|| Volume 9 || Issue 5 || May 2025 || ISSN (Online) 2456-0774
INTERNATIONAL JOURNAL OF ADVANCE SCIENTIFIC RESEARCH
AND ENGINEERING TRENDS

Revolution on Wheels: The Past, Present, and Future of Electric Vehicles

ChandrakeshShukla[1] , Sunil Kumar Pandey[2]
Department of Electrical and Electronics Engineering, MAIT, Sector-22, Rohini, Delhi-110086
Chandrakeshshukla122@gmail.com[1]; skpandey@mait.ac.in[2]

***

Abstract: Electric Vehicles (EVs) have proved to be one of the biggest and the most revolutionary inventions of mankind. Though a concept very popular in the 1800s, there was a decline in the popularity of EVs in the twentieth century due to the rise of Internal Combustion Engines (ICEs). Presently, the EV industry is witnessing a boom due to awareness about climate change and the depletion of conventional sources of energy like Coal, Petroleum, and Crude Oil reserves. This paper gives an insight into the development of EVs as a world-class technology and how successive generations of scientists, researchers, inventors, and engineers have worked to make it reach to the stage where we see it today. It also gives ideas for future research and considers that might be required to be addressed in the forthcoming scenarios to achieve more stability and better efficiency in the EV Sector.

Keywords: *Electrical Vehicle (EV), Internal Combustion Engine (ICE), Variable Frequency Drive (VFD),Electronically Controlled Continuously Variable Transmission (e-CVT), Zero-Emission Vehicle (ZEV).*

***

I.INTRODUCTION:

One of the biggest sources of greenhouse gas emissions is the transportation industry, which is fueling the global movement for greener and more sustainable mobility options. Electric vehicles (EVs), one of the many alternatives to traditional internal combustion engine (ICE) vehicles, have become a promising technology because of their potential to lower carbon emissions, improve energy efficiency, and lessen reliance on fossil fuels. Electric propulsion was first tested as a practical substitute for steam and gasoline-powered engines in the early 19th century, but EVs are frequently viewed as a contemporary invention.

Three main stages can be distinguished in the development and early adoption of EVs in the late 19th and early 20th centuries, their decline in favor of gasoline-powered vehicles as a result of improvements in ICE technology and mass production, and their resurgence in the late 20th and early 21st centuries as a result of environmental concerns and battery technology advancements. With the advent of lithium-ion batteries, government subsidies, and quick advancements in charging infrastructure, EV adoption has increased even more, positioning them as a major force in transportation in the future.

The goal of this review article is to present a thorough examination of the evolution of EVs over time, as well as significant technological advancements, market trends, and potential future developments. It highlights the problems and breakthroughs that have shaped the present EV industry, as well as emerging technologies including solid-state batteries, hydrogen fuel cells, and self-driving EVs. Understanding the evolution of EVs allows us to get insight into the forces driving the current shift to electrified transportation as well as the future of sustainable mobility.

Early History of Electric Vehicles

Early basic electric motors were built and utilized to propel vehicles. In 1827, Slovak-Hungarian priest AnyosJedlik (1800-1895) developed the first primitive but workable electric motor, furnished with stator, rotor, and commutator, and the next year used it to propel a miniature automobile. [1]

In 1835, SibrandusStratingh, a professor of chemistry and technology at the University of Groningen (Netherlands) along with Christopher Becker built an electric motor that powered a small model car built a small-scale electric cell-supplied electrical vehicle weighing about 3 kg and could move for 20 minutes with a 1.5 kg load with its fully charged cells. Its application was made by Thomas Davenport. [1-3].

Between 1832 and 1839, Robert Anderson developed the first crude electric vehicle, using non-rechargeable power cells. Anderson's electric carriage was powered by non-rechargeable primary batteries, which provided the energy needed to drive an electric motor also referred to as the “horseless carriage”. The design was basic and lacked the practical application required for everyday use. Various details about this carriage are unclear from the available sources [4]. The vehicle’s range and utility were severely limited without the ability to recharge the batteries, restricting its applications to demonstrations or short trips. Anderson used crude oil to generate power (in the form of electric current) in the battery he invented. In contrast to the gasoline-powered vehicles, which came later, the crude electric carriage is environmentally friendly. Other inventors during that time used electromagnets (components of electric motors) and batteries to power the electric vehicle.

Robert Davidson, in 1842, built what Mackie, in his article published in Glasgow technical journal “Mr. Davidson's Electro-Magnetic Locomotive" - Galvani. Inspired by the ideas of electromagnetism given by Hans Christian Oersted and William Sturgeon the vehicle has four opposing pairs of electromagnets, with parallel arms twenty-five inches long and rectangular poles five by eight inches. Each of these magnets is timed to attract each of the three armatures approaching successively as the spools rotate, then to cut off as it comes into direct opposition. Two ten-cell batteries with plates twelve by fifteen inches are located at each end. (Later, when forty cells proved insufficient during road tests, Davidson installed two additional nine teen-cell units, one along either side between the armatures.) [6]

The electric motor is often credited to Hungarian engineer AnyosJedlik, while French physicist Gaston Plane invented commercial, rechargeable lead-acid batteries in 1859. It took an Englishman - Thomas Parker - to combine the two in a carriage to create the first production electric car, built in London in 1884 [5]. Thomas Parker was a pioneer in the field of developing Electric Vehicles. He is also credited for the electrification of London Underground and Blackpool Electric Tram. The Elwell-Parkercar was fitted with Parker's high-capacity rechargeable batteries, later vehicles had hydraulic brakes on all four wheels, as well as four-wheel steering. These features are even now being described as revolutionary.

Frenchman Gaston Planté (1834–1889), in 1860, invented the first practical version of a rechargeable battery based on lead–acid chemistry. This battery turned out to be the most successful one of all time. Planté's fundamental concepts were decisive for the later development of practical lead–acid batteries. The 'Pile Secondaire' was indeed ahead of its time in that an appropriate appliance for charging the accumulator was not available. The industrial success came after the invention of the Gramme machine. [7]

After a few 'formation' cycles, French engineer Camille Alphonse Faure (1880-81) was able to achieve high capacities from electrode coatings of sulfur-containing lead powder pastes. Faure covered both sides of smooth lead plates with a thick layer of red lead (Pb_3O_4). During the initial charging, which lasted about two days, the red lead at the positive electrode was converted to PbO_2, while the negative electrode was reduced to spongy lead. [7]

William Morrison, a chemist by trade and an inventor by interest, made a six-passenger electric vehicle in the U.S. considered one of the first practical EVs. Morrison's first electric vehicle, made in 1887, consisted of a carriage manufactured by the Des Moines Buggy Company, equipped with Morrison's new storage batteries and an electric motor to power the right rear wheel. This early model wasn't a great success. Still, The -Twenty-four batteries under the seats gave the carriage just 4 horsepower and a top speed of 20 mph as it rolled on steel-clad wooden wheels. Iowa State Register reported news of Morrison's horseless carriage, then picked up by the Associated Press and soon thousands were reading about this Des Moines pioneer of electronics. -Twenty-four batteries under the seats gave the carriage just 4 horsepower and a top speed of 20 mph as it rolled on steel-clad wooden wheels.

Early 20th Century - The Rise &Fall of Early EVs

In 1899 the "JamaisContente" driven by Belgian Camille Jenatzy was the first electric car to transcend the speed barrier of 100 km/h making it the fastest vehicle to run on electric power. However, since the commencement of the 20th century, the EV industry and ideas witnessed a sharp decline due to the rise of vehicles made with ICEs. At the beginning of the 20th century, gasoline-powered cars became much more popular due to their range and availability of fuel.

Internal combustionvehicles (ICE) replaced electric vehicles at the beginning of the 20th century for several reasons:

- **Range**: At that time, electric vehicles had limited range due to limited battery capacity. ICE cars could travel much longer distances without the need to recharge or change fuel.
- **Availability of Fuel**: Gasoline, needed to run internal combustion engines, was much more accessible and widespread than electricity. At the time, infrastructure for charging electric vehicles was virtually non-existent.
- **Cost**: At the beginning of the 20th century, the production of cars with internal combustion engines was cheaper than the production of electric vehicles. This made cars with internal combustion engines more accessible to a wider audience.
- **Technological Advancement**: At that time, ICE technology was advancing faster than electric vehicle technology.

This has led to improvements in the performance and efficiency of ICE vehicles. In the mid-19th century, electric cars became more popular due to the development of battery technology [8].

After the introduction of the Model T in 1908, Ford took production to 2 million units annually by 1923 and commanded more than 50% of the American car market [9] thus ending the dominance of Electric Vehicles. The EV industry was on the verge of massive destruction and decline after the release of Model T and this led to a boom in the industry running in the manufacturing of vehicles with Internal Combustion engines (ICEs). Had this model failed, the ICEs would never have overtaken the global markets.

The Cadillac Motor Car Company, 1912, introduced the electric self-starter to replace the hand crank. Henry Leland, head of Cadillac, approached Charles F. Kettering of the Dayton Engineering Laboratory Company (DELCO) in 1910 to develop the starter [10]. This helped complement the dominance of ICEs and proved to be one of the key reasons for the decline of EVs which were dominant in the contemporary markets of the 1910s and 1920s.

Thus, after an initial success, there was a significant decline in the market share of Electric Vehicles. The growth of the industry first stagnated and then declined. New inventions and technologies were halted. More stress was placed on the utilization of ICEs and hence, its influence caused a key drop in the number of EVs on roads.

Mid-20th Century: Decline and Brief Revival

World War II and the Rise of Electric Vehicles

World War II led to gasoline shortages worldwide. Major European nations had their economies on the verge of collapse. Moreover, the fall of Germany and Japan caused a setback to the automobile industry. To stabilize the automobile sector, various new companies came into the picture.

"TAMA" is an electric vehicle developed by Tokyo Electro Automobile Co. (later named *Prince Motors, Ltd.) that was a spin-off of Tachikawa Aircraft. When this car first rolled out in 1947, Japan was suffering from an acute shortage of oil, goods, and food while the supply of electricity had a surplus since there were almost no home appliances or bulk users of electricity. Under such conditions, with the government's encouragement, there were many electric vehicles by start-up car manufacturers.

"TAMA" achieved a driving range of 96km and a maximum speed of 35km/h on the 1st Electric Vehicle Performance Test. It worked very well as a taxi until about 1951. The model code is E4S-47 I. E is for electric, 4S is for a 4-seater sedan, 47 is for the year, and I stands for the initial type. The brand name "TAMA" comes from the name of the place where the factory was located. It is not very well known that electric vehicles have a long history --they were running in Japan shortly after WWII and helped reconstruction of Japan. This car was fully restored to the original specifications of the year 1947 and returned to moving state in 2010 when the production model of the electric vehicle "NISSAN LEAF" was rolled out. [11]

General Motors Electrovair, 1963

General Motors (GM) experimented with electric vehicles long before the EV1, commonly regarded as the first modern EV. In 1963, GM developed the Electrovair, an electric version of the Corvair, as an early attempt at a practical EV. While most early EVs used DC motors, the Electrovair featured a 3-phase AC induction motor, a significant technological leap. This motor was powered by a DC to AC inverter, marking one of the earliest uses of modern variable frequency drive (VFD) technology in an electric car. However, the Electrovair remained an experimental prototype rather than a commercially viable vehicle due to battery limitations.

Electric cars have been part of automotive development since the early 1900s, competing with gasoline-powered cars before losing relevance due to limited range and slow charging. However, by the 1950s and 1960s, growing concerns over air pollution, particularly in California, led to renewed interest in alternative powertrains. The Corvair was chosen for this experiment because of its lightweight design and rear-engine layout, which made it a suitable test platform for an electric powertrain.

One of the most important breakthroughs in the Electrovair was the use of solid-state electronics, specifically silicon-controlled rectifiers (SCRs), which allowed precise control over the AC motor's speed and torque. This technology laid the groundwork for the modern inverter-driven AC motors used in today's electric vehicles. However, despite its advanced motor system, the Electrovair was severely limited by its battery technology. The prototype relied on silver-zinc batteries, which were not only extremely heavy but also had short lifespans and poor rechargeability. These limitations meant that, although the Electrovair demonstrated the potential of electric propulsion, it was far from practical for everyday use.

The key lesson from the Electrovair project was that EV technology was ready decades ago, but batteries were not. The concepts developed in this experimental vehicle—AC motors, inverter-based control, and solid-state switching—are still central to modern EVs. However, it took the advent of lithium-ion batteries in the late 20th and early 21st centuries to finally make electric vehicles commercially viable. The development of the Electrovair reflects a long history of innovation in electric transportation, driven by environmental concerns and technological advancements, much like the current push toward electrification in the automotive industry. [12].

Sebring-Vanguard CitiCar

Electric car pioneer Bob Beaumont was the visionary behind the CitiCar, a compact and efficient electric vehicle designed as an alternative to gas-guzzling cars of the 1960s. Originally a car dealer, Beaumont became frustrated with the environmental impact of traditional vehicles and sought a better solution. Reflecting on his motivation, he once remarked, “There’s got to be a better way than to pump this stuff out of the ground and piss it away in gas tanks,” as quoted in a 2008 interview with the *Baltimore City Paper*.

Through his company, Sebring Vanguard Motors, Beaumont became the most prolific electric car manufacturer in U.S. history, producing over 2,000 vehicles in just three years. The first CitiCar model, introduced in 1974, featured a 2.5-horsepower motor powered by a 36-volt battery pack. It was priced at approximately USD 3,000 and had a top speed of 42 km/h. A later version, the SV-48, improved performance with a 48-volt battery, allowing speeds of up to 62 km/h.

Despite safety concerns, the CitiCar paved the way for future compact EVs. After Sebring Vanguard Motors was acquired, production continued under a new name, resulting in the Comuta-Car. Beaumont’s impact on the electric vehicle industry remains significant, and in 1992, he humorously noted, *“*We’ve had more CitiCar sightings than Elvis.”

Late 20th Century: Modern Research and Experimentation

The end of the 20th Century saw tremendous growth in the EV sector. In 1976, the US Department of Energy (DOE) started funding the research and promotion of Electric Vehicles playing a crucial role in the development of advanced battery management systems and technologies. This initiative led to the rise of several new players to foster and propagate the Electrification of Vehicles.

A great deal of this progress is attributed to the California Air Resources Board (CARB), which, in 1990, mandated automakers to develop zero-emission Vehicles (ZEVs) to ensure that Californians could breathe clean air following the problem of Smog in the 1970s and 1980s. The ZEVs were made available in the marketplaces. The strength of the ZEV production requirement has been the promise of a market for these clean technologies, making car makers and suppliers take a giant step forward during the past decade. [14].

General Motors EV1

GM's entry into the foray of environmental awareness came not in the form of recyclable automotive parts (where Ford had begun to venture) but from improved fuel economy (where Honda and Toyota have made significant strides). Rather, GM had introduced one of the most technologically advanced vehicles ever produced—the EV1. What made the EV1 so revolutionary was that it was not powered by gasoline; it was an electric car. The EV1 (Electric Vehicle 1) was not only a symbol of corporate change at GM but also a driving force behind further change. The EV1 was produced in an unprecedented blend of technological innovation and executive-level transformation, which resulted in a product that was produced on time, nearly on budget, and in many ways, on target. [15]

The GM EV1 featured an aerodynamic design with a drag coefficient of 0.19, a lightweight aluminum space frame, and composite body panels for efficiency. It was powered by a three-phase AC induction motor (137 hp) with lead-acid or NiMH batteries, offering a range of 70-140 miles. The EV1 included regenerative braking, low-rolling resistance tires, and a heat pump-based climate control system to maximize efficiency. [16]

It had advanced electronics, including a Power Electronics Module (PEM) and a digital instrument cluster, alongside inductive charging (MagnaCharge) for safer, wireless charging. Safety features included a high-strength safety cage, dual airbags, ABS, and traction control. The EV1 was a pioneering electric vehicle, influencing the future of EV technology despite its short production run. [16]

Toyota Prius

The 1997 Toyota Prius, the world's first mass-produced hybrid car, featured a compact aerodynamic design with a drag coefficient of 0.29, optimizing fuel efficiency. It used a Hybrid Synergy Drive, combining a 1.5L 4-cylinder gasoline engine (58 hp) with a 33 kW electric motor, delivering a total output of 98 hp. The nickel-metal hydride (NiMH) battery provided electric power assistance and enabled regenerative braking for energy recovery.

The Prius had an electronically controlled continuously variable transmission (e-CVT) for smooth power delivery and low rolling resistance tires to enhance efficiency. Safety features included dual airbags, ABS, and traction control. With a fuel efficiency of around 50 mpg, the 1997 Prius revolutionized hybrid technology, paving the way for modern fuel-efficient vehicles.

Honda Insight

The 1999 Honda Insight, Honda's first hybrid car, featured a lightweight aluminum body, making it one of the most fuel-efficient cars of its time. It had a drag coefficient of 0.25, enhancing aerodynamics for better efficiency. The Insight used a 1.0L 3-cylinder gasoline engine (67 hp) paired with a 10 kW electric motor, utilizing Honda's Integrated Motor Assist (IMA) system to improve fuel economy.

It was equipped with a nickel-metal hydride (NiMH) battery, regenerative braking, and a 5-speed manual or CVT transmission. The Insight also had low rolling resistance tires and an auto stop-start system to reduce fuel consumption. With an impressive fuel efficiency of up to 70 mpg, the Honda Insight set new standards for hybrid technology, influencing future eco-friendly vehicles.

21st Century: The EV Revolution

The 21st century has witnessed a remarkable shift in the automotive industry, driven by the urgent need for sustainable transportation. The Electric Vehicle (EV) revolution is transforming the way we think about mobility, offering a cleaner, more efficient alternative to traditional internal combustion engine vehicles. Advances in battery technology, charging infrastructure, and government policies have accelerated EV adoption worldwide, making them more accessible and practical for everyday use. With major automakers committing to electrification and technological breakthroughs enhancing performance and affordability, EVs are set to dominate the future of transportation, reducing carbon footprints and reshaping global energy consumption.

Battery Management System

The EV performance mainly relies on the battery performance and battery management system (BMS). Recently, the Lithium-ion (Li-ion) battery has been mainly used as a battery in EVs due to its smaller weight, high energy density, and capability of fast charging and discharging. Considering the dynamic performance, economy, safety friendliness to the environment of the EVs, the BMS is designed such a way to meet challenges like the energy management of battery, reduction of heating-time at low temperatures, and enhancing remaining-useful life (RUL) with the accuracy of prediction. The battery is managed and controlled by BMS and it is mainly focused on maintaining reliability and safety. [17]

Development of the latest EV Technology

Tesla

Tesla as a high-tech company without any background in the automotive industry, only used more than ten years to become one of the world's top ten innovative companies in the vehicle manufacturing industry. The reason is that Tesla is in a better innovation environment, Tesla is headquartered in the Silicon Valley, California area.

Tesla turned out in Silicon Valley, with a new way to think about the design manufacture, and operation of vehicles, from luxury cars to making drawings into reality. Standing at the intersection of science and technology, cars, and energy, Tesla conducted subversive thinking and research and development about the new energy vehicle. Tesla is the only one using batteries 18650 ternary lithium-ion battery electric car company; in motor, which uses a dual motor all-wheel drive; the body, which uses an aluminum body, has become North America's only aluminum body car; in terms of security, the Tesla Model S is only European Euro NCAP and US high-speed Road Safety Authority dual star-winning car. [18]

Toyota

Japanese car enterprises committed to the development of lightweight and low energy consumption, Toyota as Japan's largest car company, in hybrid cars, in research and development of plug-in hybrid electric vehicles, pure electric vehicles, and fuel cell vehicles at the forefront of the world. At present, Toyota's hybrid car sales are in the world's first position, the development of pure electric vehicles and the pace of industrialization is the fastest, fuel cell vehicle industry is also the world's leading. Toyota over a long period of development and application of new energy vehicles has mastered the advanced of new energy vehicle technology, formed a very mature new energy automotive industry, and established a fairly complete charging infrastructure, the new energy vehicle development path can be summarized as: The fuel diversification, the comprehensive development of pure electric vehicles, hybrid vehicles, and fuel cell vehicles, pure electric mainly for a close and small family, as a normal hybrid vehicle for the average family car, commercial fuel cell vehicles for long-distance transport. At the same time, Toyota developed an overseas expansion strategy, which can achieve the development of new energy vehicles in the localization. For example, in North America, Toyota's car sales in the United States, are approximately 70% by the Toyota assembly plant in the United States, Canada, and Mexico. At the same time, set up research and development centers around the world to understand the needs of different consumers, which is a major component of the development of Toyota's overseas strategy. [18]

Future (2025 and Beyond)

The future of electric vehicles (EVs) beyond 2025 promises groundbreaking advancements in battery technology, charging speed, and autonomous driving integration. Innovations like solid-state batteries will offer higher energy density, longer range, and faster charging, addressing current limitations. The expansion of ultra-fast charging networks and wireless charging will make EVs more convenient for users.

Governments worldwide are pushing for stricter emission regulations and incentives, accelerating EV adoption. The rise of AI-driven autonomous EVs and vehicle-to-grid (V2G) technology will further revolutionize mobility. With major automakers committing to an all-electric future, EVs are set to dominate the roads, leading to a cleaner, more sustainable transportation era.

Wireless Charging

Wireless charging or wireless power transfer (WPT) enjoys significant interest because of the conveniences it offers. This system does not require the plugs and cables required in wired charging systems, there is no need to attach the cable to the car, low risk of sparks and shocks in dirty or wet environments. and less chance of vandalism.

Inductive power transfer (IPT) is a mature technology, but it is only contactless, not wireless. Capacitive power transfer (CPT) has a significant advantage at lower power levels because of low cost and size, but not suitable for higher power applications like EV charging. Permanent magnet coupling power transfer (PMPT) is low in efficiency, other factors are not favorable as well. Resonant inductive power transfer (RIPT) as well as Online inductive power transfer (OLPT) appear to be the most promising ones, but their infrastructure may not allow them to be a viable solution. Resonant antennae power transfer (RAPT) is made on a similar concept as RIPT, but the resonant frequency, in this case, is in the MHz range, which is capable of damage to humans if not shielded properly. The shielding is likely to hinder range and performance; generation of such high frequencies is also a challenge for power electronics. [19]

Solid State Batteries

SSBs are an emerging technology that has the potential to revolutionize the energy storage industry. Unlike traditional LIBs, which use a liquid electrolyte to transport ions between the cathode and anode, SSBs use a solid-state electrolyte (SSE) to perform the same transport function. [20]

Solid-state batteries (SSBs) are emerging as a game-changer in the electric vehicle (EV) industry, promising higher energy density, faster charging, and improved safety over conventional lithium-ion batteries. Unlike traditional batteries that use a liquid electrolyte, solid-state batteries use a solid electrolyte, which reduces the risk of overheating, fire, and degradation over time.

These batteries offer greater efficiency, allowing EVs to achieve longer ranges on a single charge while reducing overall weight. Additionally, solid-state technology enables faster charging times, potentially reducing the time needed to recharge an EV to just a few minutes.

Despite challenges in scalability and production costs, major automakers and battery manufacturers are heavily investing in R&D to commercialize solid-state batteries by the late 2020s. As advancements continue, solid-state batteries could redefine EV performance and accelerate the transition to a fully electric future.

Hydrogen Fuel Cells

Hydrogen fuel cell electric vehicles (FCEVs) are expected to see significant growth between 2030 and 2050, driven by cost reductions, extended range, and improved refueling infrastructure. With zero emissions (only water as a byproduct), fast refueling times (3-5 minutes), and increasing efficiency, FCEVs are positioned as a strong alternative to battery electric vehicles (BEVs), especially for long-range and heavy-duty applications.

Investments in hydrogen refueling stations (HRS) worldwide will be crucial for widespread adoption. Countries like Japan, the U.S., and Germany are leading infrastructure development, with plans to expand networks significantly by 2050. Moreover, advancements in hydrogen production and storage, including the use of renewable energy sources for green hydrogen, will enhance sustainability.

While challenges such as high production costs and limited refueling stations remain, ongoing research and policy support indicate that FCEVs will play a vital role in the decarbonization of the transportation sector, complementing BEVs and shaping the future of clean mobility [20]

II.CONCLUSION

The journey of electric vehicles (EVs) from their early conceptualization in the 19th century to their resurgence in the 21st century highlights the dynamic nature of technological progress and environmental consciousness. Once overshadowed by internal combustion engine (ICE) vehicles due to limitations in battery technology, range, and infrastructure, EVs have made a strong comeback, driven by advancements in lithium-ion batteries, solid-state batteries, and fast-charging networks. The shift towards electrification is further accelerated by government policies, global sustainability goals, and the urgent need to reduce carbon emissions.

Today, EVs are no longer a niche technology but a mainstream alternative to traditional vehicles, with continuous innovations making them more efficient, affordable, and practical for everyday use. The rise of autonomous EVs, wireless charging, and vehicle-to-grid (V2G) technology promises to reshape mobility, making transportation not just cleaner but also smarter and more interconnected. Additionally, hydrogen fuel cell technology is gaining traction for long-range and heavy-duty applications, complementing battery-electric solutions in the push toward carbon neutrality.

Despite the challenges of battery production, supply chain constraints, charging infrastructure, and initial costs, the global push toward electrification is irreversible. Major automakers and governments worldwide are investing heavily in sustainable mobility solutions, ensuring that EVs will dominate the future of transportation. As research continues to address existing limitations, the next few decades will witness an even faster acceleration of EV adoption, ultimately leading to a world with cleaner, more efficient, and environmentally responsible transportation systems.

III.REFERENCES

1. M. Guarnieri, "Looking back to electric cars," IEEE History of ELectro-technology Conference (HISTELCON), Pavia, Italy, 2012, pp. 1-6.
2. H. Scheer, Energy Autonomy: The Economic, Social and Technological Case for Renewable Energy. London (UK): Earthscan, 2007.
3. Morimoto, M. (2015), Which is the First Electric Vehicle? ElectrEngJpn, vol.192, pp. 31-38.590807.pdf

   Sci-Hub | | 10.2307/43520448TrygubO._electric car.pdf
4. A. Korneev, Y. Niu, and A. Ibrahim, “Electric Vehicles in the 21st Century: Historical Evolution, Environmental Impact, and Safety Challenges for Sustainable Mobility”, KHWARIZMIA, April 2024, pp. 32–38.Ford vs. Tesla: What Does a Transformational Automobile Scale-up Look Like?
5. Cho, C. P., Wylam, W., & Johnston, R. (2000). The Integrated Starter Alternator Damper: The First Step Toward Hybrid Electric Vehicles. SAE Technical Paper Series. Nissan | Heritage Collection | Tama Electric Car
6. The history of GM's Electovair EV“Up Front.” ReNew: Technology for a Sustainable Future, JSTOR, 2012.vol. 118, pp. 12–15.
7. Turrentine, T., &Kurani, K. S. Progress in Electric Vehicle Technology and Electric Vehicles from 1990 to 2000: The Role of California's Zero Emission Vehicle Production Requirement. UC Davis: Institute of Transportation Studies.
8. Johnson, B. (1999). Environmental products that drive organizational change: General Motor’s electric vehicle (EV1). Corporate Environmental Strategy, 6(2), 140–150.

   The GM EV1 Was GM's First Major Effort In Modern All-Electric Vehicles.
9. S. Mishra, S. C. Swain and R. K. Samantaray, “A Review on Battery Management system and its Application in Electric Vehicle,” International Conference on Advances in Computing and Communications (ICACC), Kochi, Kakkanad, India, 2021, pp. 1-6.

10. Liu, J. H., &Meng, Z.. Innovation model analysis of new energy vehicles: taking Toyota, Tesla and BYD as an example. Procedia engineering, 174,pp. 965-972.
11. Un-Noor, F., Padmanaban, S., Mihet-Popa, L., Mollah, M. N., &Hossain, E. (2017). A Comprehensive Study of Key Electric Vehicle (EV) Components, Technologies, Challenges, Impacts, and Future Direction of Development. Energies, 10(8), 1217.
12. Thomas, F., Mahdi, L., Lemaire, J., & Santos, D. M. F. (2024). Technological Advances and Market Developments of Solid-State Batteries: A Review. Materials, 17(1), 239.
13. Tanç, B., Arat, H. T., Baltacıoğlu, E., &Aydın, K. (2019). Overview of the next quarter century vision of hydrogen fuel cell electric vehicles. International Journal of Hydrogen Energy, 44(20), pp.10120-10128.