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Future of Transportation- A Comparison between Internal Combustion Engine, Electric Vehicles and Fuel Cell Vehicles

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Abstract Today, the transportation sector is mainly dependent on internal combustion engines. The total number of vehicles running on the road has reached 1.2 billion. The transportation sector is responsible for a 23% share of greenhouse gas emissions. As a result, researchers and governments are debating the future of the transportation sector. The main factors driving the discussion and development of alternatives for internal combustion engines are air pollution caused by transportation, energy security concerns, rising hydrocarbon fuel prices, climate change issues, the desire to develop economic infrastructure in rural areas by promoting biofuels and bio-waste management, and the desire to lead the world in new technology development. Currently, four types of configurations are in use: internal combustion engines, battery electric vehicles, fuel cell vehicles, and hybrid vehicles. The major advantages, disadvantages, problems, future, cost, emissions produced, environmental impact, fuel and material availability, efficiency, etc., of all these available options for transportation are presented in this paper. The results of this study show that there are a number of alternatives emerging for transportation, but internal combustion engines will still remain as the primary source for transportation for the coming decades.

Keywords Internal Combustion Engines, Fuel Cell, Fuel Cell Vehicles, Battery Electric Vehicles, Emissions, Pollution, Low Temperature Combustion Engines, Reactivity-Controlled Compression Ignition Engines

1. Introduction

Today the whole world is suffering from a big problem, i.e., environmental pollution. There are two major sources of pollution, i.e., rapid industrialization and transportation. The total number of vehicles running on roads is around 1.2 billion currently, and it is estimated to increase to 2 billion by 2040 [1]. Among these vehicles, more than 99.9% run on internal combustion engines (ICE), such as cars, trucks, buses, rail, small boats, marine ships, etc. These vehicles use crude oil for their power production and thus emit harmful emissions like nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) and particulate matter (PM). Crude oil has been extensively used for various applications like transportation, industrial products, air conditioning, etc., and has been a primary source of energy for the world since the 19th century. The characteristics of crude oil like high power density, low operating temperature, easy transportation and storage, highly developed infrastructure, and fast start-up are ideal for vehicle applications [2, 3]. Passenger cars, which are also called light duty vehicles (LDVs), run on gasoline and account for a very large global transportation energy demand of 44% [4]. The transportation of people and goods accounts for 20% of global energy consumed. This produces 23% of CO_2 emissions, and with other gases like methane taken into account, it is equivalent to 7 billion tonnes of CO_2 equal to livestock farming [4, 5]. In the U.S. alone, 28% of greenhouse gases and 34% of CO_2 emissions are produced by the transportation sector [6]. Globally, 30% of nitrogen oxides (which include $NOx=NO+NO_2$), 14% of CO_2, 54% of CO, 10% of PM, and 47% of non-methane hydrocarbon (NMHC) are emitted only because of traffic [7]. Due to these emissions, some major environmental issues like air pollution and global warming occur and dangerously affect living organisms and the environment [8]. Some of the direct problems that occur in humans due to emissions are high blood pressure, asthma, lung cancer, Alzheimer's disease, diabetes, dementia, and premature deaths. In Connecticut and Massachusetts, because of PM2.5 emissions, 2.1% and 3.5% increases in cardiovascular and respiratory patients' admissions in hospitals have been reported [7]. These direct and indirect effects of transportation emissions on people's health and the environment raise a number of questions about the current transportation systems from environmental, health, and economic points of view [7]. To control these harmful engine emissions, various governments and organizations have imposed emission regulations, such as the European Union standard, the Bharat standard, the US emission standard, etc. One such emission standard is shown in table 1 and is followed by various countries.

Table 1. Euro standards of European Union for heavy-duty vehicles *[10]*

	CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	PM (g/kWh)
Euro I	4.5	1.1	8.0	0.61
Euro II	4	1.1	7.0	0.15
Euro III	2.1	0.66	5.0	0.13
Euro IV	1.5	0.46	3.5	0.02
Euro V	1.5	0.46	2.0	0.02
Euro VI	1.5	0.13	0.4	0.01

Further, in the process of reducing emissions from vehicles, various researchers have proposed using different types of emission control systems, like diesel particulate filter, exhaust gas recirculation, lean NOx trap, selective catalyst reduction, diesel oxidation catalyst, etc., [9]. Apart from that, use of alternate fuels like natural gas (NG), biodiesel, liquified petroleum gas (LPG), ethanol, etc., is also promoted, but their growth rate, availability, and production technology have some constraints. Thus, these are in limited use as of now. Currently, these fuels together account for only around 5% of total global transport energy. The share of electric vehicles is very small and that of hydrogen or synthetic fuels is negligible. To develop these alternates, many initiatives have already taken place across the world, especially for electric vehicles [5]. So, it is thought that by 2040, around 90% of the energy used for transportation will still come from combustion engines that run on petroleum [4, 5].

2. Internal combustion engine

2.1. Current status of the development of ICE

Internal combustion engines (ICE) are the most developed technology that is currently used for transportation. Basically, there are two types of engines that are used on the basis of their combustion process, i.e., gasoline engines and diesel engines. The gasoline engine is generally used for two-wheelers and light-duty vehicles like scooters, motorcycles, cars, etc. The diesel engine is generally used for heavy-duty vehicles like buses, trucks, rail, marine ships, power production devices, etc. Currently, the total number of ICE is around 1.58 billion, including 1.2 billion passenger cars and 380 million commercial vehicles. Among them, 95% of the vehicles run on petroleum liquid fuel [5].

2.2. Availability of Fuel and Materials for ICE

The ICE uses crude oil for its power production. Due to this, the demand for crude oil is increasing day by day. The report of the U.S. Energy Information Administration, International Energy Outlook, 2021 showed that the demand for oil throughout the world in 2017 was nearly 97.7 million barrels per day on average [4]. The world energy balance showed that transportation was by far the predominant oil-consuming sector, taking up 56% of the world oil consumption [11]. This led the oil industry to go for new discoveries of oil reserves and also improved the recovery rate of oil. Thus, global crude oil supply capacity has been growing faster than demand in the last several decades. It has been estimated that the remaining recoverable crude oil reserves can be sustained for approximately 60 years from now [5, 8]. Today, many alternate fuels are also available that can be used to run an ICE. Among them, some of the most important options are biodiesel, compressed natural gas (CNG), LPG, biogas, ethanol, methanol, hydrogen, etc. The total production of biofuel in 2022 was 171 billion liters and is expected to increase to 182 billion liters by 2050. However, currently, the production of biofuel is expensive. The total production of hydrogen in 2018 was 73.9 Mt and is expected to increase in coming decades [11]. The total reserves of natural gas remaining throughout the world are 1,153,820 million barrels of oil equivalent [4]. Currently, more than 28 million NG vehicles run across the world, having 33,383 NG fueling stations with a 1% share in 2019 and is expected to reach 5% by 2040 [12]. There were 17 million LPG vehicles in 2010, which consumed 23 million tonnes of LPG gas and accounted for 1% of transportation energy demand [5].

2.3. Advantages and Disadvantages of ICE

Advantages [5, 13–15]

(i). Well-stablished technology of more than 100 years.
(ii). Lower vehicle and maintenance cost.
(iii). High power to weight ratio.
(iv). Higher driving range.
(v). Easy and fast refueling ability.
(vi). Well-developed infrastructure.

Disadvantages

(i). Produces harmful exhaust emissions.
(ii). Fuel prices are rising.
(iii). Fuel scarcity: petroleum fuel will run out in 50-60 years.

2.4. Emissions and Environmental Impact of ICE

Under an ideal combustion process, the hydrocarbon fuel is completely burned; thus, it does not produce harmful gases. But during the combustion process of fuel in an engine, the complete combustion of fuel does not occur because of various operating parameters. For example, the combustion of diesel fuel typically produces approximately 67% N_2, 12% CO_2, 11% H_2O, 9% O_2 and 1% other pollutant emissions containing CO, HC, SO_2, NOx and PM. The burning of 1 kg of diesel produces approximately 1.3 kg of H_2O and 3.1 kg of CO_2 [16, 17]. The NOx emissions are a mixture of NO and NO_2. NOx emissions cause various problems for living organisms and the environment, such as lung disease, respiratory infection, visibility impairment, pollutant haze, nutrient enrichment, smog formation, acidification of water bodies, acid rain, and the formation of ozone [18]. PM emissions have effects on the environment, such as polluting the air and water, making it harder to see, getting dirt on buildings and monuments, changing the global environment, and lowering the amount of food that can be grown. PM also affects human health by causing suffocation, asthma, dyspnoea, premature death, lung cancer, and further leads to other types of cardiovascular diseases [19, 20]. When CO is inhaled, it combines with hemoglobin and reduces oxygen transfer capacity, resulting in slow reflexes, leading to asphyxiation. It also leads to concentration losses, and affects the functioning of various human organs, bewilderment, and confusion [20]. HC has several hazardous effects on the environment, climate conditions, living organisms and human health. They form ground-level ozone, which is toxic and causes cancer and respiratory tract irritation [18, 21].

2.5. Future of Internal Combustion Engine

The ICE technology is fully developed and has been used for more than 100 years. But, due to its disadvantage of producing harmful emissions and an increase in oil prices, the focus of governments of different countries is shifting towards electric vehicles. In fact, many governments around the world have announced their desire to ban cars powered by ICEs. However, they have not shown their intention clearly to ban all ICEs or ICEs without any electrical assistance [5]. In September 2017, China announced that manufacturing and selling of conventional ICEVs would be stopped in the near future, while some countries, such as the Netherlands and Norway, Germany, India, England, and France, have announced they will stop selling conventional ICEVs in 2025, 2030, and 2040, respectively [8, 22]. As for China, it looks like their decision is more influenced by their policy to reduce their dependency on imported oil than to reduce air pollution [22]. However, dismantling such a developed system abruptly and banning the production of ICEs, as some politicians suggest, could have extreme economic, social, environmental, and political impacts and could be extremely unexpected [5].

ICEs continue to improve, as researchers are focused on improving combustion, advanced after-treatment, and control systems. However, more and more research is required to develop highly efficient, affordable, and safe engines to meet increasingly strict engine emission regulations on air pollution and GHG emissions. There are some methods that can be used to improve the ICE technology. The fuel and engine should be co-developed as a system rather than the development of an engine according to the fuel available in the market. Low octane fuels can be processed in refineries in place of conventional gasoline and diesel [5].

Another hotly debated area of research is low temperature combustion engines (LTCE). The LTCE has various variants, like homogeneous charge compression ignition (HCCI), premixed charge compression ignition (PCCI), reactivity-controlled compression ignition (RCCI), and gasoline direct injection (GDI). Among these, the RCCI engine is a combustion technology that is being developed to get high efficiency, high power output, fuel flexibility, and very low soot and NOx emissions. Hence, LTCE could be a much better option for the future since it can be operated with any kind of fuel, either conventional or non-conventional [23].

3. Battery Electrical Vehicles

3.1. Current Status of the Development of BEV

Electric vehicles (EVs) can be put into four groups: i) Hybrid Electric Vehicles (HEVs), which are mostly powered by gasoline and have a small battery to help the combustion engine; ii) Plug-in Hybrid Electric Vehicles (PHEVs), which are powered by both gasoline and electricity; iii) Battery Electric Vehicles (BEVs), which are only powered by electricity; and iv) Fuel Cell Electric

Vehicles (FCEVs), which are powered by hydrogen-electric vehicles consisting of an electric motor driven by rechargeable battery packs and thus emit no tailpipe pollutants. Today, there are three main types of batteries which are suitable for road transportation applications: lead-acid batteries, nickel-based batteries, and lithium-based (Li-based) batteries [8]. Among numerous battery technologies, for automotive applications, the Li-ion battery system is mostly preferred due to its higher energy density compared to others. Currently, battery electric vehicles are in their initial phase and, thus, it is very important to examine the various aspects of Li-ion batteries related to safety, performance, durability, and energy management for automotive applications [24]. The share of EVs in Norway was 23%, the Netherlands 10%, Sweden 2%, the United Kingdom, France and China 1%, the U.S. 0.7% and Canada 0.4% [7]. According to the report of the International Energy Outlook, 2019 [11], the total number of EVs worldwide was 1.2 million and would continue to rise. Currently, the total number of battery electric vehicles around the world is 580,000 electric cars, 250,000 electric light commercial vehicles (LCVs), nearly 900 million electric two-wheelers, 50 million electric three-wheelers, and 370,000 electric buses were in 2017 [8, 25].

3.2. Availability of Fuel and Materials for BEV

The total number of EVs was more than 10 million in 2020. The batteries have high energy density up to 2 kWh/kg, no memory effect and no direct environmental problems during usage, a high cycle life of more than 2,000 cycles, good reliability and ruggedness, low-cost performance, high energy efficiency (90-100%), low self-discharge, longer lifetimes with moderate cost [8]. To recharge these EVs, there were 1.3 million publicly accessible chargers in 2020, but out of these, only 30% were fast chargers [26]. To charge these EVs, large amounts of electricity are required. According to the IEO 2019 report, coal generated 36.7% of the electricity, natural gas 23.5%, oil 2.8%, hydroelectric 16.0%, nuclear power 10.3%, solar/wind/geothermal/tidal/other 8.4%, and biomass and waste 2.4%. The electricity generated by non-renewable sources accounts for 62.9% and only 37.1% is from renewable sources [11]. In countries like the U.S.A, India, and China, the electricity sector is dominated by fossil fuels, particularly coal, which produce more than 60% of the country's electricity. The electricity required to charge EVs is expected to nearly triple between 2018 and 2050, accounting for approximately 6% of total electricity consumption in 2050 [11].

The increasing number of EVs would also require a large number of batteries. As a result, a large quantity of battery materials, such as lithium, lead, nickel, and so on, would be required. These materials are found in a few countries, like Australia, Chile, and Argentina. In 2016, the average price of lithium was $7.5/kg, which further increased to $16.5/kg. Similarly, the price of cobalt increased from $24/kg in 2016 to $93/kg in 2018. This would increase the cost of the battery pack. Further, the mining of these metals would create serious social, ethical, economic, and environmental impacts [5].

3.3. Advantages and Disadvantages of BEV

Advantages [8, 22]

(i). EVs do not produce tailpipe emissions.
(ii). On an economic scale, considering the whole life, EVs cost the same as or lower than ICEs.
(iii). Batteries have a high energy density of up to 250 Wh/kg and a high cycle life of more than 2,000 cycles.
(iv). Batteries have good reliability and ruggedness, good cost performance, high energy efficiency (90-100%), low self-discharge, and long lifetimes with moderate cost.

Disadvantages [8, 22, 27, 28]

(i). The cost of EVs is much higher than that of ICEs.
(ii). The driving range of EVs is 200-400 km less than that of ICEs.
(iii). EVs have a long battery charging time of 4–12 hrs.
(iv). The life of a battery is approximately 3–4 years and depends upon the number of charges and discharges.
(v). The lifetime of the Li-ion battery can be reduced abruptly due to the effects of the high temperature and deep discharge, whilst a protection circuit is required to ensure safe operation.
(vi). The weight of EVs is 24% heavier than that of ICE vehicles.

3.4. Emissions and Environmental Impact of BEV

Weiss et al. [29] and Michalek et al. [30] contend that BEVs, as compared to HEVs with a large battery capacity, can produce 2 to 3 times as many greenhouse gases (GHG) emissions, depending on the source of electricity generation and the time at which the BEV is charged from the grid. If the electricity is generated by nuclear power, hydro power, or renewable energy sources such as biomass, solar, and wind energy, the well-to-wheel GHG emissions for BEVs are much less than those for ICEVs [8]. One important factor that should be considered is the toxic gases released from Li-ion batteries if they catch fire. This releases toxic gases like CO, CO_2, HF, SO_2, NO_2, NO and HCl and poses a very large threat to human health. Not much study and research have been done on this yet. Thus, much safer and more environmentally friendly batteries will be required in the future [31]. Huo et al. (2013) [32] showed that EVs in China can be able to reduce GHG emissions by 20%, but along with that, they also increase PM10, PM2.5, NOx, and SO_2. Nichols et al.

(2015) [33] reported that in the Texas state of the U.S., EVs can reduce GHG emissions, NOx, and PM10, but produce much higher SO_2 emissions as compared to ICEs. Along with that, there are some indications that the non-exhaust PM emissions vary among BEVs and ICE vehicles because the non-exhaust emissions are influenced by vehicle weight. For example, the wear of tyres, brakes, and roads is increased by around 50% for heavy vehicles as compared to small (1,200 kg) and medium (1,600 kg) weight cars. It has been found that the weight of EVs is 24% heavier than that of ICE vehicles [28,34]. For example, in the Tesla S series, only the 85-kWh battery pack weighs 544 kg [5]. On a life cycle basis, BEVs can actually produce a higher CO_2 impact than ICEVs. The human toxicity potential (HTP) of a BEV has been estimated to be three to five times worse compared to a similar-sized ICEV, which impacts human health via exhaust pollutants. Also, BEVs are linked to higher impacts on human toxicity, acidification, photochemical ozone formation, particulate matter, and resource depletion [35, 36].

Furthermore, the manufacturing of the battery accounts for the largest GHG emissions of the BEV's lifecycle. The safe disposal of used batteries is very important due to the heavy metals. Thus, along with the charging stations, infrastructure related to the recycling and disposal of batteries also requires special focus [27].

On the basis of this information, it suggests that the evaluation of EVs and their environmental implications is overlooked and undervalued in the present scenario. The adoption and use of EVs is complex, as a number of factors would need to be considered and studied, such as the electricity generation, manufacturing process, fuel or energy consumption, materials required, and their emission impacts. This will make it clear that the impacts of EVs on the environment are heavily context-dependent [7].

3.5. Future of Battery Electric Vehicles

There are four ways that a Li battery can fail: assembly, abuse, thermal runaway, and eruption. One major battery failure mode is thermal runaway, which occurs due to an increase in temperature, which further increases the temperature during drive. Battery thermal runaway in BEVs and PHEVs can occur in normal operational conditions, electricity charging, parking, road cruising, and during vehicle collisions [37–40]. Safety aspects of BEVs are one of the major concerns due to the hazards of venting gas or smoke and the difficulty in fire-fighting, which is usually caused by failures of on-board large capacity power batteries [25].

According to current trends, it is expected that the total number of BEVs across the world will reach 1.7–1.9 billion by 2040. This will increase the demand for raw materials and battery capacity. Also, the LDVs can be converted to BEVs, but the shifting of commercial transport, which is more than half of the transportation, to BEVs cannot be realistic. This is because of two important factors. The first is the weight of the battery pack to power such a heavy load and the second is the requirement for a large amount of electricity. More importantly, BEVs are not 'zero emission' vehicles; they simply shift their emission impact from the tailpipe to somewhere else. In the United States, for example, coal is still used in power generation, and charging BEVs at night results in extra emissions (CO_2 and SO_2), which can result in a 50% increase in environmental and human health costs compared to using "average" electricity [41]. There will be an increase of SO_2 emissions by 3 to 10 times and NOx emissions by 2 times as compared to gasoline-powered ICE. [5, 7]. Meanwhile, South Korea plans to install 3,000 charging stations and will invest 760 billion KRW by 2020, which is 25% of the total number of gas stations [42]. The National Energy Board (NEB) of Canada has planned to project and operate 7,00,000 BEVs by 2035 [43].

Nevertheless, the acceptance of BEVs among customers will largely depend on the type of BEVs, vehicle cost, the source of energy generation, charging infrastructure, charging pattern, driving conditions, environmental considerations, government policies, fuel consumption, and fuel price. According to the current scenario, the transition from ICVs to BEVs will take more than 20 years [7, 22].

4. Fuel Cell Vehicles

4.1. Current Status of the Development of FCV

Fuel cells (FCs) can be divided majorly into six types depending on fuel and electrolytes, such as proton exchange membrane fuel cells (PEMFC), alkaline electrolyte fuel cells (AFC), phosphoric acid fuel cells (PAFC), direct methanol fuel cells (DMFC), molten carbonate fuel cells (MCFC), and solid oxide fuel cells (SOFC) [44]. The main advantages and disadvantages of fuel cells are shown in table 2. Among the different types of fuel cells, PEMFCs are generally used for automobiles. The process of electricity generation using FCs is highly efficient, highly reliable, quiet, and pollution-free [8]. The total number of FCVs throughout the world was 34,804 at the end of 2020, which included 25,932 passenger cars, 5,648 buses, 3,161 medium-duty trucks, 49 light commercial vehicles, and 14 heavy-duty trucks. It has been forecasted that the total number of FCVs will be 400 million, which includes 15-20 million trucks and 5 million buses in 2050 [45].

Table 2. Advantages and disadvantages of fuel cells *[27, 45–48]*

Advantages	Disadvantages
No pollution is created; the by-products are only pure water and heat.	Pure fuel is required, free from any contamination.
No combustion and only chemical reactions occur. Hence, fuel cells have higher thermodynamic efficiency.	Production and storage of hydrogen are extremely difficult.
Fuel cell efficiency does not drop with a decrease in power plant size.	Fuel cells for automotives require a platinum-based catalyst, which increases the component's cost.
Fuel cells are in a solid state and react almost instantly with load variations. Hence, they are very useful in co-generation applications.	An uncontrolled state change of produced water (drying or freezing) will negatively affect the fuel cell operation and life span.
PEMFC used in automotive applications has a low (below 100 ℃) operating temperature. Hence, they require little warmup time.	To supply the air to fuel cells, a compressor is required to supply compressed air. This reduces system efficiency and power output.
Fuel cell systems require refuelling, which is a faster process as compared to recharging a battery pack.	Fuel cell systems are heavier and bulkier as compared to IC engines because of the support and fuel storage systems.

FCEVs have the advantage of not emitting polluting gases directly during their operation. The major drawback to the use of fuel cells in vehicles is their limited capability to handle loads during transients, which is usually circumvented by using an auxiliary battery bank [49]. The main advantages of PEM fuel cells are their lower operating temperatures, robustness, flexibility in fuel types, high power density, fast start-up, and fewer problems with corrosion and leaks [50].

4.2. Availability of Fuel and Materials for FCV

The PEMFC is generally used in automobiles, and the fuel required is pure hydrogen. Hydrogen is abundantly available in the environment. There are some barriers to using hydrogen for automobiles. These include the production of pure hydrogen from the available sources, transportation, storage, and safety. Hydrogen is produced most commonly by two methods, i.e., steam methane reforming and water electrolysis. Both these processes require electricity for hydrogen production, and their environmental friendliness depends on the source of electricity, i.e., conventional or non-conventional. Conventional sources use coal or oil for electricity generation, which emit more GHGs, while non-conventional sources like solar, wind, biomass, etc., can be pollution free sources. There are two types of hydrogen refuelling stations (HRS), classified according to the hydrogen production location. The first type is those in which the hydrogen is produced somewhere and then transported to the fuel station by means of road, rail, ship, or pipeline. The second type is those in which the hydrogen is produced at the fuel station. Hydrogen currently costs $13.55/kg for small HRS and $8.96/kg for large HRS [51, 52]. There were only 540 public and non-public HRS worldwide at the end of 2020 [45].

4.3. Advantages and Disadvantages of FCV

Advantages [5, 45, 46, 53]

(i). Fuel cells have high efficiency.
(ii). Refuelling of hydrogen in the FCVs is much faster and easier.
(iii). The driving range of FCVs is much higher compared to BEVs.
(iv). No tailpipe pollution is created. Hence, they can be considered zero emission vehicles.
(v). The driving range of FCVs is 478 km to 756 km on a single recharge with fuel consumption of 0.89-1 kg/100km.

Disadvantages

(i). The cost of FCVs is much higher than that of BEVs and ICEVs. The cost of the Toyota Mirai, including government subsidies, is well over $125,000.
(ii). Production, storage, and transportation of hydrogen are still facing problems.
(iii). Hydrogen as gas cannot be used in vehicles as it requires large space and, thus, needs to be liquified under high pressure, which consumes high energy.
(iv). The total number of hydrogen refueling stations is very small.
(v). Infrastructure needs to be developed and, thus, requires a lot of capital investment in the coming decade.

4.4. Emissions and Environmental Impact of FCV

FCVs require hydrogen as fuel and require electricity to produce hydrogen from natural sources with the help of water electrolysis and methane steam reforming. This produced hydrogen is further compressed or liquefied to store and transport [15]. Many researchers say that if coal and oil were used for the production of electricity, the charging batteries of BEVs or the production of hydrogen for FCEVs would produce equal or more GHG emissions compared to ICEs [8]. Even considering the fact that more than 60% of electricity is generated by non-renewable sources, FCVs produce fewer NOx and CO emissions compared to ICEs [15].

However, if solar electrolysis is used for hydrogen production for FCEVs, the GHG emissions can be reduced by about 99.2% as compared to the gasoline ICEVs [8]. The FCVs would be able to reduce the societal cost by $480 billion as compared to the ICEs per year with equal business [15]. The studies show that FCVs exhibit 5%–33% lower WTW fossil-energy use and 15–45% lower WTW GHG emissions compared to ICEs. Even by this pathway, FCVs are able to reduce GHG emissions by 15% compared to ICEs [54].

4.5. Future of Fuel Cell Vehicles

The fuel cell vehicle market is primarily driven by the advantages associated with fuel cells. These are: longer driving range, high fuel efficiency, faster refueling, increasing government subsidies and initiatives, stringent emission norms, high technology development investments and many more [5, 13, 45]. There are many technical challenges for the commercialization of PEMFC. Among these, the two main technical problems are the stack durability and short life cycle for the vehicle applications [55, 56]. However, the production of hydrogen requires a lot of energy, and if this energy comes from a non-renewable source like coal, gas, oil, etc., the CO_2 emissions would be higher for FCV than for ICE vehicles [46, 57]. By reducing air pollution, GHG emissions, and oil consumption, FCVs can save society up to $480 billion per year [15]. Considering all the factors taken into account, in the long term, FCVs could be the better alternative to ICEVs, but to accomplish this, hydrogen infrastructure is required to be built [5].

5. Comparison between ICE, BEV and FCV on Different Factors

The comparison of internal combustion engines, battery electrical vehicles, and fuel cell vehicles is done on the basis of comparison of some factors like power produced, efficiency of vehicle, pollution created, performance, durability, energy management, safety, weight, customer choice, infrastructure availability, vehicle after service, etc., shown in table 3. The ICEs are the leading vehicles among all types of vehicles because of their stabilized technology, lower cost, high power, fast refueling and many more. But as the alternative to ICEs, BEVs are leading the market among all other types, such as FCVs and HEVs. The number of BEVs was 10 million in 2020 and is increasing day by day. BEVs have their own benefits, such as zero tailpipe emissions and lower fuel costs. But some of their disadvantages are things like lack of infrastructure, high vehicle costs, and high battery charging time. FCVs are still not very popular and are in a serious development and testing stage. FCVs have advantages like zero tailpipe emissions, lower fuel costs, longer driving range and short refueling times. But some of their disadvantages are things like lack of infrastructure and high vehicle costs. Renewable hydrogen can be potentially used in several applications, such as energy storage for power systems, mixture in natural gas networks, or as part of a power-to-gas system. It has also been widely used in the transport sector and even in the composition of gaseous fuels in thermal power plants [58]. In 2017, all over the world, only 328 hydrogen filling stations were available, while China had only 12. On a single energy source, PEVs have a short driving range and poor dynamic performance. To eliminate this problem, infrastructure needs to be built that may be either charging stations or hydrogen refueling stations. The cost of fuel cells is highest, followed by batteries in terms of per kW. Currently, the cost of PEVs is very high and, even after government subsidies, it is just equal to the cost of ICEs [59, 60].

The batteries and fuel cells contain several hazardous materials such as cobalt, nickel, lead, and lithium. These substances are very dangerous for human health and the environment. So, disposal of batteries and fuel cells is still a challenge [61, 62]. The standardization of PEVs' components is still a challenge [63]. Tesla, Audi, Tata, and other companies have already begun producing BEVs, while Hyundai, Toyota, Honda, and General Motors are producing FCVs [42].

Table 3. Comparison between ICE, BEV, FCV and HEV *[5, 8, 15, 22, 27, 48, 52, 64, 65]*

Factors	**ICE**	**BEV**	**FCV**	**HEV**
Current status	More than 1.58 billion automobiles, widely used in land, sea, air and has 99% share of total automobiles.	Around 10 million of automobiles all over the world.	Around 34,804 vehicles throughout the world.	Very few and still in development phase.
Infrastructure	Plentiful	Medium	Very limited	Very limited
Power	High power	Lower than ICE, and depends upon the battery pack.	High power, and depends upon fuel cell stack size.	Intermediate
Pollution	Produces HC, CO, CO_2, NOx and PM emissions.	Zero tailpipe emission vehicles locally, but depends upon the source of electricity generation.	Zero tailpipe emission vehicles locally, but depends upon the source of hydrogen generation.	Lower but still produces emissions
Efficiency	20-35%	60-70%	55-66%	25-43%
Well-to-wheel efficiency	14-18%	18-42%	4-25%	Good Well-to-Wheel efficiency
Driving Range	Higher (500-600 km)	Shorter (150-200 km)	Higher (478-756 km)	Higher (500-600 km)
Performance	High, Known proven technology	Good, Newly and generative technology	Good, Newly and generative technology	Challenges in production
Cost	Lower vehicle and maintenance cost	Higher vehicle and maintenance cost	Higher vehicle and maintenance cost	Higher vehicle and maintenance cost
Fuel	Limited oil reserves last up to 60 years from now.	Infrastructure and electrification problems	Infrastructure and hydrogen refuelling problems	Depends upon the type of hybrid vehicle
Refuelling time	Very low in few minutes	High 4-8 hrs	Very low in few minutes	Intermediate
Coding	Basic coding	Complicated algorithm and difficult coding	Complicated algorithm and difficult coding	Complicated algorithm and coding
Durability and life	High and approximately 15 years or more.	Battery charging repeatability and battery life are low of 2-3 years.	Fuel cell life is around 40,000 hours.	Depends upon the type of hybrid vehicle.
Energy management	More energy destruction	Less energy destruction	Less energy destruction	Depends upon the type of hybrid vehicle
Fuel cost per km	\$0.081-0.13	\$ 0.0315-0.0541	\$ 0.080-0.18	\$0.079
Weight	Complicated and heavy engines	Lighter weight, but battery pack is much heavier.	Intermediate	Heavy weight vehicles

6. Conclusion

The transportation requirement is very large and is continuing to increase, and 99% of the transportation depends on ICEs powered by hydrocarbon liquid fuels such as gasoline and diesel. ICEs are well-established and proven technology, but they are producing harmful emissions. However, engine emission regulations are becoming stricter year by year, but still, due to the large number of vehicles, the transportation sector is responsible for 23% of air pollution. Various governments are now looking into and adopting alternates for transportation such as BEVs, FCVs, and HEVs. Among them, BEVs are more popular due to their zero-tailpipe emissions. The major conclusions drawn from this study are as follows:

- In order to convert all LDVs into BEVs, the capacity of current available batteries will have to be increased by several hundred times, and still accounts for less than half of the total transportation sector.
- The BEVs can produce more GHG emissions than ICEs, if the electricity used for charging the battery is produced from non-renewable sources which currently accounts for more than 60%. This would result in high local pollution, including emissions such as NOx, PM, and SOx, and would be extremely harmful to humans and the environment.
- Manufacturing of batteries requires mining of metals such as lithium and cobalt and would have serious

human toxicity impacts. The recycling and disposal of batteries are also of serious concern and a large investment and infrastructure is required.

- FCVs are growing rapidly due to their zero tail-pipe emissions, and high fuel economy and driving range.
- The major problems encountered with FCVs are production, storage, and transportation of hydrogen. There are only 540 HRS available worldwide, and heavy investments are required to develop infrastructure related to FCVs.
- Currently, BEVs and FCVs are more expensive than ICEs, and long-term subsidies are required to make these vehicles popular and acceptable among customers.
- No doubt, the share of BEVs, FCVs, and HEVs is increasing, but ICEs will be at the center of the transportation sector, especially in HDVs, commercial and sea transport, for decades to come.
- The role of alternate fuels such as LPG, CNG, biodiesel, biofuels, ethanol, and hydrogen is increasing to power ICEs. These could help in reducing GHG emissions and improving energy security concerns and are estimated to power 10% of total energy demanded in transportation by 2040.
- Banning or not investing in the improvement of ICEs would be very short-sighted indeed. So, the transport policies made by different governments should be based on taking account of all available technologies, GHG impacts, local and global environmental, security of energy and supply, economic, social, political, and ethical impacts.

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