

Clean Hydrogen and Fuel Cell Vehicles

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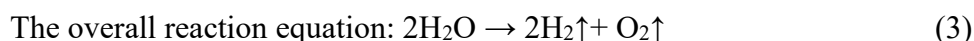
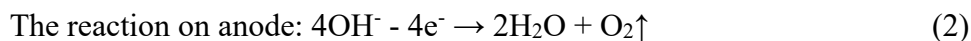
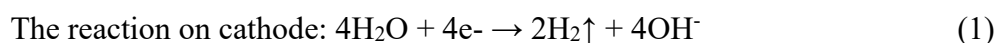
Abstract. In this paper, a comprehensive synthesis of salient points from pertinent literature in the field is presented, accompanied by an analytical review of extant experimental data. The mechanisms underlying the utilization of green hydrogen in fuel cell vehicles are meticulously dissected from the perspectives of hydrogen production, storage, and utilization. An in-depth investigation into the energy conversion efficiency within the hydrogen production phase is conducted, as well as an examination of the energy conversion efficiency when utilizing green hydrogen as a fuel within fuel cell vehicles. Moreover, the article provides an informative overview of the fundamental attributes and performance metrics of fuel cell vehicles. It conducts a comparative analysis against traditional internal combustion engine vehicles, considering variables such as safety profiles, refueling duration, fuel mass, and fuel cost implications. The advantages of deploying fuel cell vehicles are analyzed, elucidating their benefits. Conversely, the article also enumerates the shortcomings and current bottlenecks faced by fuel cell vehicles, offering a critical view of their current limitations. Furthermore, the study delves into prevalent methods for green hydrogen production, positioning green hydrogen as a viable solution to the current challenges of carbon neutrality. The article culminates by suggesting the role of green hydrogen in spearheading future low-carbon development initiatives, thereby delineating a prospective roadmap for sustainable energy advancement.

Keywords: green hydrogen, fuel cell vehicles, fuel vehicles.

1. Working Mechanism

1.1. The production of green and blue hydrogen

In order to enhance the environmental protection characteristics of fuel cell vehicles, this article only studies the use of clean hydrogen in fuel cell vehicles. The clean hydrogen is green and blue hydrogen, respectively. Green hydrogen is produced using the method of electrolysis of water, and the electricity used for the electrolysis of water is produced from renewable energy. In this way, no carbon-containing compounds are produced in the process of producing hydrogen [1]. Energized in pure water without the addition of electrolyte, the anode of the battery produces oxygen and the cathode produces hydrogen, which is dehydrated by a desiccant to obtain dry pure hydrogen.



Blue hydrogen is more common than green hydrogen, and its production process is less environmentally friendly. Blue hydrogen is produced from fossil fuels, and carbon capture is used to reduce carbon emissions in the hydrogen production process, making it a relatively clean hydrogen. Common carbon capture technologies are carbon capture storage (CCS) and carbon capture utilization (CCU) [2].

1.2. Components of fuel cell vehicles and principles of power generation

The important parts of fuel cell vehicles are hydrogen fuel tank, power electronic controller, DC converter and electric traction motor. Hydrogen is usually stored in a fuel tank in a liquid state, and it reacts in the Fuel Cell Stack to generate electricity, which is stored in a battery pack at the rear of the vehicle. Then, the electrical energy stored in the battery is converted to the appropriate voltage by

the DC/DC converter, which in turn powers the electric motor. Subsequently, the electric motor transforms this electrical energy into mechanical energy, propelling the car forward.

The basic power generation principle of fuel cells is that hydrogen is dissociated into hydrogen ions and electrons at the anode of the battery, and the hydrogen ions move through the electrolyte layer of the fuel cell to the cathode, while the electrons cannot pass through the electrolyte layer, but can only form an external circuit to flow to the cathode. Oxygen dissociates at the anode into oxygen atoms, which combine with external electrons and hydrogen ions to form water and produce electricity.

1.3. Components of fuel cell vehicles and principles of power generation

At present, the prevalent methods of hydrogen storage primarily encompass three types, storing hydrogen in high-pressure steel cylinders is likely the most common approach to hydrogen storage. However, for transport and stationary applications, the amount of hydrogen that can reasonably be stored is small. Even at very high pressures, this technique suffers from the problem of low bulk density and is inferior in energy intensity to gasoline under the same conditions. Despite the fact that the storage capacity of liquid hydrogen significantly surpasses that of high-pressure hydrogen storage by a factor of two, the volumetric storage capacity of liquid hydrogen remains relatively limited in practical applications when it comes to meeting half of the power requirement standards set by the United States Department of Energy (DOE). This indicates that there is still room for further improvement in terms of energy density and volumetric efficiency. When considering methods for hydrogen storage, we must confront the high costs associated with the storage of liquid hydrogen, as well as the safety challenges involved. These include the dangers related to the handling of low-temperature storage tanks and potential losses due to hydrogen evaporation. Amid these challenges, the storage of hydrogen in solid form, particularly through the formation of metal hydrides, has emerged as an attractive field of research. This technology offers significant potential for increasing storage efficiency and ensuring safety. It not only enhances the storage density of hydrogen but also reduces safety risks, representing an important approach to the safe and efficient utilization of hydrogen energy. The technology under consideration is distinguished by its extensive scale and its insusceptibility to the limitations typically linked with liquid hydrogen. Solid-state hydrogen storage leverages the distinctive characteristics of a spectrum of metals renowned for their hydrogen adsorption capabilities, attributed to the metals' intrinsic capacity to incorporate hydrogen atoms within their crystalline lattice frameworks. Furthermore, in light of the comparatively modest operational pressures necessitated, solid-state hydrogen storage is posited as a comparatively more secure option, attenuating the perils concomitant with high-pressure systems and bolstering the safety paradigm of hydrogen storage modalities. [3].

1.4. Energy conversion efficiency

The energy conversion efficiency of hydrogen as a clean energy source is not a constant value but varies with the different methods of hydrogen production. The level of this conversion efficiency is contingent not only on the specific technologies employed for hydrogen generation but is also directly influenced by the environmental sustainability performance of these production methods. Among the plethora of technologies for hydrogen production, coal gasification stands as a traditional method, typically utilizing coal as a feedstock. In the course of producing what is termed "black hydrogen," the emission of harmful gases such as carbon monoxide and methane is an inevitable consequence. When hydrogen is produced via coal gasification, the associated carbon dioxide emissions can reach as high as 157 kg CO₂/GJ, and this figure can rise to 170 kg CO₂/GJ when lignite is used as the raw material. This undoubtedly imposes a significant environmental cost in comparison to cleaner hydrogen production methodologies [4]. The efficiency of producing hydrogen from natural gas is around 65%-80%, At the same time, for every kilogram of hydrogen produced, there will be 9,066 grams to 10,728 grams of carbon dioxide [5]. The efficiency of producing hydrogen from coal as a feedstock is 50%-80%, and 24.2 kg of CO₂ is emitted for every kilogram of hydrogen produced [6].

2. Comparison of common cars and FCEVs

2.1. Common information

Common types of cars include those powered by electric energy as well as those fueled by traditional fossil fuels (gasoline, diesel). By comparing four different electric vehicles and fuel cell vehicles, they are: ICEVs, PHEVs and two kinds of FCEVs. ICEVs have the lightest batteries, while fuel cell vehicles 2 and PHEVs have comparatively heavier batteries. But the fuel cell car 2 is the safest, and it usually has a probability of no explosion. Fuel cell vehicles are characterized by a short charging time, which basically only takes 3-5 minutes, and FCEV2 even only takes 1 minute. But for electric vehicles, the charging time is basically 5 hours. In the case of the same range, fuel cell vehicles have the advantage of convenience. In terms of fuel prices, hydrogen and electricity are cheaper than conventional fuel vehicles. Among them, hydrogen is cheaper than electricity, and the price of hydrogen is about USD0.0024 (for a car with a tank of 5 L), the price of electric energy is about USD3.6/MJ [7]. The detailed comparison of common cars and FCEVs are summarized in Table 1.

Table 1. Comparison of common cars and FCEVs

Type of vehicles	ICEV	PHEV	HFCV1	HFCV2
Security	Explosion limit 1.2-7.1%	Battery explosion	Explosion limit 4-75%	No explosion limit
Time used to charge	3-5min	5h	3-5min	Less than 1min
Fuel weight	Light	Heavy	Medium	Heavy
Price	0.045USD/unit	3.6USD/unit	0.0024USD/unit	0.0048USD/unit

2.2. Performance and life of FCEVs

Since the fuel of FCEVs needs to be stored in a high-pressure and low-temperature environment, such storage conditions will deplete the durability of the fuel tank [8]. When fuel cell vehicles use magnesium-based hydrogen to store fuel, the cycle life of the fuel tank is more than 1,000 times, and the purity of the fuel is 99.99% [9]. When the cycle life of the tank decreases, the probability of gas leakage and explosion increases. For fuel cell vehicles, in order to increase the range, there is no need to increase the weight of the battery like electric vehicles, which leads to load problems and safety issues on the chassis. In general, fuel cell vehicles only need to increase the fuel space to increase the range to 600 kilometers [10].

3. Advantages and disadvantages

3.1. Advantages

One of the advantages of FCEVs when using hydrogen as a fuel is that greenhouse gas emissions such as carbon dioxide, carbon monoxide, and sulfur dioxide can be reduced by using clean hydrogen. This is because the method of producing hydrogen does not produce greenhouse gases. And, in the case of using hydrogen as fuel, only water will be produced as a product [11]. One of the advantages of FCEVs is the price advantage of FCEVs, with the price of hydrogen in 2020 ranging from 1 to 6.8 USD/kg compared to conventional combustion engine vehicles (the price varies depending on the type of hydrogen used) [12]. During the same timeframe, gasoline was priced at \$1.01 per liter. In terms of energy yield, hydrogen proves to be a substantially more cost-effective option compared to gasoline. Additionally, hydrogen serves as a highly efficient energy carrier, facilitating the shift towards sustainable energy systems and harmonizing the use of renewable resources [13]. Hydrogen, as a versatile energy carrier, extends its utility beyond mere fuel to encompass the production of chemicals, transportation, construction, and food processing industries. As a low-carbon energy

source, the application of hydrogen technology in the transportation sector promises to substantially enhance air quality and reduce urban noise pollution, particularly within the realm of fuel cell vehicles where hydrogen utilization ensures high efficiency in power conversion and has now reached the stage of commercial operation. Furthermore, hydrogen serves as a raw material for residential heating or as an alternative reserve fuel to traditional natural gas or coal gas. Given the construction industry's heavy reliance on fossil fuels, the adoption of hydrogen as a clean, renewable energy source is poised to mitigate environmental degradation. In the chemical industry, hydrogen is an indispensable raw material for the production of ammonia and in the refining of petroleum, with ammonia being a crucial ingredient in the manufacture of fertilizers and the significance of petroleum in daily life being self-evident [14].

3.2. Drawbacks

The biggest disadvantage of clean hydrogen is that it is expensive, with green hydrogen typically costing six times more than grey hydrogen [15]. Because hydrogen does not exist in nature, the production and preparation of hydrogen require other fuels to provide energy, and the use of these fuels will increase the carbon produced in the process of hydrogen preparation, to purify such gray hydrogen, it will be necessary to increase the cost and carbon neutrality will be generated. Or use the more expensive way to prepare hydrogen. So the price of using clean hydrogen has always been one of its drawbacks. The popularity of hydrogen in daily life is significantly lower than that of other fuels. In developing countries, the number of gas stations, gas stations and charging stations in cities is significantly higher than that of hydrogen refueling stations [16]. For fuel cell vehicles, less charging time is an advantage, but it can be difficult to find a place to supply fuel. This is very detrimental to the development of fuel cell vehicles and clean hydrogen.

3.3. Bottleneck issues

The challenge for hydrogen to overcome is how to store and transport it efficiently. The difficulties in the storage of hydrogen should be solved. Firstly, hydrogen has a low density, close to 1/10,000 of the density of water at room temperature, and is stored at 70 g/L at absolute zero. Secondly, the atomic radius of hydrogen is small, which requires high airtightness of the storage container. Finally, hydrogen is chemically active and prone to chemical reactions. Moreover, the construction of the aforementioned infrastructure serves not only as a pivotal element in advancing the development of clean hydrogen energy and fuel cell vehicles but also emerges as a significant bottleneck within their developmental trajectory. The inadequacy of infrastructure has led to a pronounced deceleration in the commercialization process of clean hydrogen energy and fuel cell vehicles. This sluggish progress has, in turn, dampened the enthusiasm of corporations and research institutions in pursuing research and development efforts. Furthermore, it has adversely affected the widespread adoption and market acceptance of fuel cell vehicles, thereby impeding the healthy evolution of the entire industry [17].

4. Conclusion

In order to control the greenhouse effect, it is inevitable to use green energy to replace traditional fossil fuels. Green hydrogen, as a renewable green energy, should receive more attention. The current development of hydrogen is facing the bottleneck problem of hydrogen storage difficulties. Secondly, as a fuel cell vehicle that uses hydrogen as fuel, its development is based on the advancement of hydrogen storage technology and the construction of infrastructure. For future technological progress, cleaner cars will gradually replace heavily polluting cars. FCEVs have a good prospect, and hydrogen will become a mainstream energy type in the future.

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