehicle demonstration city group project has been implemented, which will use the effects of industry promotion to gradually overcome the core fuel cell technology problems and reduce the purchase cost of fuel cell vehicles. Meanwhile, a large-scale and low-cost hydrogen energy supply system can be established and the hydrogen energy infrastructure layout can be improved, reducing the price of hydrogen and improving the filling convenience. In combination with the development status of China's hydrogen energy industry, it is expected that fuel cell heavy-duty trucks can be commercialized within the next 5–10 years and will gradually replace traditional-fuel trucks on the market.

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