Bulletin of Materials Science & Metallurgy

Periodical Scientific Journal of UCTEA Chamber of Metallurgical and Materials Engineers

Volume 2, Issue 1, 2025, Pages 1-5 Received: 21 October 2024 Accepted: 18 October 2025

https://doi.org/10.70342/YCIN5024

Review Article

The Importance of Green Transport Today: Time for Hydrogen Buses

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Abstract

New technologies are being developed to reduce CO_2 emissions due to climate change and increasingly stringent sustainability standards, which are prominent both globally and nationally. In response, the automotive sector has begun transitioning from diesel buses to electric buses (E-buses), and more recently to hydrogen-powered buses (H-buses). Many public transport companies have already completed pilot projects involving hydrogen fuel cell buses (FCEBs), signaling growing confidence in this emerging technology. This paper aims to present the technical, environmental, and economic prospects of hydrogen fuel cell buses. It investigates the necessary steps and potential challenges in achieving carbon neutrality within the competitive bus transportation market. Expectations and obstacles related to fuel cell vehicles have been identified. As the use of renewable energy becomes better integrated into buses, interest in this area has grown. A key advantage is their lower CO_2 emissions compared to diesel buses. Although the technology may seem immature, hydrogen buses are expected to reduce CO_2 emissions by 93% compared to diesel buses. Despite their environmental benefits, hydrogen buses face economic challenges. Notably, their initial investment cost is approximately 40% higher than that of diesel buses. However, ongoing technological advancements and increased R&D efforts are expected to reduce this cost disparity over time. With the right policy support and infrastructure investment, hydrogen buses have strong potential to play a leading role in the decarbonization of public transportation.

Keywords

CO_2 emission, Energy efficiency, Green transport, Hydrogen bus, Sustainability

1. Introduction

In urban settings, private car usage is a major contributor to overall carbon emissions, while public transport is widely regarded as a more environmentally sustainable mode of travel. Developed countries have long made significant improvements in improving air quality in densely populated cities. They advocate for the use of alternative energy sources in transportation as a way to reduce air pollution, particularly emphasizing the use of electric buses powered by hydrogen fuel cells as a significant factor in achieving air quality and pollution reduction goals [1].

With the Paris Agreement, the goal is set to keep global warming below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels within this century. Furthermore, to achieve these goals, it is desired that greenhouse gas emissions reach optimum levels and decrease as rapidly as possible [2]. Considering the conditions of the Paris Agreement, fuel cell electric buses (FCEBs) are anticipated to offer numerous operational, environmental, and economic benefits compared to traditional diesel or diesel hybrid buses. These buses operate with significant reductions in greenhouse gas emissions, without any local emissions, less noise, and with performance, range, and route flexibility [3].

As part of its commitment to the goals of the Paris Agreement, the United Kingdom believed that more emphasis should be placed on decarbonizing public transportation and moving away from conventional fuel vehicles (CFVs) and electric vehicles (EVs) in personal transportation. They were of the opinion that electric buses (EBs) and hydrogen buses (HBs), powered by low-carbon renewable energy sources, have the potential to meet all requirements. A comparison of carbon dioxide (CO_2) emissions produced by conventional fuel buses (CFBs), EBs, and HBs between 2017 and 2050 was conducted. Emissions per person for CFBs, HBs, EBs, and personal transportation at different vehicle capacity levels (100%, 75%, 50%, and 25%) were estimated assuming a maximum of 80 passengers per bus and four passengers per personal vehicle. The results indicated that by 2050, conventional fuel buses would produce 16.3 gCO_2 km-1 per person compared to 30 gCO_2 km-1 per person for conventional fuel vehicles. Considering all these scenarios, at 100% capacity, it was concluded that by 2050, emissions from conventional fuel buses would be 36 times higher than electric buses, 9 times higher than hydrogen buses, and 12 times higher than electric vehicles. Cumulative emissions under all electric scenarios remained lower for EBs and HBs by 2050 [4].

Electric buses are powered by a lithium-ion battery charged with electricity [5]. However, if the electricity is generated from fossil fuels, the environmental benefits will be reduced [6, 7]. Hydrogen buses, on the other hand, are powered by fuel cells that convert hydrogen (H_2) into electricity and emit water vapor as a byproduct [5]. H_2 is chemically produced by splitting water into oxygen and H_2 using electricity or by converting carbon monoxide with methane into H_2, as a byproduct. Additionally, using H_2 as a fuel for buses with fuel cell propulsion systems will provide an opportunity for a sustainable alternative by allowing the replacement of mineral oils [8]. The transition to an H_2 energy system will likely rely on electrolysis supported by the National Grid, which may involve a mixture including H_2 derived from natural gas or fossil fuel-powered plants. Similar to EBs, it is believed that if H_2 is produced from fossil fuels, there will be no advantage in transitioning from conventional fuel buses unless carbon emissions can be indefinitely isolated as an inert chemical or in a geological repository [1]. Comparison of the properties of hydrogen and diesel fuel is given in Table 1. In Figure 1, the types of fuel used are classified according to vehicle types.

Table 1. Properties of hydrogen and diesel fuel [9].

Property	Diesel Fuel	Hydrogen
Moleculer weight, [kg/kmol]	226	2.016
Density at 0°C, 760 mmHg, [kg/m³]	820-860	0.0899
Ignition limits in air, at 20°C, 760 mmHg, % vol	0.7-5	4.1-75.6
Ignition limits in air, at 20°C, 760 mmHg, Λi..λs	0.34..1.68	0.136..10.12
Heat of vaporization [kJ/kg]	250-314	458.1
Boiling temperature, °C, la 101300 Pa	180-359	-253
Diffusivity in air, cm²/s	0.038	0.63
Energy Density at 15°C, 100kPa, MJ/m³	35.8	10.3

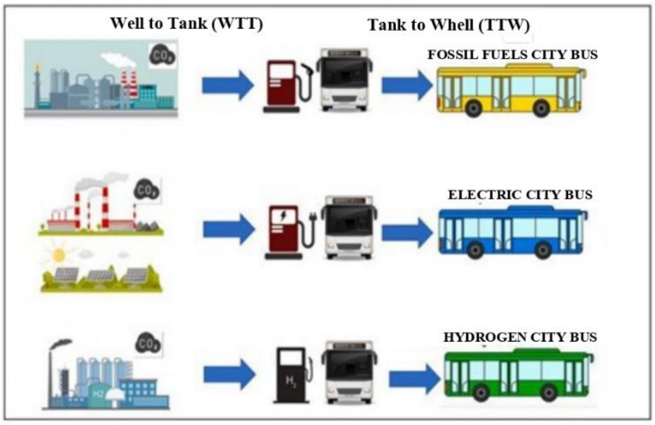

Figure 1. Fuel types used according to vehicle types [10].

For any new technology to enter the market and be used, acceptance is crucial. Failure in marketing and acceptance of the product can lead to inadequate adoption of the technology or even resistance or opposition to it [11]. Among experts in hydrogen technology, the widespread perception that the public may reject new H_2 technologies due to associations with the 1937 Hindenburg disaster or 'hydrogen' bomb has been considered [12, 13]. The importance of determining the acceptability of hydrogen-fueled transportation by the public and engaging the public in discussions about the future of hydrogen transportation has been addressed and debated with numerous documents [14, 15]. Hydrogen (H_2) buses are being tested in selected cities worldwide, providing practical experience in their operation, maintenance, and the development and operation of relevant H_2 fueling infrastructure [16].

While public transportation is generally cleaner and cheaper than driving cars, there are compelling factors to consider in the choice, especially in large cities like those in South America. Despite the low costs of internal combustion engine vehicles, the high acquisition cost of zero-emission vehicles slows down the entry of electric vehicles and fuel cell hydrogen vehicles into the market. This situation is even more pronounced in South America, where the entry of electric vehicles into the market is very low. In 2018, there were 250 electric vehicles and 680 plug-in hybrid electric vehicles in stock in Chile and Brazil, representing less than 0.03% of the global stock of 3 million [17].

2. Evaluation of Hydrogen

Hydrogen vehicles represent a promising advancement in the quest for sustainable and environmentally friendly transportation solutions. Unlike conventional gasoline-powered cars, hydrogen vehicles utilize a fuel cell to convert hydrogen gas into electricity, emitting only water vapor as a byproduct. This innovative technology offers the potential for zero-emission driving while providing the convenience of quick refueling and extended driving ranges. As the world increasingly shifts towards reducing carbon footprints and combating climate change, hydrogen vehicles emerge as a viable and attractive option for the future of mobility. However, several challenges remain before full cell electric vehicles can achieve widespread adoption. The primary issue is the limited hydrogen refueling infrastructure, with only a few stations available in India, restricting the range and usability of these vehicles. Additionally, hydrogen production and storage costs are currently higher than traditional fuels, though this is expected to improve as the technology advances [18].

Components required for a hydrogen vehicle;

Hydrogen Storage Tank: It safely contains the hydrogen fuel until it is needed for energy conversion in the fuel cell.

Fuel Filler: The nozzle from a fuel dispenser connects to the vehicle's receptacle to fill the tank

Fuel Cell Stack: The core component where hydrogen reacts with oxygen to produce electricity.

Battery(auxiliary): In an electric vehicle, the low-voltage auxiliary battery starts the car and powers accessories before the traction battery engages

Battery Pack: It stores excess energy generated by the fuel cell and regenerative braking, providing additional power during high demand situations like acceleration.

Electric Motor: It converts electrical energy from the fuel cell and battery into mechanical energy to propel the vehicle.

Power Control Unit (PCU): It regulates the flow of electricity between the fuel cell, battery, and electric motor to ensure efficient operation.

Air Compressor: It ensures an adequate supply of oxygen to the fuel cell for the electrochemical reaction with hydrogen.

Cooling System: It manages the temperature of the fuel cell stack and other components to prevent overheating and maintain optimal performance.

Hydrogen Sensors: They detect any hydrogen leaks and alert the driver or initiate safety protocols to prevent accidents.

Regenerative Braking System: It converts kinetic energy back into electrical energy, which is then stored in the battery for later use.

Vehicle Control Unit (VCU); It coordinates the operation of all components, ensuring the vehicle operates efficiently and safely.

Inverters: They ensure the electric motor receives the correct type of electrical current to operate.

Within the fuel cell (FC) industry, five key market segments have been identified: portable, stationary, vehicle propulsion, fuel infrastructure, and auxiliary power units. Portable applications account for more than 50% of the market share, whereas stationary applications represent around 20%. Between 2003 and 2006, there was a 26% increase in R&D expenditures and a 36% increase in the number of workers across companies working on this subject. Between 2005 and 2008, there was a 4-fold increase in portable units. Large companies have produced or are in the R&D of different types of portable fuel cells, especially for military use, and are awaiting commercialization [19].

3. FCEVs vs BEVs

Hydrogen fuel cell vehicles (FCEVs) and battery electric vehicles (BEVs) each have their own set of advantages and disadvantages, depending on technological characteristics and infrastructure requirements. One of the main advantages of hydrogen vehicles is their shorter refueling time. Unlike electric vehicles that can take several hours to fully recharge, hydrogen vehicles can be refueled in just 3-5 minutes, similar to conventional gasoline vehicles. This makes them more convenient for long trips and commercial applications where downtime needs to be minimized [20].

FCEVs (Fuel Cell Electric Vehicles) operate similarly to BEVs but on hydrogen. A fuel cell is used for this. The vehicle has a special tank to hold pressurized hydrogen. The hydrogen is then passed through a fuel cell; It produces electricity by combining hydrogen and oxygen from the air using electrolysis to produce only H_2O as a byproduct, which charges a small capacity battery [21]. FCEVs have a clear advantage over other battery-powered vehicles as they do not need to be charged and can be charged in just a fraction of the time. The average fuel cell electric car can travel between 400 and 500 carbon-free miles.

However, hydrogen vehicles also face several challenges. The production, storage, and distribution infrastructure for hydrogen is currently underdeveloped and costly to build. In contrast, the infrastructure for charging electric vehicles is more widespread and continually expanding. Producing hydrogen, especially green hydrogen, is energy-intensive and expensive, making the overall cost of hydrogen vehicles higher. In terms of energy efficiency, hydrogen vehicles are generally less efficient than electric vehicles because of the energy losses that occur during hydrogen production, storage, and conversion back to electricity in the fuel cell. FCEVs weigh more than BEVs because they have 1-2 tanks and multiple fuel cells, which reduces the practicality of the vehicle [22]. Many automobile companies have begun to invest in hydrogen as an alternative fuel. However, production has been suspended due to the high cost of producing carbon-free hydrogen and transporting high-pressure hydrogen to fuel facilities [23].

Moreover, the technical challenges associated with hydrogen storage and transport are significant. Hydrogen needs to be stored at high pressures or at very low temperatures, both of which require advanced and expensive technology to ensure safety and efficiency. Despite these challenges, hydrogen vehicles hold great potential for reducing dependence on fossil fuels and lowering greenhouse gas emissions, especially in applications where electric vehicles might not be as practical.

4. Test standards for Hydrogen Buses

For hydrogen fueled vehicles, basic tests as well as ECE R134 Safety-related performance of hydrogen fuelled vehicles and 2021/535 Annex XIV - Hydrogen System Material Compatibility and Fuelling Receptacle regulations must be approved.

To give an example of a requirement also mentioned in the ECE R134 Regulation, all new compressed hydrogen storage systems for road vehicles must have a nominal working pressure of 70 MPa or less and a service life of 15 years or less [24].

Also as mentioned in the ECE R134 Regulation, The hydrogen storage system shall meet the performance test requirements specified in this paragraph. The qualification requirements for on-road service are:

-Verification tests for baseline metrics,

-Verification test for performance durability (hydraulic sequential tests),

-Verification test for expected on-road system performance (pneumatic sequential tests),

-Verification test for service terminating system performance in fire,

-Verification test for performance durability of primary closures [25].

To mention some of the obligations that must be made according to the 2021/535 Annex XIV regulation, in the case of hydrogen vehicles of M3, labels shall be installed on the front and rear of the vehicle, in the vicinity of the fueling receptacle and to the side of each door or set of doors [25].

5. Conclusion

Considering the type of fuel, hydrogen bus technology replaces new generation technologies with its environmental friendliness and low emissions. However, as can be understood from R&D studies, it has advantages and disadvantages compared to other electric and diesel vehicles.

Hydrogen vehicles also generally offer a longer driving range compared to many electric vehicles. It can generally travel 500-700 kilometers with a single hydrogen tank, which is especially advantageous in long-distance driving. Additionally, hydrogen fuel cells perform better in cold weather conditions compared to batteries, which will result in a loss of efficiency at low temperatures. This makes hydrogen vehicles a more reliable option in colder climates.

Another important advantage is its suitability for heavy-duty applications. Hydrogen vehicles are well-suited for heavy transport vehicles such as trucks, buses and other commercial vehicles due to their high energy density and rapid refueling capabilities. This has made them a promising option for industries requiring long-distance and heavy load transportation. High costs stand out as the biggest disadvantage in the production sector.

Authors' Contributions

Methodology: Songül Kılınç; Ferhat Ağaç; Nurşah Kübra Ekmekçi; Samet Onur Emir, Investigation: Songül Kılınç; Ferhat Ağaç; Nurşah Kübra Ekmekçi; Samet Onur Emir, Data curation: Songül Kılınç, Writing – original draft: Songül Kılınç, Writing – review and editing: Songül Kılınç, Project administration: Songül Kılınç

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