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Comparing the Feasibility of Electric vs. Hydrogen Fuel Cars in India

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Abstract

In the quest for absolute sustainability and to combat increasing greenhouse gas emissions over the world, India, the world's most populous country, whose vast road network is also primarily dominated by fossil-fuel-powered vehicles, can play a pivotal role by transitioning to more sustainable transportation alternatives. This research paper aims to address the question of which sustainable transportation option is more feasible for the Indian market: electric vehicles (EVs) or fuel cell vehicles (FCVs). To achieve this, a comprehensive analysis is conducted, encompassing cost-benefit evaluations of both electric and hydrogen-powered vehicles as well as in-depth examinations of the technical functioning of EVs and FCVs. Ultimately, one of these alternatives reigns over the other in terms of aspects such as technological advancement, affordability and established charging infrastructure, becoming the panacea as the viable alternative in India's pursuit of sustainable mobility.

Introduction

In the global effort of achieving absolute sustainability and freeing our Earth from the shackles of greenhouse gas emissions, India, now the largest population, can play a crucial role by switching over to more sustainable alternatives of transportation to ensure a greener and cleaner ecology (Kumar and Aggarwal, 2020).

India is known to have one of the largest road networks in the world, with trains, auto rickshaws, buses and motor cars being the dominant modes of transportation on land. Yet there is one common drawback among them – they are powered by fossil fuels, mainly petrol and diesel, whose impact on our environment needs no introduction. 10% of India's carbon emissions alone are a consequence of the transport industry, while India as a nation produces 62% of its power through fossil-fuel-based sources including coal and lignite (ET Auto, 2021). As per the 2022 World Air

Quality Report, India's annual average concentration of PM2.5 (particulate matter) was 10.7 times the WHO's recommended levels, posing serious respiratory problems for those exposed to it and ranking the nation at 8th place in terms of air pollution (IQAir, 2023). Then why is it that people are still reluctant to the idea of shifting to more sustainable alternatives over these conventional vehicles? There are broadly two misconceptions surrounding sustainably powered vehicles – firstly, fossil fuels are incredibly "energy dense" (Cheek, 2020) and considered much more efficient than their sustainable alternatives, although sustainable cars have proven to be just as efficient as conventional vehicles, and secondly, the alternating sustainable options such as electric vehicles are significantly more expensive than conventional vehicles, however over time sustainable alternatives have become just as affordable as traditional fuels.

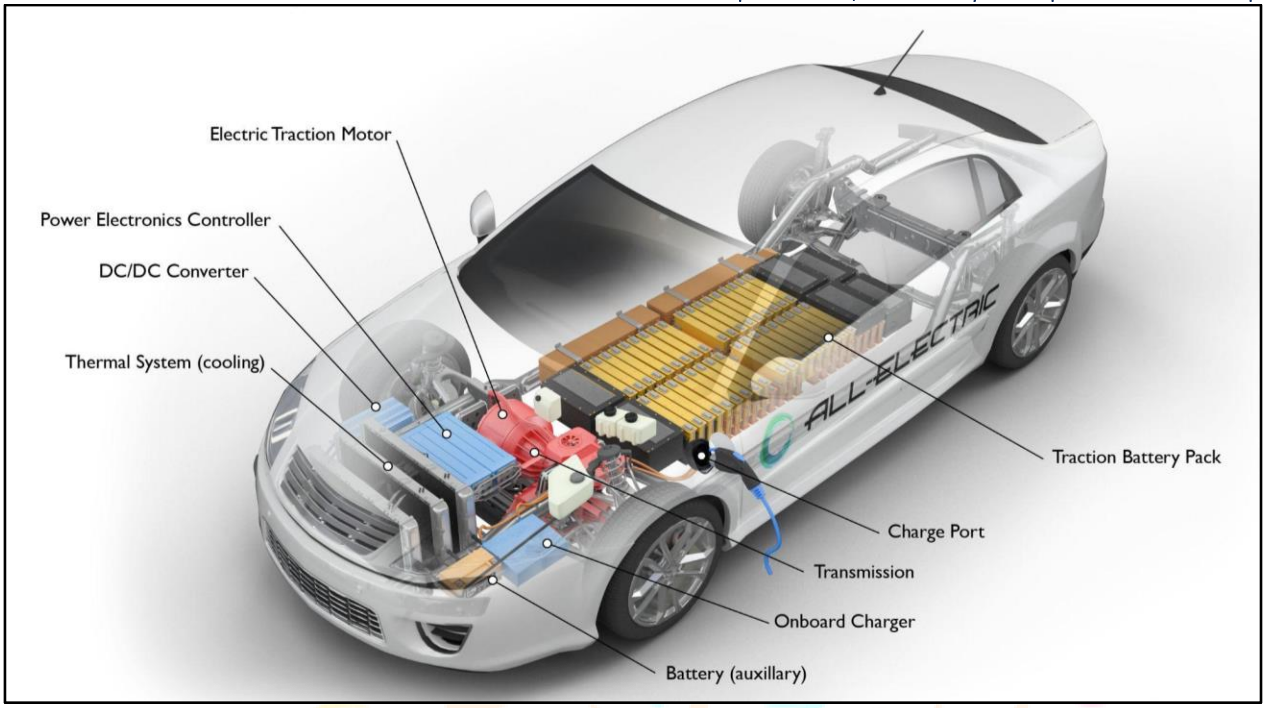
Amidst the vast mosaic of solutions for conventional vehicles of transportation, there are a plethora of alternative fuel sources for cars, such as electricity, hydrogen, biodiesel, ethanol, natural gas and propane, of which the most efficient and popular have proven to be electricity and hydrogen. Having different technical and socio-economic factors to consider while choosing either an electric or fuel cell vehicle, it can become a complex process to compare both of these fuel sources. In line with the aforementioned, this paper aims to answer the research question **"How do electric and fuel cell vehicles function and which is more feasible for the Indian market?".**

This paper aims to conduct a comprehensive analysis of the feasibility of electric vehicles (EVs) and fuel cell vehicles (FCVs) in India. This will be facilitated by detailed cost-benefit analyses of both electric and hydrogen-powered vehicles in the context of India, taking into consideration the involved costs, socioeconomic challenges as well as environmental implications – all that work as important measures for comparing any vehicles.

Technical Functioning of Electric Vehicles

In recent years, the rapid advancement of electric vehicle (EV) technology has revolutionized the automotive industry. EVs are powered by electricity stored in high-capacity batteries, offering a clean and sustainable alternative to traditional internal combustion engine (ICE) vehicles (Sanguesa et al., 2021). Understanding the technical functioning of EVs is crucial for comprehending their operation and the benefits they bring to our society.

Based on their engine technologies and settings, EVs can be classified into various categories, such as hybrid EVs (HEVs), plug-in hybrid EVs (PHEVs) and battery EVs (BEVs), although there are some main components that are found in every EV. The remainder of this section explores the key components and processes that enable the functioning of EVs.



(US Department of Energy, 2019a)

Battery and Electric Motor

At the heart of every EV lies a high-capacity traction battery pack – the core component that powers the operation of EVs. A traction battery pack, also known as an EV battery (EVB), is a rechargeable energy storage that acts as the power supplier for the electric motor and is the reason for EVs' high performance and rapid acceleration (US Department of Energy, 2019a). Numerous individual lithium-ion battery cells form a battery module, and a group of battery modules enclosed within a battery casing make the battery pack. The cells are connected in series or parallel configurations to provide the desired voltage and capacity. The battery capacity often directly determines the maximum driving distance of an EV, meaning that the higher the battery capacity, the higher the driving distance, and fewer stops at charging stations for the consumer. Although increasing the battery capacity is not an obvious choice, since that, in turn, means a larger and heavier battery pack that would occupy more cabin space, and therefore the best way to optimize battery performance is to maximize the battery's energy density – as much electric energy as possible stored in a small, lightweight battery (Hyundai Motor Group, 2020). In a typical passenger EV, there is a single rectangular or 'T'-shaped battery pack located along the floor pan of the vehicle, although commercial and public transport EVs do have multiple EVBs located at the front and rear as well as the sides of the vehicle.

The battery pack stores electrical energy in the form of direct current (DC) that powers the electric motor, which is the primary propulsion system of the vehicle. The electric motor, or traction motor, converts electrical energy from the battery into mechanical energy that rotates the wheels. It is the main component that differentiates an electric car from a conventional one (Deng, 2022). Permanent magnet synchronous motors (PMSM) and induction motors are commonly used in EVs due to their efficiency, power density, and compact size (Yang et al., 2020). The motor is controlled by an electronic control unit (ECU) that regulates the flow of electricity to achieve the desired speed and torque.

Power Electronics and Charging Infrastructure

EVs rely on power electronics systems to manage the flow of electricity between the battery pack, electric motor, and other vehicle components. The power electronics consist of various components, mainly inverters, converters, and controllers. The power inverter converts the direct current (DC) power from the battery into alternating current (AC) power required by the electric motor. It also enables regenerative braking, which converts the kinetic energy during braking into electrical energy and stores it back in the battery. The DC-DC converter, on the other hand, distributes the output power coming from the battery to a required level, that is, may be employed to step down the high-voltage DC power from the battery to a lower voltage suitable for powering auxiliary systems like lights, air conditioning, or infotainment. Lastly, the power electronics controller determines the working of an EV, as it regulates the flow of electrical energy from the batteries to the electric motor and ensures the overall efficiency and safety of the system by utilizing advanced algorithms and sensors to optimize power flow and protect the components from overloading, overheating, and other potential risks (Deng, 2022).

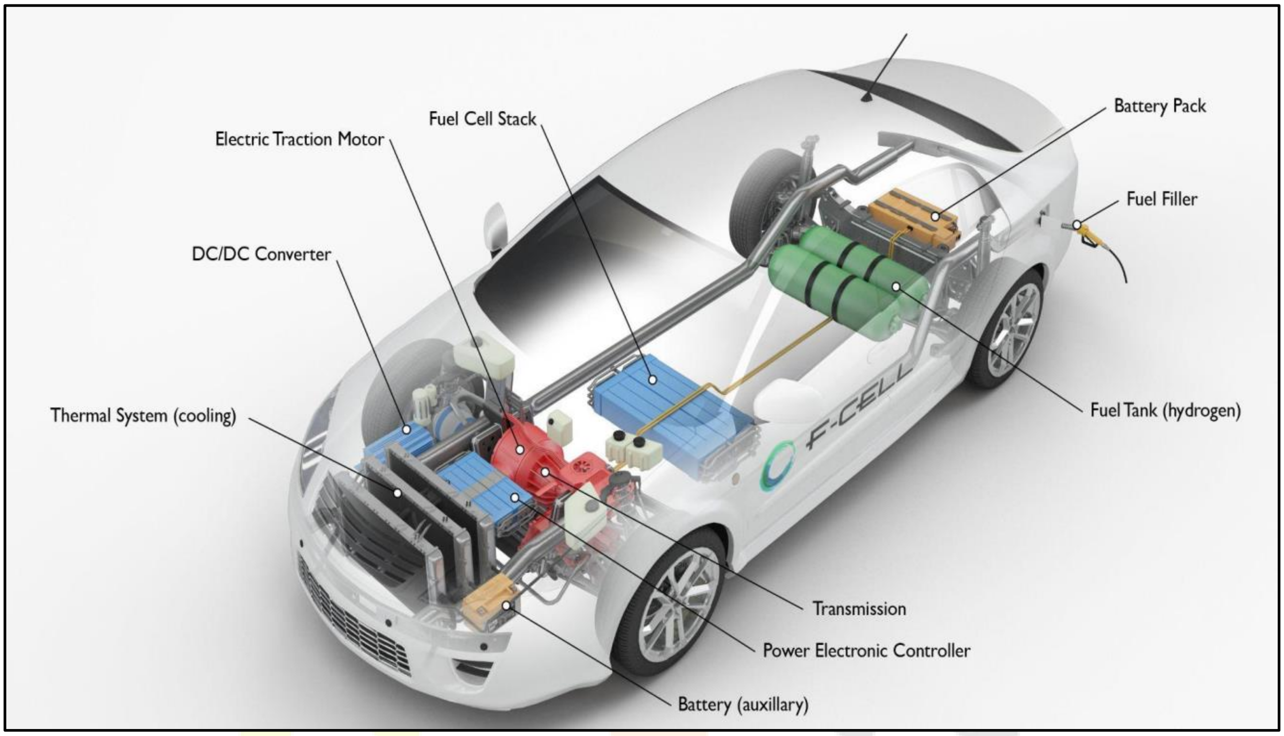
Charging systems play a vital role in the widespread adoption of EVs. EVs can be charged using different methods, broadly regular AC charging and fast DC charging. AC charging is commonly done at home, workplace or public charging stations, where an onboard charger converts AC power from the grid into DC power to charge the vehicle's battery. The onboard charger not only acts as an AC-to-DC converter to charge the EV battery but also monitors various battery characteristics and controls the current flowing inside the battery pack (Deng, 2022). DC fast charging stations, on the other hand, provide high-power DC charging directly to the battery, bypassing the need for an onboard charger and enabling rapid charging times typically ranging from just 30 minutes to an hour. Smart charging systems have further optimized EV charging speeds as they can dynamically adjust charging rates based on the availability of renewable energy sources or schedule charging during off-peak hours when electricity demand is low.

Understanding the technical functioning of EVs provides valuable insights into the remarkable advancements that have transformed the automotive industry. As EV technology continues to evolve, we can anticipate even greater improvements in battery capacity, motor efficiency, charging infrastructure, and intelligent power management systems, ultimately accelerating the global shift towards sustainable transportation.

Technical Functioning of Fuel Cell Vehicles

Electric and hybrid cars are gaining much popularity, in part because they help lower the amount of carbon emissions that are released into the atmosphere. Although they are not the only option for more environmentally friendly transportation. Hydrogen fuel cell cars, or FCVs, sound like something out of science fiction, but these vehicles have been around for longer than many might think (Bogna, 2022), going as back as the 1960s when the first on-road fuel cell-powered vehicle was introduced by General Motors, named the 'Chevrolet Electrovan' (Corby, 2021).

FCVs represent a promising advancement in sustainable automotive technology. By utilizing hydrogen gas and oxygen from the air, fuel cells produce electricity to power the vehicle, emitting only water vapour as a byproduct. Understanding the technical functioning of FCVs is crucial to comprehend their operation and their potential for a greener transportation future. The remainder of this section explores the key components and processes that enable the functioning of FCVs.



(US Department of Energy, 2019b)

Fuel Cell Technology

Like all EVs, FCVs use electricity to power an electric motor. In contrast to other EVs, however, FCVs produce electricity using a fuel cell powered by hydrogen rather than drawing electricity from only a battery (US Department of Energy, 2019b). Similar to how the traction battery pack is the heart of an EV, the fuel cell stack is the heart of every FCV. Fuel cells are electrochemical devices that convert the chemical energy of a fuel, in this case, hydrogen, into electrical energy through an oxygen reduction reaction. Proton Exchange Membrane Fuel Cells (PEMFCs) are commonly used in FCVs due to their high efficiency, rapid response time, and compact size. It consists of multiple individual fuel cells connected in series or parallel configurations. Each fuel cell contains an anode, a cathode, and a proton exchange membrane (Han et al., 2022). Pressurized hydrogen is stored in special tanks onboard the vehicle. The gas (H_2) is supplied to the anode, while atmospheric oxygen (O_2) from the surrounding air enters the cathode. At the anode, hydrogen molecules split into protons and electrons. The protons pass through the proton exchange membrane, while the electrons are forced to travel through an external circuit, generating an electric current. At the cathode, the protons and electrons combine with oxygen to produce water vapour (H_2O) – the only emission from the fuel cell. In short, hydrogen gas stored onboard the vehicle and oxygen from the surrounding air are supplied to the fuel cell where these two gases undergo an electrochemical reaction, in turn producing electricity, heat and water vapour, which is released in the form of gas via a small tube located underneath the vehicle (Renault Group, 2021).

Hydrogen Storage and Delivery

One critical aspect of FCVs is the storage and delivery of hydrogen fuel. One of the major concerns surrounding FCVs is the hydrogen fuel itself since hydrogen is a highly flammable gas, which if mishandled, can have fatal consequences for the passengers. Hydrogen can be stored in different forms, including compressed gas or liquid form. Compressed hydrogen gas is the most common method in FCVs, where hydrogen is stored in high-pressure tanks. These tanks are made of lightweight materials with high strength to ensure safety and maximize the storage capacity of hydrogen (Bogna, 2022). FCVs incorporate various safety systems to ensure the safe operation and handling of hydrogen fuel, including sensors for detecting leaks, flame arrestors to prevent hydrogen combustion, and rigorous testing and certification procedures. To fuel an FCV, hydrogen is delivered from a hydrogen fueling station to the vehicle's hydrogen storage tanks through a fuel filler. The process typically involves the compression and cooling of gaseous hydrogen, followed by its transfer into the vehicle's fuel tanks. Hydrogen fueling stations are also designed with safety measures to handle hydrogen delivery, storage, and refuelling operations.

Power Electronics and Electric Motor

FCVs integrate power electronics and electric motor systems similar to EVs. The electricity generated by the fuel cells is converted from DC to AC by power electronics components such as inverters and converters. The electric traction motor in an FCV converts the electrical energy from the fuel cells into mechanical energy to drive the wheels. Depending on the vehicle, different types of electric motors, such as permanent magnet synchronous motors (PMSM) or induction motors, can be employed. The motor is controlled by a power electronic controller that regulates the flow of electrical energy delivered by the fuel cell and the traction battery, controlling the speed of the electric traction motor and the torque it produces. Other key components include the DC-DC converter, which converts higher-voltage DC power from the traction battery pack to lower-voltage DC power needed to run vehicle accessories, the auxiliary battery, which provides electricity to start the car before the traction battery is engaged, and the high-voltage battery pack, which stores energy generated from regenerative braking and provides supplemental power to the electric traction motor (US Department of Energy, 2019b).

FCVs demonstrate outstanding potential for a sustainable and zero-emission transportation future. Fuel cell technology harnesses the power of hydrogen to produce electricity, emitting only water vapour as a byproduct. As hydrogen fuel infrastructure continues to develop and advancements in fuel cell technology are made, FCVs hold the promise of reducing greenhouse gas emissions, improving air quality, and fostering a cleaner and greener mobility landscape, paving the way for a greener future.

Cost-Benefit Analysis of Electric Vehicles in India

EVs are gaining significant traction globally as a sustainable and environmentally friendly mode of transportation. India, with its growing population, rapid urbanization, and increasing concerns about air pollution and carbon emissions, has recognized the potential of EVs to address these challenges. This cost-benefit analysis examines the advantages and disadvantages of EVs in the Indian context.

Purchase Cost: EVs typically have a higher upfront cost compared to conventional internal combustion engine (ICE) vehicles (Kumar and Kanuri, 2020). For a very long time, the Indian car market was deemed price-sensitive implying that consumers were greatly influenced by the price of a product when making a purchasing decision. With 90% of two-wheel vehicles with ICE's costing between INR70,000 - INR140,000 and the starting price of electric two-wheel vehicles being as high as INR160,000, the price sensitivity of consumers has proven to be a key barrier to EV adoption in India for many years (Jacob, 2023).

That being said, as per Bain & Co., the relatively high cost of EVs has been attributed to the disrupted supply chains and high inflation levels which have driven the prices for essential EV components such as batteries incredibly high. With advancements in technology and economies of scale, the price of EVs will decrease and gradually compete with those of ICE vehicles in India - as is being evidenced already. Furthermore, many reports suggest that consumers of the Indian vehicle market are now becoming less price sensitive due to a myriad of factors including but not limited to an increasing median income and an increasing number of young buyers (Nerurkar, 2020). As a result of this, Deloitte's Global Auto Consumer Survey (GACS) 2023, has found that vehicle consumers are now prioritising experience over cost. With product quality, vehicle features and brand image now being key considerations, the EV market is set for a more positive future (Mohile, 2023).

Fuel and Maintenance Cost: Other than the initial purchase cost, it is also important to consider the fuel and maintenance cost of a vehicle. With regard to fuel, electricity is cheaper than conventional fuels like petrol and diesel in India. As per research published in a 2020 article, it was estimated that the fuel cost of running an ICE vehicle came to around INR INR3.6 - INR5.6/km whereas, for EVs, the cost of running was close to only INR 1/km driven (Patel and Saini, 2020). EV owners can, therefore, benefit from lower fuel costs as the cost per kilometre travelled is significantly lower compared to ICE vehicles.

Furthermore, the maintenance cost of ICE vehicles is estimated to be about INR90,000 for approximately 1.60 lakh kilometres (Patel and Saini, 2020). Since EVs generally have fewer moving parts, the need for regular maintenance such as oil changes, oil filter and spark plug replacements and new components to replace those that have suffered wear and tear, is eliminated. The aforementioned implies relatively lower maintenance costs to be enjoyed by EV owners.

Charging Infrastructure: One of the challenges in the widespread adoption of EVs in India is the limited charging infrastructure. The issue of inadequate power grid infrastructure in rural areas of the country has been particularly highlighted as a hindrance to the deployment of EV charging stations. Ultimately, establishing an extensive network of charging stations requires substantial investment. In line with this, the Indian government, in collaboration with private entities, is rapidly expanding the charging infrastructure across the country. As the charging infrastructure improves, the convenience and accessibility of charging EVs will increase (Michael et al., 2022).

Environmental Benefits: As per studies, conventional vehicles in India contribute about 290 gigagrams (Gg) of PM2.5 on an annual basis. Moreover, around 8% of the total greenhouse gas emissions in India are from the transport sector with certain cities like Delhi witnessing contributions exceeding 30% (Singh and Sharma, 2022). These pollutants have great implications for the environment as they contribute to the ever-worsening issue of global warming.

Luckily, EVs offer significant environmental benefits by reducing greenhouse gas emissions and air pollution. India, with its high population density and polluted cities, can greatly benefit from the adoption of EVs. EVs produce zero tailpipe emissions, resulting in improved air quality and reduced carbon footprint. Transitioning to EVs aligns with India's commitment to the Paris Agreement and its goal of achieving a clean and sustainable future (Khurana, Kumar and Sidhpuria, 2019).

Social Benefits: The reduction of air pollution from EVs has a direct positive impact on public health. India faces severe air pollution challenges, leading to various health issues. For instance, exhaust emissions from diesel vehicles were deemed responsible for nearly 385,000 deaths in the country in 2015 (PTI, 2019). By transitioning to EVs, the harmful emissions from conventional vehicles, such as particulate matter and nitrogen oxides, can be significantly reduced, improving respiratory health and reducing the burden on healthcare systems. EVs not only help in reducing air pollution but also noise pollution in urban areas, especially when driven in all-electric mode, wherein only the electric motor is used to drive the vehicle and the noise produced is insignificant (Ashok et al., 2022).

Energy Security: India is heavily dependent on oil imports to meet its energy demands. Promoting the adoption of EVs can reduce the country's reliance on fossil fuels, enhancing energy security and reducing the impact of volatile oil prices. By shifting to electric mobility, India can utilize its domestic energy resources, such as renewable energy, for vehicle charging, thus improving energy self-sufficiency.

Economic Opportunities: The adoption of EVs presents economic opportunities for India. The shift towards EVs can stimulate the domestic manufacturing industry, creating job opportunities and attracting investments in EV production, battery manufacturing, and charging infrastructure development. It also fosters the growth of a robust ecosystem around EVs, including research and development, component manufacturing, and technology innovation. Lower running and maintenance costs encourage EV adoption asserted (Khurana, Kumar and Sidhpuria, 2019).

Cost-Benefit Analysis of Fuel Cell Vehicles in India

Similar to EVs, FCVs are emerging as a potential alternative to conventional internal combustion engine vehicles, offering a clean and sustainable mode of transportation. In the Indian context, where air pollution and dependence on imported oil are significant concerns, assessing the cost and benefits of FCVs becomes crucial. This analysis examines the advantages and disadvantages of FCVs in India.

Purchase Cost: Much similar to EVs, it is known globally that FCVs too have a higher upfront cost compared to ICE vehicles resulting from the complexity, limited production scale of fuel cell technology as well as the cost of components such as the fuel cell stacks and hydrogen storage systems. However, the hydrogen fuel cell is an infant technology and whilst EV technology has established itself in India, FCVs still have a long way to go. As of date, there are no FCVs on sale in India but there has been a great level of demand shown as well as willingness to introduce such vehicles to the country by several manufacturers. That being said, in 2022, Toyota launched a pilot project to test their Mirai FCEV (Fuel Cell Electric Vehicle). Experts have suggested that if this were to be launched in the country then it could cost around INR60,000,00 ex-showroom (Team Ackodrive, 2022). So, whilst the upfront cost is expected to be relatively high, there are hopes that as technology matures and economies of scale come into play, this cost may decrease over time.

Fuel and Maintenance Cost: Hydrogen, the fuel that makes the magic behind FCVs possible, is the most abundant element in the universe. However, contrary to the assumption that this would make the cost of hydrogen relatively low, hydrogen is currently more expensive than conventional fuels like petrol and diesel in India. For instance, it has been estimated that the cost of green hydrogen could be anywhere between INR400 - INR500/km. To put that into context, a full tank of hydrogen for a car like the Toyota Mirai could cost INR2,500 - coming to a running cost of INR4/km. Whilst this is relatively costly when compared to the running cost of pure EVs as well as CNG vehicles that cost between INR2 - INR3/km, it may still make for a cheaper alternative to vehicles that use petrol or diesel (Bhoir, 2022). That being said, advancements in hydrogen production methods and increased hydrogen availability can lead to cost reductions. Additionally, the Indian government and some private companies are exploring strategies to promote the production and distribution of affordable hydrogen (Barooah, 2023). In line with this, in 2021, Reliance Industries announced that it is working towards bringing the green hydrogen price down to INR160 by 2029-30 (Livemint, 2021). All the aforementioned, if successful, could contribute to lowering the fuel cost of FCVs and facilitate making them a more feasible choice for vehicles in India.

With regard to the maintenance cost of FCVs, just like for EVs, these tend to be relatively lower compared to ICE vehicles, as FCVs also have fewer moving parts and no internal combustion, resulting in reduced wear and tear. This translates to fewer maintenance requirements, such as oil changes and component replacements. However, specialized training and infrastructure are needed for maintenance and repair services, which may lead to higher servicing costs in the longer run.

Infrastructure Investment: Fuel cell technology, have been not as greatly evolved as EV technology as of yet, demands the requirement of establishing a hydrogen infrastructure for the successful operations of FCVs in India, which is a significant cost associated with FCVs. The production, storage, and distribution of hydrogen require substantial investment in dedicated facilities and infrastructure, including hydrogen production plants and refuelling stations (Greene, Ogden and Lin, 2020). The development of a comprehensive hydrogen infrastructure network across India would require collaboration between the government, the private sector, and other stakeholders.

Environmental Impact: EVs, although rightly considered sustainable, are not fully, as they release a small but noticeable amount of emissions – FCVs are the solution to this downside of EVs, as they offer significant environmental benefits over EVs by producing zero tailpipe emissions. India, known for its air pollution challenges, particularly in urban areas, can greatly benefit from the adoption of FCVs. The use of hydrogen as fuel results in only water vapour as the byproduct, contributing to improved air quality and reduced greenhouse gas emissions (Greene, Ogden and Lin, 2020).

Energy Security: India heavily relies on imported oil to meet its energy demands, leading to concerns regarding energy security. FCVs, powered by domestically produced hydrogen, just like EVs, offer an opportunity to reduce dependence on imported fossil fuels. Promoting indigenous hydrogen production through renewable energy sources can enhance energy security and reduce vulnerability to fluctuating oil prices.

Economic Opportunities: Very similar to EVs, the widespread adoption of FCVs in India presents economic opportunities. The establishment of a hydrogen economy would create job opportunities across various sectors, including hydrogen production, fuel cell manufacturing, and infrastructure development. It can also foster collaborations between industries, research institutions, and startups, driving innovation and economic growth. The very adoption of FCVs on the road in the Indian market can stimulate technological innovation, thereby producing both social and economic benefits for India (Kumar, 2022).

Conclusion

India's struggle with air pollution is undoubtedly real, being one of the most polluted countries in the world, and the high concentration of PM2.5 in its atmosphere is a threat to the integrity and future of the Indian nation. One of the major contributors to India's air pollution is its transport industry, which alone is responsible for 10% of the country's carbon emissions. In the wake of this increasing destruction of the nation's environment, sustainable transportation provides the key to a greener and cleaner ecology for India. Among the multitude of sustainable fuel sources for powering vehicles, electricity and hydrogen have attracted the most attention, yet both demand the consideration of different functional characteristics and socioeconomic factors for a holistic comparison. This paper aimed to conduct a comprehensive analysis of the feasibility of EVs and FCVs in India, facilitated by detailed explanations of the working principles of EVs and FCVs as well as cost-benefit analyses.

In terms of technical functioning, electric and FCVs are not very different from each other, as they both comprise the same basic components – at the heart of both EVs and FCVs lies what powers their operation, the battery pack in the case of EVs and the fuel cell stack with FCVs, with the only difference being that while EVs draw their energy directly from the battery pack, FCVs convert the chemical energy of the hydrogen fuel stored inside of them to electric energy to power the vehicle. EVs and FCVs also have almost similar power electronics and charging infrastructures, with components like the AC-DC converter, thermal cooling system and power electronics controller found in both of them. Although a cost-benefit analysis of both EVs and FCVs revealed some areas where one shines over the other. For one, EV technology has evolved better and more reliably than fuel cell technology, as EVs have been on the road for a much longer duration than FCVs. In India's price-sensitive automobile industry, the initial purchase cost of FCVs is a major barrier to its country-wide adoption, with starting prices of a four-wheeled FCV going as high as INR60,000,00, while for an EV being as low as INR8,69,000 – a much affordable and reasonable price for many people looking for a sustainable yet efficient car. Moreover, a reasonable reluctance to FCVs by the public is the safety concerns surrounding the fuel, hydrogen, which being a highly flammable gas, if not dealt with vigorous measures, can pose the chance of serious injuries for the passengers.

Therefore, while both electric and FCVs offer potential solutions, a comprehensive analysis reveals that EVs currently have an advantage in terms of technology maturity, affordability, and public safety. With their lower purchase cost and established track record, EVs present a viable and practical choice for a cleaner transportation future in India, contributing to a healthier environment and improved quality of life.

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