Comparison of Hydrogen Fuel Cell Vehicles and Electric Vehicles in Terms of Range, Lifespan, and Refueling Methods

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Abstract: With the increasing emissions of greenhouse gases, air pollution has become a more serious issue. To address environmental problems,morecountries are developing hydrogen fuel cell vehicles and electric vehicles, as these new energy vehicles have the potential to achieve zero emissions compared to traditional fuel vehicles. The electric vehicle market has matured over time, and many European countries and the U.S. have begun experimenting with and using hydrogen fuel cell vehicles. Although both types of vehicles are powered by electricity, there are significant differences in their structures, energy storage methods, and energy production processes. This paper will discuss the advantages of hydrogen fuel cell vehicles over electric vehicles. Compared to electric vehicles, hydrogen fuel cell vehicles offer longer range, faster refueling, and greater lifespan. The paper will provide a detailed comparison of the two types of vehicles in these three aspects.

Keywords: Hydrogen Fuel Cell Vehicles; Pure Electric Vehicles; Range Lifespan Refueling Methods

1. Introduction

As air pollution worsens and the return on investment for fossil fuel resources declines, many countries are focusing on developing electric and hydrogen fuel cell vehicles to mitigate greenhouse gas emissions and reduce fossil fuel use. These vehicles have the potential to eliminate greenhouse gas emissions from energy production to final emissions compared to conventional fuel vehicles. Electric vehicles have been developed since the early 20th century and have become more widespread by the 21st century. In 2020, despite the pandemic, global sales of plug-in electric vehicles were approximately 3.1 million, accounting for 4.2% of total light vehicle sales, compared to 2.2 million in 2019. At the same time, the hydrogen fuel cell vehicle industry has also begun to emerge, with the U.S. starting significant investment in hydrogen vehicle development in 2003. China also began investing in the hydrogen industry from 2005. Although hydrogen fuel cell vehicles are newer, they possess certain advantages and greater development potential compared to electric vehicles.

Both electric and hydrogen fuel cell vehicles are powered by electricity, but they differ in energy storage methods. Hydrogen fuel cell vehicles store energy in the form of hydrogen gas, which is then converted into electricity by fuel cells, typically proton exchange membrane (PEM) cells or alkaline fuel cells. Electric vehicles, on the other hand, mainly use batteries for energy storage, such as lead-acid batteries, graphene batteries, or lithium-ion batteries, with lithium-ion batteries being the most common but also having several drawbacks. Despite their own limitations, fuel cells have strong future competitive potential against lithium-ion battery electric vehicles and offer several advantages.

The first section will compare the range of hydrogen fuel cell vehicles and pure electric vehicles. The second section will compare their refueling methods and costs. The third section will compare their lifespans and reasons. The fourth section will compare the suitability of these two types of light vehicles for different user groups.

2. Range

2.1 Comparison of Range between Hydrogen Fuel Cell Vehicles and Electric Vehicles

In comparable models, hydrogen fuel cell vehicles generally have an advantage in range. For instance, the Tesla Model S Plaid offers a range of 359 miles, while the BMW iX5 has a range of 504 km, and the Mirai series has a minimum range of 357 miles [1]. This advantage is even more pronounced for larger vehicles. For example, electric large vehicles typically have a range of 100 to 200 kilometers, with lithium-ion battery electric buses having ranges between 136 and 193 miles. While Tesla claims its trucks can travel 800 kilometers on a single charge, these trucks require substantial power, with batteries weighing up to 12,000 pounds. In contrast, large hydrogen fuel cell vehicles can achieve ranges over 800 kilometers [2]. Hydrogen fuel cell vehicles with 600-bar hydrogen tanks can reach a range of 500 to 670 miles.

2.2 Reasons for Range Differences between Hydrogen Fuel Cell Vehicles and Electric Vehicles

The differences in range are significantly influenced by the energy storage methods used by the two types of vehicles. The choice of storage method affects the vehicle's weight, which in turn impacts range. For example, comparing the Toyota Mirai hydrogen fuel cell vehicle (maximum weight 4,335 pounds, length 195.8 inches, width 74.2 inches, height 57.9 inches) with the Tesla Model S electric vehicle (lightest at 4,561 pounds, length around 195 inches, width around 77 inches, height around 56 inches), electric vehicles rely on lithium-ion batteries for energy storage, while hydrogen fuel cell vehicles use hydrogen gas. Hydrogen has a high energy density, approximately 34 kWh/kg [3], nearly three times higher than diesel, making it an efficient energy source. Typically, a hydrogen fuel cell vehicle can store 5 kilograms of hydrogen, equating to nearly 17,000 kWh of energy. To achieve longer ranges, hydrogen storage tanks can be increased in volume or pressure, which is relatively cost-effective. In comparison, lithium-ion batteries have an energy density of 110-160 Wh/kg, significantly lower than gasoline or hydrogen, necessitating heavier batteries for electric vehicles. This battery weight constitutes a significant portion of the vehicle's overall weight, especially noticeable in larger vehicles, affecting both range and payload capacity. Additionally, battery weight does not decrease with distance as hydrogen or traditional fuels do, remaining a constant load. Hydrogen combines with oxygen to form water, reducing vehicle weight, whereas battery charging and discharging involve only the movement of electrons (lithium-ion batteries), with minimal impact on mass. Furthermore, self-discharge in batteries reduces their lifespan and range, with most lithium-ion batteries having a self-discharge rate of 1-2% per month, a problem not present in hydrogen fuel cell vehicles. Thus, the different characteristics of energy storage methods significantly influence the range, giving hydrogen fuel cell vehicles an advantage over electric vehicles.

3. Energy Storage and Refueling

3.1 Comparison of Refueling Methods for Electric Vehicles and Hydrogen Fuel Cell Vehicles

Hydrogen fuel cell vehicles typically refuel by pumping compressed or liquefied hydrogen into tanks. According to official data from Toyota, Honda, Hyundai, and BMW, refueling hydrogen takes less than 6 minutes on average (Mirai 3 to 5 minutes, BMW iX5 3 to 4 minutes), comparable to traditional fuel vehicles. However, hydrogen fuel cell vehicles face challenges due to the flammable and explosive nature of hydrogen, as well as issues with storage and transportation. Despite this, hydrogen's small molecular size allows for high dispersion, making it relatively safe even in accidents where hydrogen can be rapidly released without severe explosions. In contrast, electric vehicles have more flexible refueling locations, with the ability to install charging stations in garages or homes, but this puts significant pressure on city power grids. Rapid and excessive charging can cause irreversible damage to the battery, resulting in longer refueling times compared to hydrogen fuel cell vehicles. Moreover, varying charging interfaces, voltages, and the rusting or aging of charging connectors can complicate the refueling process for electric vehicles. Hydrogen fuel cell vehicles require a well-established hydrogen transport system, which can involve pipelines similar to those for natural gas or the use of large trucks for compressed hydrogen transport.

3.2 Comparison of Refueling Costs between Hydrogen Fuel Cell Vehicles and Electric Vehicles

Currently, electric vehicles are more cost-effective in terms of refueling prices. However, hydrogen fuel cell vehicles may become competitive with both traditional fuel vehicles and electric vehicles in the future. The cost of refueling electric vehicles varies significantly based on location, policy, and vehicle model. In the U.S., the average cost to charge a pure electric vehicle from empty to full is \$10.78[4]. Hydrogen fuel, on the other hand, is more expensive. Producing hydrogen using polymer electrolyte membrane (PEM) electrolyzers costs about \$5 to \$6 per kilogram of H_2(2020). Hydrogen fuel cell vehicles generally store 5 kilograms of hydrogen, making a single refueling cost over \$25. However, according to the HDSAM model, the price of compressed and liquid hydrogen in the U.S. is expected to decrease to \$4 per kilogram by 2025[5]. Although compressing and cooling hydrogen incurs additional costs, these costs are not significant for light vehicles. Despite the current higher refueling costs, hydrogen fuel cell vehicles may become competitive with traditional fuel vehicles in the future, especially if their prices decrease.

3.3 Environmental Impact of Energy Sources

Neither hydrogen fuel cell vehicles nor electric vehicles produce greenhouse gases during operation; their environmental impact primarily arises from energy production and vehicle manufacturing. Hydrogen production is categorized into "gray hydrogen" and "green hydrogen." "Green hydrogen" is produced through the electrolysis of water using renewable electricity. Currently, most hydrogen is produced as "gray hydrogen," through steam methane reforming, which emits about 13.2 kg of CO_2 per kilogram of hydrogen. Despite this, hydrogen's high energy density results in a CO_2 emission factor of approximately 0.3882 kg CO_2/kWh, compared to "green hydrogen," which emits about 0.02059 kg CO_2/kWh. The greenhouse gas emissions from electricity generation depend on the energy mix of different countries or regions. Coal-based power generation accounts for 41% of global electricity production, meaning electric vehicles can still contribute to air pollution. In fossil fuel-dominated countries like Germany, the CO_2 emission factor is 0.4408 kg CO_2/kWh, while in countries with a focus on renewable energy, such as Austria, the CO_2 emission factor is 0.0851 kg CO_2eq/kWh[6]. The average CO_2 emission factor for the EU's 28 member states is 0.2958 kg CO_2/kWh. It is evident that vehicles powered by "gray hydrogen" emit more CO_2 than electric vehicles or even diesel vehicles. However, advancements in electrolysis technology and the widespread adoption of "green hydrogen" could significantly reduce CO_2 emissions.

4. Lifespan

4.1 Comparison of Lifespan Between Electric Vehicles and Hydrogen Fuel Cell Vehicles

Due to the relatively short development history of hydrogen fuel cell vehicles, there is limited data on their lifespan. However, data from hydrogen fuel cell vehicles like the Toyota Mirai and BMW ix5 suggest a lifespan of approximately eight years or 100,000 miles . Many passenger vehicle manufacturers aim for a fuel cell stack lifespan of at least 5,000 hours, which translates to about 150,000-200,000 miles. In heavy-duty vehicles, many bus fuel cell stacks have already reached lifespans of 20,000 hours or more, with a goal of reaching 30,000 hours by 2030 .

In contrast, for electric vehicles, manufacturers often advertise a lifespan of over 10 years. However, due to battery degradation, the practical lifespan of electric vehicles can be shorter. According to data from MOT, the median lifespan of electric vehicles, assuming battery replacement, is around 18 years with a total mileage of approximately 120,000 miles [7]. Without battery replacement, most electric vehicles typically last between 8 to 10 years. Electric buses generally have a lifespan of 10 to 12 years. Hence, the lifespan of electric vehicles is significantly affected by battery longevity, which generally tends to be limited.

4.2 Reasons for Short Battery Lifespan

The battery is a critical component of most electric vehicles, influencing both their value and technological core. The battery not only constitutes a significant portion of the vehicle's weight but also serves as the primary energy storage. Compared to other vehicle components, the battery has more stringent operational conditions. Electric vehicles predominantly use lithium-ion batteries, which have several drawbacks, with battery degradation being a primary concern. Once a lithium-ion battery is in use, it begins to age. Battery degradation can manifest as a decrease in power and capacity. The main factors contributing to lithium-ion battery aging include electrolyte loss, reduction in lithium inventory, and degradation of active materials. These issues are influenced by temperature, depth of discharge, and charging current.

Temperature affects battery capacity, with low temperatures causing a decrease and moderate heating increasing capacity at the expense of battery lifespan. High discharge currents accelerate battery degradation, while fast charging rates also damage battery capacity. Charging batteries quickly in low temperatures exacerbates this issue. Additionally, the depth of discharge, which is the ratio of the discharged capacity to the battery's rated capacity, impacts battery lifespan. Generally, fewer deep discharge cycles lead to a greater number of charge-discharge cycles. These are challenges that currently cannot be fully addressed in electric vehicle batteries.

5. Impact of Hydrogen Fuel Cell Vehicles VS. Electric Vehicles on Different User Groups

5.1 Commercial Vehicles

In the realm of light-duty vehicles, the most common types are commuter cars and taxis, with varying needs for each. Taxis and ride-hailing services represent typical light-duty public transport vehicles. Both types have similar daily mileage requirements, though there are significant differences based on region. In rural areas, light-duty public transportation is scarce and therefore not considered here. For example, in Shenzhen, the average daily mileage for taxis is around 384 kilometers.

Electric taxis have become popular in some major cities as part of the push towards electrification. To maximize profitability, these vehicles are designed to have lower costs, shorter range, and reduced lifespan. Taxi drivers typically need to charge their vehicles once or twice a day, though the charging process does not always require a full charge. Charging to 80% takes approximately 40 minutes, and the cost of charging varies by region and policy. In China, the average electricity price is \$0.1082/kWh, while hydrogen costs around \$0.147/kWh, though this can be lower with supportive policies. Electric taxi drivers earn about 45 yuan per hour. If they spend nearly an hour daily charging, this results in an annual cost of about 15,750 yuan. This issue is exacerbated in winter, especially in northern regions. Cold weather significantly reduces battery capacity (20% reduction when the operating temperature drops from 45°C to 20°C), leading to shorter ranges and requiring more frequent charging, which is economically unfeasible for taxi drivers.

For hydrogen fuel cell vehicles to enter the taxi market, the cost of hydrogen vehicles must be reduced, as current prices are two to three times higher than electric vehicles. Despite their longer lifespan and greater range, hydrogen vehicles are not cost-effective for taxi companies. Additionally, a network of hydrogen refueling stations and pipelines needs to be developed, which is costly compared to electric charging stations and requires substantial government investment. This may be particularly unfeasible in economically less developed regions. Northern, colder areas might be suitable as hydrogen fuel cells are less affected by temperature, avoiding the frequent and time-consuming charging issues faced in colder climates.

In the realm of heavy-duty vehicles, such as buses and freight trucks with a gross vehicle weight greater than 8,501 pounds, hydrogen fuel cell vehicles have notable advantages over electric vehicles. Electric vehicles are limited by battery weight, reducing their payload capacity compared to hydrogen fuel cell vehicles. Even with advances in battery technology over the next decade, the maximum cargo capacity of pure electric trucks is expected to be only about 5% of that of fuel cell electric vehicles (FCEVs) or internal combustion engine vehicles. The advantage of hydrogen fuel cell vehicles becomes even more apparent in heavier vehicles, where their higher payload capacity is beneficial. Furthermore, in terms of range, heavy-duty hydrogen fuel cell vehicles outperform electric vehicles with similar payloads. Electric long-haul buses and freight trucks face significant limitations due to the time-consuming nature of recharging. However, hydrogen fuel cell vehicles are still expensive, though their competitiveness will improve as prices decrease.

5.2 Family Vehicles

For commuter cars, the average daily driving distance for American drivers is around 29 miles, with most using small sedans. For urban residents who frequently drive short distances, electric vehicles may be more advantageous due to their lower purchase price and cheaper electricity costs. Additionally, electric vehicles generally offer better acceleration over 100 kilometers compared to hydrogen fuel cell vehicles, making them more suitable for city driving with complex traffic and numerous traffic lights. However, for those who frequently take long trips or live in colder regions, hydrogen fuel cell vehicles might be more appropriate. Hydrogen vehicles are less affected by weather conditions, and extreme temperature fluctuations exacerbate battery aging in electric vehicles. For infrequent drivers, prolonged periods of inactivity can lead to battery self-discharge, which accelerates aging and significantly reduces the vehicle's lifespan. In this regard, hydrogen fuel cell vehicles have an advantage.

6. Conclusion

As global warming and rising energy prices become increasingly pressing issues, reducing greenhouse gas emissions and managing non-renewable resources are crucial. New energy vehicles, capable of achieving zero emissions from production to use, are gaining attention worldwide and include electric and hydrogen fuel cell vehicles. However, both hydrogen and electricity production still largely rely on fossil fuels in many countries, which negatively impacts the environment. Nonetheless, advancements in electrolytic hydrogen production will improve environmental outcomes. Hydrogen fuel cell vehicles may be more suitable for northern regions (temperate continental climates) and heavy-duty applications, while electric vehicles are better suited for urban residents who drive frequently. Despite the later development of hydrogen fuel cell technology compared to electric vehicles, increased investment from governments and companies will likely lead to widespread adoption. As market competition drives down hydrogen prices, hydrogen fuel cell vehicles will soon be able to compete effectively with gasoline and electric vehicles.

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