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TOPICAL REVIEW

Challenges, Solutions and Future Trends in EV-Technology: A Review

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ABSTRACT The transportation industry is one of the greatest contributors to a growing carbon footprint. As the world increasingly prioritizes a greener and cleaner future, the transition from ICEs to EVS offers significant benefits as EVs are zero-emission vehicles. However, considering the production and disposal stages of EVs, they cannot be considered entirely emission-free. But in comparison to ICEs, they still have a much smaller carbon footprint. Moreover, studying EV technology is essential to bringing this to the lowest possible extent. However, these advancements come with challenges. In this review article, we have taken an in-depth look into the various challenges, namely the economic challenges, technological challenges, and environmental challenges, faced by EV technology today and the various solutions proposed by researchers, their limitations, and future potential in EV technology advancement. Within this context, we discuss the influence of governmental policies, accessibility and affordability of EVs to the masses, natural and man-made disasters, economic instability, technological limitations posed by the vehicle technology, and limitations posed by battery technology with batteries being the central element for EVs, limitations associated with the existing infrastructure and its ability to support widescale use of EVs, and environmental factors like carbon footprint, among other factors, on EVs technology and the opportunities this technology can make use of in the future. This paper discusses these concerns in detail and gives extensive insight into the challenges, solutions, and future trends pertaining to economic impacts, vehicle technology, battery technology, power grids and charging infrastructure, and environmental impact, of EVs and EV technology.

INDEX TERMS Electric vehicles, LIBs, power grid, WPT.

I. INTRODUCTION

As the world population grows, so do people's desires and energy demands. These demands have been increasing exponentially in recent years. This holds true, especially for the transport/vehicle industry. With very urgent issues like global warming, ozone layer depletion, pollution, and the health hazards that these problems bring, it has become imperative to reduce our carbon footprint. With new and better technology developed over the past decades making automobiles more accessible and affordable for the masses. Consequently, the energy required to meet public demand and the energy needed to keep these automobiles or vehicles running has also been increasing. However, using fuel as a source of this energy can leave a significant carbon footprint. The transport industry has one of the largest carbon footprints, leading to heavy greenhouse emissions which can cause a variety of environmental problems [1]. The introduction of Electric Vehicles, also referred to as battery cars, is thought to hold the key to resolving the smog problem. This is because Electric Vehicles do not depend on conventional fuel sources and exhibit considerably lower levels of carbon emissions in comparison to conventional internal combustion engine vehicles. Plug-in hybrid electric vehicles (PHEVs) are believed to have the potential to decrease carbon dioxide (CO2) emissions, whereas battery electric vehicles (BEVs) have the capability

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to reduce CO2 emissions by as much as 90%. In general, the impact of EVs on CO2 emissions showed that the use of EVs can reduce these emissions by 72%. Although EVs reduce greenhouse gas emissions during the consumption phase, they increase emissions during the production phase. However, the significant reduction in greenhouse gas emissions during the consumption phase outweighs this increase [2], [3]. This leads to a notable decrease in the overall carbon footprint. Moreover, due to the absence of an IC engine, EVs run quieter, addressing noise pollution, which is a prevalent concern in many urban areas, without forgetting the reduction of fossil fuels dependence [4], [5]. Additionally, over time, owners of EV can benefit financially from decreased maintenance and fuel expenses. Moreover, EVs are found to reduce greenhouse emissions by 30-80% [6]. Such advantages explain the growing popularity of EVs nowadays and thus, for the aforementioned reasons, it is imperative to study the challenges we face while transitioning to battery-based vehicles, that is, EVs. A complete transition to EVs is a long process due to the myriad of problems we face. The expansion of electric vehicles (EVs) in the industry is currently restrained by various challenges, including elevated acquisition expenses, restricted driving range, inadequate charging infrastructure, and prolonged charging duration, which affect its market penetration. Therefore, it is crucial to investigate and understand these challenges to find appropriate solutions. Figure 1 shows a flow chart outlining these challenges and opportunities associated with EV technology, as discussed in this paper.

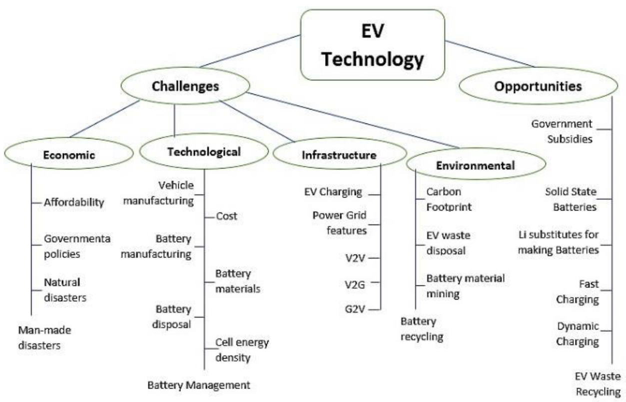

FIGURE 1. Challenges and opportunities discussed in this paper.

II. ECONOMIC CHALLENGES

A significant major challenge limiting EVs popularity and accessibility is the economic challenge associated with them. Compared to the still-developing EV technology, conventional IC engine vehicles, which have matured over time, are much more affordable. This results in higher prices for EVs in the current market. Figure 2 shows EV sales in various countries around the globe up until 2020. The EV technology requires further improvement and refinement to become economically viable and widely affordable [7]. Furthermore, the promotion of EVs will also need the help of the government in framing EV-beneficial policies. EVs can have a very significant economic impact on many industries and economic sectors, sometimes even negative. This holds particularly for oil-producing countries that rely heavily on revenues from these industries [8], [9]. The sudden introduction and heavy support for EVs by the government can lead to disrupt the economic balance. For efficient promotion of EVs one of the biggest hurdles is still their market price. Along with this, a severe deficiency in the knowledge regarding EVs by end users and the uncertainty in the residual value of EVs are other contributing factors that induce a negative impact on the integration of these battery-powered vehicles into the market [4]. As a result, EV technology research and improvement should be accelerated as much as possible. Studies have shown that a 1% decrease in retail price could boost EV sales up to 4% [10], [11]. Government-sponsored financial incentives are responsible for the strong sales of EVs, especially in nations like Norway. Some of these incentives, such as the exemption from toll fees, might, however, have unfavorable results, such as a sharp decline in toll income. Additionally, the National Statistical Institute of Norway [8] reports that there was 3.6% fewer passengers using public transit during the same quarter last year. This kind of trend could result in the country having a larger carbon footprint.

Li-ion batteries powering EVs, present economic challenges by themselves. In recent years, while the energy density of those batteries has increased, costs have declined, thanks to technological advancements. However, their mass production remains challenging. Also, making batteries for EV applications using conventional materials is not possible. Highly advanced technology, scarce and expensive materials like cobalt, are required as these batteries need substantial capacities to ensure long ranges [12]. Consequently, The high cost of batteries and their production contributes to elevated prices of EVs today.

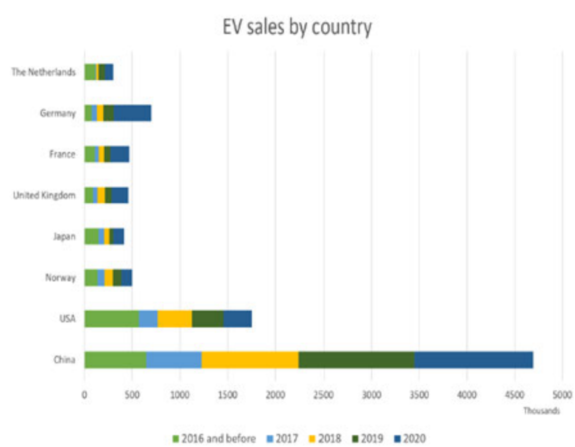

FIGURE 2. EV sales in various countries up until 2020 [8].

EV charging infrastructures can be categorized into three types based on their accessibility: public, semi-public, and private. The availability of semi-public charging infrastructure is restricted to a specific group of individuals, while public charging infrastructure is universally accessible and is commonly situated at public parking facilities. Infrastructure located in private garages or homes is referred to as 'private'. Private charging infrastructures outweigh public charging infrastructures because they are more convenient for EV customers and are more preferred by users [13], [14]. Nonetheless, it is well established that public charging facilities are essential for EV adoption and for helping EV customers get over their range anxiety [15]. The present growth of electric vehicles (EVs) in the market is hindered by a notable impediment, specifically the financial burden of establishing public charging infrastructure. The significance of this factor is pivotal in the market penetration of electric vehicles. Typically, due to high initial costs and dwindling profit margins resulting from low adoption, the economy has been adversely affected. Schroeder and Traber discovered that the charging stations in Germany had poor profitability due to high initial installation costs and low usage rates [16]. Additionally, the charging price has an impact on the viability of the charging stations. As per the findings of Li and Ouyang, it is imperative to raise the charging price by at least 25% to ensure the economic feasibility of charging stations in China [17]. The profitability of charging stations necessitates consideration of multiple factors. Among the most significant ones is demand. Densely populated cities or towns are ideal for charging stations given the higher probability of accommodating EV users [18], [19]. Another significant barrier is the cost of constructing a power system that has the capability to accommodate EV charging stations. The lack of proper power grid infrastructure and charging stations to support EVs is one of the major reasons why the sales of EVs are very low and the price is high and stagnant [5].

Economic challenges can also be caused by unforeseen disasters. Events such as the Covid pandemic, economic recessions, and the Ukraine-Russia war are illustrative examples. A good example of this is the surging energy prices seen in Europe, and in particular the UK. The Pandemic, followed by the war, led to severe restrictions and reduction in many necessary resources not available in the UK was restricted and reduced severely. This coupled with the shutdown of many facilities producing fossil fuels needed to meet the energy requirements, caused severe deficiency in the fuel reserves held. This in turn caused a deficiency in the energy supply while demand remained the same. Energy prices surged as a result. This condition was further intensified by the Ukraine-Russia war as Russia stopped the export of oil which severely reduced the amount of oil imported and available to the UK. This resulted in a scarcity of vital resources for energy production. With increased energy prices the costs associated with EVs can also increase and can discourage people from buying EVs.

Another economic challenge relates to geography's impact on raw material availability. Batteries constitute roughly 33% of the cost of the vehicle and the materials needed for making Li-ion batteries like Li and Co are expensive. Moreover, some countries do not possess any of these specific minerals. Thus, many countries rely on importing these minerals for local battery manufacturing. One example of this is India's lack of Li deposits. The import and the diplomacy with the exporting countries can all have a significant influence on the battery cost. This can lead to a higher cost of batteries and in turn the higher cost of EVs. Thus, making it more unaffordable for the masses [20].

In summary, the retail price of EVs remains notably higher than that of conventional ICE vehicles, rendering their widespread adoption a challenge without further technological advancements.

III. TECHNOLOGICAL CHALLENGES POSTED BY THE VEHICLE

There are a lot of challenges we face in the manufacturing, maintaining, and supporting of EV technology. An EV's body must be constructed as light as possible, as other components like batteries and motors can be significantly heavy despite their small size. Moreover, the electric motors driving the EVs are not yet at a point where they can still produce enormous power, instantaneous torque or maximum, speeds like IC engine vehicles. Evs with a bulky body that can match IC engine vehicle outputs are still considered luxury vehicles. Thus, the materials chosen to make the vehicle body lightweight might be costly because they need to be strong and safe. The development and manufacturing of such materials can be complex. Similarly, EV energy systems require high-grade materials, intricate manufacturing methods, and rigorous safety procedures' Due to the advanced technology, rigorous safety standards, and complex manufacturing of EV parts, their repair and replacement can be complicated, time-consuming, and costly, resulting in high maintenance costs. This can only be resolved by developing new technologies that make EVs more easily manufacturable [21]. The production of EVs can be done via two different methods. One is the conversion of an IC engine vehicle into an EV by facilitating the replacement of the engine, fuel tank, and associated equipment with batteries, electric motors, and controllers. This conversion process is cheaper in comparison to buying an originally designed EV. However, vehicles that undergo this kind of conversion will end up having a bigger curb weight, a center of gravity set at a higher point than before conversion, and a potential weight imbalance [22]. All these unnecessary developments can lead to difficulty in handling the vehicle. For safety reasons, choosing an originally built EV is often more feasible than opting for a converted one.

IV. TECHNOLOGICAL CHALLENGES POSTED BY THE EV BATTERIES

Lithium-ion batteries are the predominant type of battery utilized as a source of energy for electric vehicles (EVs). In comparison to other types of batteries, lithium-ion batteries possess a higher energy density, occupy less physical space, and demonstrate superior efficiency. But this technology is not perfect either. The use of Li-ion batteries comes with its challenges, which if not paid attention to can be extremely dangerous. The batteries employed in electric vehicles (EVs) are widely regarded as one of the most expensive components of electric vehicles. Therefore, it is imperative to examine the constraints and investigate methods to enhance them.

Safety is a primary concern associated with the utilization of Li-ion batteries. The topic of the potential detonation of Li-ion batteries used in mobile devices and other electronics, which can result in severe harm, including permanent disability or fatality in rare cases, is frequently discussed. These incidents take place because of batteries that can fit within our palms. However, EV batteries are much larger, and their failure can result in fatal incidents. This is why it is required to make sure that the batteries are designed with compatibility with EVs in mind, and extra caution must be taken. In most cases, such explosions are caused by a rise in temperature. A notable rise in battery temperature can give rise to safety apprehensions, including but not limited to thermal runaway, electrolyte fire, swelling, and explosions [23]. For EVs, it's crucial to monitor and prevent over-discharge or overcharging, as this can spike the battery temperature and trigger adverse chemical reactions [24]. Prudent measures must be taken to maintain battery temperature within a certain range to avoid unwanted problems. This is another challenge that the industry faces unlike traditional vehicles, which are designed to withstand prolonged high-temperature engine operation, the functioning duration of lithium-ion batteries is considerably limited [25]. When exposed to temperatures above 150 °C, electrolytes undergo a process of self-destruction. This can lead to a rapid decline in the performance of the battery, and in some cases, may even give rise to security concerns. (e.g., cause it to catch fire or explode) [8]. Currently, a significant proportion of contemporary Plug-in Hybrid Electric Vehicles (PHEVs) and Electric Vehicles (EVs) rely on this specific type of battery as their primary power source. Thus, it is important to conduct further research into the thermal and chemical stability of these batteries, the factors that influence them, and what improvements can be made. Li-ion batteries today can operate in a range between −20°C and 60°C. The temperature of the environment can have a significant influence on the Li-ion battery's charging rate. To prevent any detrimental iToe batteries, the charging system restricts the charging rate during low-temperature conditions. This is because temperatures below 0°C can impede charging, reducing battery functionality and efficiency due to slower ionic movement and diminished ionic conduction. Fast charging of Li-ion batteries is an essential factor for the proper functioning of EVs and is also one of their great selling points. However, this function is highly restrained in severely cold climatic conditions. This was seen to occur due to the kinetics of the graphite anodes being slower in cold conditions. Metallic plating of lithium being deposited on the graphite anode was also observed and, the plated lithium was seen to undergo further reaction with the electrolyte and result in the thickening of solid electrolyte interphases combined with increased polarization. This was seen to lead to decreased lifespan and battery capacity. According to reports, the phenomenon of lithium plating has been observed to promote the generation of gas, leading to the formation of gas pockets on the electrodes, thereby hastening the failure of the cell. The interaction of coated lithium and ions, as well as the incidence of internal short-circuiting brought on by lithium dendrites, may cause the phenomenon of thermal runaway. This can exacerbate the situation. It is highly important to install temperature management systems that keep the batteries warm around 25-40°C by heating in extremely cold weather conditions and cooling in extremely hot weather conditions. Very high temperatures can lead to degradation of the cell. If the battery temperature for Li-ion batteries reaches 150°C it may lead to the decomposition of polymer material in these batteries and thus cause damage to the battery, and even lead to safety issues [5], [8], [25], [26], [27], [28], [29], [30], [31], [32]. This makes the recharging function of the Li-ion batteries poor in cold regions. Hence, recharging EVs in cold regions is a huge unsolved challenge.

Emerging technologies in EVs propose alternatives to overcome the safety and thermal limitations of Li-ion batteries. These technologies encompass the substitution of lithium-ion batteries with either solid-state batteries or aluminum-ion batteries. Unlike Li-ion batteries that have liquid electrolytes which are prone to leaking and causing explosions in case of atmospheric exposure, solid-state batteries have only solid components and no liquid components. This helps in eliminating the chances of leaks and fires caused by liquid electrolytes. Solid-state batteries offer a superior energy density, an extended lifetime and reduced size and weight, without the need for intricate cooling and heating systems. Their mass production and integration into EVs could also reduce overall vehicle costs [33], [34], [35], [36].

Al-ion batteries, using aluminum as an anode instead of lithium, can be both safer and more cost-effective than their Li-ion counterparts, although there's a trade-off in terms of charging times and overall life cycle [8].

A compelling alternative to Li-ion batteries is sodium-ion (Na-ion) batteries. Na and Li both belong to the group-1 batch of elements and both of them have a loose electron that they can very readily lose in order to oxidize ionic state of Na+ and Li+. Also, Na-ion batteries can be near Li-ion batteries in performance. Li is expensive and limited in supply when compared to Na. This is a major constraint imposed on Li-ion batteries that makes them very expensive and hard to manufacture. Replacing Li with Na can solve this issue. Considering that the batteries cost around one-third of the EV cost, this development can help greatly in reducing the overall costs of EVs in the market and make EVs more affordable. Na-ion batteries employ a hard carbon (HC) anode, which exhibits a low voltage and a high gravimetric capacity of 300 mAh g-1, a value that is similar to that of graphite in Li-ion batteries. This is one of the main reasons Na-ion batteries are being considered to replace Li-ion batteries (372 mAh g-1). This was seen to be occurring because of the intercalation of Na in HC. Due to its abundant availability, good intercalation of Na in HC, it being cheap, HC is currently the best choice for the anode material in Na-ion batteries, as the main goal of developing Na-ion batteries is to have a battery cheaper than Li-ion batteries but can deliver the same performance as a Li-ion battery. This can also solve the issue of supply risk shortage for Li in Li-ion batteries, as Na is abundant and thus is more suitable for making batteries that have a very widespread application. One additional reason that makes Na-ion batteries cheaper and more attractive compared to Li-ion batteries while giving the same performance as Li-ion batteries are the layered metal-oxides, polyanion compounds, and Prussian blue analogs. Using common metals like iron, manganese, and magnesium in the cathode material makes Na-ion batteries even more cost-effective. Further, they are lighter than Li-ion batteries due to both anode and cathode collectors being made of aluminum; while, in Li-ion batteries the anode is Copper, and the cathode is Aluminium. The copper is denser than Aluminium. The absence of copper along with the replacement of Li with the abundantly available Na, can make the final product lighter and much cheaper. Figure 3 presents the schematics for Li and Na-ion batteries. The utilization of collectors composed of identical materials confers an additional benefit in that it simplifies the process of charging and discharging the battery at 0V, while concurrently mitigating the deterioration of the batteries. Battery function at 0V also plays a major role in enormously improving safety and decreasing chemical hazards. The utilization of Na-ion batteries presents an additional benefit in terms of cost-effectiveness due to the utilization of a less expensive electrolyte during the production process. The cost of $NaPF_6$, which serves as an electrolyte in Na-ion batteries, is four times lower than that of $LiPF_6$, which is utilized in LI-ion batteries. This tips the economic scale in favor of Na-ion batteries. Na-ion batteries are also safer, with better abuse tolerance and thermal stability. Thus, making it a much safer option [37], [38], [39], [40], [41], [42].

Current Li-ion batteries used in EVs have a specific energy of 250-300Wh/Kg, and the battery pack costs $156/kWh. Nevertheless, for EVs to achieve very high market penetration, it is imperative that the specific energy is bought up to about 350Wh/Kg to provide a good driving range of at least 500km and, the battery pack price should be brought down to about $125/kWh. Sadly, the current EV batteries cannot achieve such high specific energy nor low battery pack costs. The electrodes are a significant contributing factor to this phenomenon. The process of lithium intercalation between the graphite anode and the lithium transition metal oxide (LMO) cathode is a crucial factor that determines the specific energy and energy density of a Li-ion battery. Currently, a solution to this issue involves the utilization of metallic Lithium anodes instead of graphite anodes. The main reason is the high disparity in theoretical capacity or energy density of metallic lithium anode (3860mAh/g) and graphite anode (372mAh/g). The metallic lithium anode has a theoretical capacity that exceeds conventionally utilized graphite anodes by a factor of more than 10. A lower electrochemical potential also accompanied the use of metallic lithium anodes compared to using graphite anodes [26].

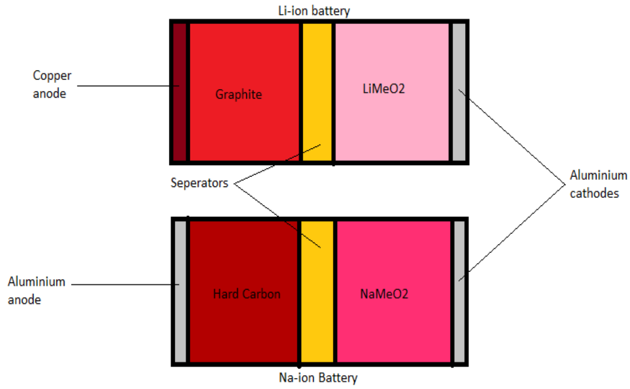

FIGURE 3. Schematics of Li-ion batteries and Na-ion batteries.

In transitioning to the Li-LMO system, it is feasible to construct cells that feature a bare copper current collector anode devoid of lithium, as the lithium required for operation is solely derived from the LMO cathode. The proposed cell configuration involves the elimination of graphite and electrolyte, which collectively constitute a significant portion of the cell's mass and thickness. The anticipated outcome of this alteration is a minimum enhancement of 30% in the energy specific to each cell, as well as an almost twofold increase in energy density. The augmentation of volumetric energy can potentially reduce the cost of battery packs, as it necessitates fewer cells and a smaller pack size to maintain an equivalent driving range. Furthermore, utilizing a non-lithium-containing anode will lead to a noteworthy decrease in the costs associated with the cell [26], [43].

The present capacities that of the batteries used in EVs today are another major challenge. The storage difficulty related costs are enormous. This is still a big problem that can only be solved by the development and improvement of battery technology, to achieve higher energy density [8], [44]. Having high energy density batteries with large capacities can also be an effective way of preventing range anxiety that is commonly faced by the masses. It can also make EVs more reliable and less prone to charging cycles. Thus, extending the battery life and postponing the need for maintenance. The evolution and improvement of battery capacity over the years for EVs have been highlighted in Table-1. The internal resistance of present-day batteries can also pose a challenge as high internal resistance can lead to prolonged charging times, dangerous amounts of heat generation, safety issues and deterioration of battery life. This is a very considerable limitation faced by the EV industry today. Developing battery technology to reduce the internal resistance can make batteries generate less heat, help avoid energy losses, make them more remediable and ensure have shorter charging times and more efficient charging and discharging performance [6].

Another issue faced is the enormous charging time of EVs. For an EV with an average 42kWh (e.g: BMW i3 that came

TABLE 1. Evolution of the battery capacity from the mid-80s until now [8].

Vehicle	Year	Capacity (kWh)
Audi duo	1983	8
Volkswagen Jetta citySTROMer	1985	17.3
Volkswagen Golf	1987	8
Škoda Favorit	1988	10
Fiat Panda Elettra	1990	9
General Motors EV1	1996	16.5
Audi duo	1997	10
General Motors EV1	1999	18.7
General Motors EV1	2000	26.4
Tesla Roadster	2006	53
Smart ed	2007	13.2
Tesla Roadster	2007	53
BYD e6	2009	72
Mitsubishi i-MiEV	2009	16
Nissan Leaf	2009	24
Tesla Roadster	2009	53
Mercedes-Benz SLS AMG E-Drive	2010	60
Tata Indica Vista EV	2010	26.5
Volvo C30 EV	2010	24
Volvo V70 PHEV	2010	11.3
BMW ActiveE	2011	32
BMW i3	2011	16
BYD e6	2011	60
Ford Focus Electric	2012	23
Renault Zoe	2012	22
Tesla Model S	2012	40, 60, 85
BMW i3	2013	22
BYD e6	2013	64
Volkswagen e-Golf	2013	26.5
Renault Fluence Z.E	2014	22
Tesla Roadster	2014	80
Chevrolet Spark EV	2015	19
Mercedes Clase B ED	2015	28
Tesla Model S	2015	70, 90
BYD e6	2016	82
Chevrolet Volt	2016	18.4
Tesla Model 3	2016	50, 75
Tesla Model X	2016	90, 100
BMW i3	2017	33
Ford Focus Electric	2017	33.5
Jaguar I-Pace	2017	90
Nissan Leaf	2017	40
Tesla Model S	2017	75, 100
Audi e-tron	2018	95
Kia Soul EV	2018	30
Nissan Leaf	2018	60
Renault ZOE 2	2018	60
Renault ZOE 2 rs	2018	100
Tesla Model 3	2018	70, 90
Mercedes-Benz EQ	2019	70
Nissan Leaf	2019	60
Volvo 40 series	2019	100
Audi e-tron	2020	95
BMW i3	2020	42
Hyundai Kona e	2020	64
Mercedes EQC	2020	93
Mini Cooper SE	2020	32.6
Peugeot e-208	2020	50
Volkswagen ID.3	2021	77
Ford Mustang Mach-E	2021	99
BYD ATTO 3	2022	60
BYD Seal	2022	82
Tesla Roaster	2022	200

TABLE 1. *(Continued.)* Evolution of the battery capacity from the mid-80s until now [8].

out in 2020) and the standard 3kW power charging ports, it will take around 13 hours to get the battery fully charged, which is a significantly long amount of time. Without fully charging the battery one cannot expect a decent range to be delivered. Even with fast charging it may require between 1 and 3 hours for full charge. The solution now being adopted by EV industry for this issue, is the introduction of battery swapping [6]. This is a process where discharged batteries are swapped for fully charged ones at battery exchange stations. The discharged batteries are then recharged and sent into circulation again. Though the swapping process takes significantly less time compared to recharging, the main issue with this is that there are no well-established stations that carry this out, nor is designing a vehicle with compatibility for such a process very easy. Another problem faced with the implementation of battery swapping stations is the lack of standardization of batteries used in EVs, and the extensive variety of battery types present today. There are also very large amounts of initial capital required to set up battery exchange stations and develop the charging and exchanging or swapping infrastructure. This is one of the major reasons why the swapping system has extremely low market penetration. One issue associated with battery exchange stations pertains to customer preference for new battery packs with a maximum battery charge range. Customers may be reluctant to use battery packs that have been previously used, as older batteries may offer reduced energy storing capacity due to degradation. The persistence of such consumer preferences can lead to a reduction in the operational lifespan of a battery pack, resulting in premature disposal before its full utilization or depletion. With the widespread development of battery swapping stations, questions such as "Who does the battery belong to?", "Who will take responsibility when it fails ?" and many other issues will also start to spring up [6], [45].

The second life use of EV batteries refers to repurposing batteries that are no longer suitable for electric vehicles in other applications. This approach aims to extend the lifespan of the batteries and reduce waste. Several potential second-life applications have been identified, including energy arbitrage, peak shaving, automated guided vehicles

(AGVs), and industrial energy storage systems (ESSs) with renewable firming purposes [46], [47]. By using retired EV batteries as energy storage systems (ESSs), the profitability of public charging stations can be improved, and peak loads to the grid can be flattened [48]. Additionally, modeling the battery degradation of second-life batteries shows that their lifetime can be extended, making them viable for ESS use before reaching their end of life [49]. This approach not only reduces the environmental impact of battery disposal but also contributes to the sustainability of the EV industry by reducing the initial cost of EVs and minimizing the need for new battery production

In the realm of electric vehicle technologies, hydrogen fuel cell vehicles (HFCVs) emerge as a significant alternative to traditional battery electric vehicles (BEVs). While both technologies signify a leap towards sustainable transportation, HFCVs offer distinct advantages, particularly in the context of environmental impact and resource utilization. A pivotal benefit of HFCVs lies in their fuel source – hydrogen, which can be produced from various renewable sources. This contrasts with the lithium-ion batteries used in BEVs, where the extraction and disposal of elements like lithium and cobalt raise concerns regarding sustainability and environmental impact. The elements in BEV batteries, often difficult to recycle, pose a significant environmental challenge. Furthermore, HFCVs excel in refueling time and range, addressing two common limitations of BEVs. Hydrogen refueling takes approximately the same time as refueling a conventional gasoline vehicle, offering a stark advantage over the longer charging times required for BEVs. This aspect makes HFCVs particularly suitable for long-distance travel and heavy-duty applications, where rapid refueling is crucial. Additionally, the weight efficiency of hydrogen fuel cells is superior to that of lithium-ion batteries, making HFCVs more viable for larger vehicles like buses and trucks. Nevertheless, it is crucial to consider the current limitations of hydrogen fuel infrastructure and production, which are pivotal factors in the widespread adoption of HFCVs [50]. The production of green hydrogen, which is environmentally benign, remains costly compared to the more prevalent grey hydrogen, produced from fossil fuels. The infrastructure for hydrogen fueling is also less developed compared to the existing network for electric vehicle charging. These challenges highlight the need for continued research and development in HFCV technology and infrastructure to fully realize their potential in complementing BEVs in the pursuit of a sustainable EV future [51].

One solution to the limitations, drawbacks, and restrictions exhibited by Li-ion batteries is the use of solid-state batteries. Unlike the conventional Li-ion battery that uses liquid electrolytes, solid-state batteries have solid electrolytes (SE). This reduces safety issues and other problems related to electrolyte leaks. Thus, avoiding situations like thermal runaways, explosions, and fires due to SEs being inherently non-flammable. The SE not only acts as a separator between the electrodes but also acts as an ionic pathway for cathode particles. The compatibility of metallic lithium cathodes with liquid electrodes is far worse in comparison to SEs. The integration of metallic lithium electrodes in solid-state batteries holds promise for significantly augmenting their energy storage capacity. With high amounts of cathode loading where the cathode is loaded with more than 80% of active material and thin separators of less than 50μm thickness, solid-state batteries can attain high levels of volumetric energy density in comparison to Li-ion batteries. Solid state batteries facilitate the utilization of bipolar electrode stacking cell design, thereby potentially decreasing the total thickness of the current collector and minimizing the inter-cellular ‘‘dead volume’’. By decreasing their size and volume, solid-state batteries can achieve a comparable capacity to that of a Li-ion battery while being significantly smaller. Thus, a solid-state battery utilizing the same space a Li-ion battery takes up in an EV can help us use a battery of vastly higher capacity and provide a much higher driving range. Also, several SEs have way better ionic conductivity when compared to liquid electrolytes. This helps solid-state batteries achieve faster charging and discharging speeds [36], [42].

V. TECHNOLOGICAL CHALLENGES POSTED BY CHARGING INFRASTRUCTURES

One of the main barriers preventing the broad adoption of electric cars (EVs) in the modern market is the absence of readily available charging facilities in the public sphere [14], [20]. Given the periodic need to recharge EV batteries there is a high requirement for involving various renewable energy sources and other conventional technologies must be used to offset the extra energy demand. Hence, the EV industry is dependent on the advancements of these fields and more importantly, the infrastructure that is used to support these technologies and deliver power to the charging stations. The efficiency of these technologies used in the power grid can have a great influence on the charging price. The EV industry is faced with a significant challenge posed by the existing infrastructure’s technological constraints.

The categorization of charging infrastructures can be based on charging parameters, resulting in two distinct types: slow charging units (SCUs) and fast charging units (FCUs). SCUs utilize two levels of electric current for recharging purposes, namely level 1 with a capacity of 3.7 kW and level 2 with a capacity exceeding 3.7 kW and up to 22 kW. These electric current levels are commonly referred to as alternating current (AC) [52]. FCUs, or Fuel Cell Units, are rechargeable devices that utilize various charging units, including three-phase AC with a capacity of 43 kW, direct current (DC) charging units with a capacity of 200 kW, and inductive charging units [53]. By quickly recharging the battery, FCUs are the most effective way to help EV consumers with range anxiety. The combined use of electric vehicles charging systems and energy storage systems (ESS) poses a technological hurdle for the charging infrastructure. Several organizations and authorities have developed multiple charging standards, considering diverse charging techniques rated power, safety, and cost. The configuration and design of charging infrastructures exhibit variability contingent upon the voltage, frequency, and national standards of diverse countries. Currently, European standards are the most prevalent in the realm of EV charging infrastructures. These standards aim to enhance the expansion of the Electric Vehicles market by enabling the use of compatible plugs and charging systems [54].

Considering the present environmental crisis, Electric Vehicles (EVs) have been suggested as a viable substitute for Internal Combustion Engine (ICE) vehicles. Concentrating exclusively on electric vehicles (EVs) is insufficient, as the deployment of Electric Vehicle Charging Stations (EVCS) is equally essential. There are several difficulties in placing these charging stations because these cars are electrically driven. Overloading the grid and load forecasting are significant issues. The latter pertains to the duration required for charging and the management of congestion at charging stations. This essay a reviews the fundamental terminology associated with charging stations, including the various types and levels of charging stations. EVCS is where electric vehicle (EV) charging occurs with the necessary safety, monitoring, conversion system, high voltage, and current for fast charging. Electric vehicle (EV) charging systems can be categorized into two distinct groups based on the mode of energy transmission. These groups are conductive charging systems and inductive charging systems. The conductive method of charging involves establishing a physical connection between the vehicle and the charger through a cable or connector. The present fundamental framework of the charging station is being referred to. At present, conductive charging systems are utilized by various automobile models, such as the Mitsubishi i-MiEV, Nissan Leaf, Tesla Roadster, and Chevrolet Volt [55]. The concept of inductive charging, commonly called wireless charging, is a nascent innovation. It requires no physical connection or touch between the car and the charger. Like transformers operate, it operates on the electromagnetic induction principle [56], [57]. By implementing inductive charging, one can avoid the hassle of dealing with heavy cables used for charging and also get rid of the entire plugging and unplugging process. Today, the connector type and standards can change concerning the company. This creates an issue of need for compatibility with all types of charging stations. Implementation of inductive charging can solve this issue as charging of all types of vehicles, irrespective of size or connector compatibility, is possible. Laying inductive charging strips along roadways can enable us to utilize a "charging while driving" strategy. This will shorten the time needed for automobiles to charge while they are stationary. The process being referred to is commonly known as dynamic wireless charging. Electrified roads or charging lanes refer to roads that utilize the wireless power technique (WPT) to provide electric power to electric vehicles. One potential limitation of this technology is its relatively low efficiency and power density compared to conductive charging, coupled with a higher cost. Numerous studies are being conducted to improve the effectiveness of this approach in various nations [58], [59]. The successful integration of Wireless Power Transfer (WPT) with Electric Vehicle technology necessitates a thorough investigation into the technological aspects of coils employed for inductive power transfer, compensation topologies, power electronics converters, and control techniques. Coil technology is a vital part that must be studied. The range within which the power transfer is possible, the amount of power transfer possible, how efficiently the power transfer is done, and how fast it can be done all depend on the coil design. The generally used designs are 2-coil and 4-coil designs, where the former is more apt for short-range power transfer, and the latter is more suitable in cases of mid or long-range power transfer. In EV charging, this "range", or in more suitable words called, the power transmission distance or air gap, can be anywhere between 100-300mm. In most cases, the coil dimensions are always greater when compared to the air gap and thus the 2-coil design is preferred. However, this is only in the case of stationary charging. If dynamic charging is considered, then the air gap will significantly increase, and the use of 4-coil designs or other newly developed novel designs might become necessary. Moreover, coil systems invariably utilize ferrite bars or plates to direct magnetic flux and furnish magnetic shielding. Coil systems frequently incorporate aluminum shields that function as magnetic shields. Figure 4 illustrates several 2-coil designs that are utilized for stationary charging. Many studies have been done in this area and these coils have been designed and largely optimized such that they can produce 2-5kW of power at very high efficiencies. However, the problem faced was the low level of magnetic flux generated in these coils. This was solved using a solenoid coil structure that gave an efficiency of up to 90%, even with an air gap of 200 mm. The solenoid arrangement demonstrated significant effectiveness in wireless charging over long distances, achieving power transmission of just over 1kW over air gaps of up to 3m. This kind of advantage can make this technology extremely useful for the dynamic charging of EVs. The only limitation that comes with the use of this technology is the double-sided flux generated by this unique design. Approximately 50% of the generated flux remains unused during the power transfer process. Thus, leading to huge losses in energy. This is a major reason that prevents this design from being implemented in EVs. The solution to this was developing the bipolar coil structure, which had similar coil sizes but varying aspect ratios. This configuration has demonstrated an efficiency of slightly over 95% when operating within an air gap of up to 300mm and with a power transfer capacity of up to 8kW [60], [61], [62], [63], [64], [65], [66], [67]. The implementation of dynamic charging systems has the potential to decrease the dimensions of the battery pack utilized in vehicles, while simultaneously providing added convenience and flexibility to the vehicle. Dynamic charging systems for electric vehicles employ two distinct types of coil structures. The primary distinction between the two coil configurations lies in the design of the primary coil. The utilization of a single-coil design is characterized by a lengthy track loop that operates on the principle of a coil. In contrast, the other employs a segmented-coil design [67], [68], [69], [70], [71], [72], [73], [74]. The effective amalgamation of Wireless Power Transfer (WPT) technology and Smart Grid technology into the pre-existing power grid infrastructure, along with devising strategies to ensure compatibility between grid-to-vehicle and vehicle-to-grid, can potentially result in noteworthy enhancements towards achieving wide-scale implementation of dynamic charging, vehicle autonomy, and extension of range to a virtually infinite amount provided we have a well-established network for dynamic charging along roadways.

Reducing range anxiety is a crucial aspect of overcoming the challenges that hinder the progress of electric vehicles [75]. However, the introduction of wireless power transfer (WPT) poses various challenges, including issues with efficiency, transmission distance, misalignment tolerance, and electromagnetic compatibility [76]. One solution researcher has found for this is the inclusion of metamaterials in WPT technology. Metamaterials are a unique category of synthetically engineered materials that exhibit specific electromagnetic characteristics, such as negative permittivity, negative refractive index, negative permeability, and amplification of evanescent waves [77], [78]. Materials with positive permittivity and permeability are the usual dielectric materials we use. At the same time, metamaterials with the opposite negative properties can help us amplify evanescent waves and focus electromagnetic radiation. The use of metamaterials was also seen to help attain low-resonant frequency, wide frequency bands, and simple structure, which are all advantageous benefits for metamaterials. The electromagnetic radiation focusing property exhibited by metamaterials can help collect any electromagnetic energy that may escape due to leaks, thus improving the inductive coupling and energy efficiency of WPT. In static charging, the inclusion of metamaterial slabs was seen to help improve the coupling effect between angularly and/or laterally misaligned transmitter and receiver coils., small misalignment angles ($\theta < 30°$) induced only negligible changes in the coupling coefficient and energy efficiency when a metamaterial slab is used. The use of metamaterials was seen to help increase efficiencies by 47-71% [76]. The requirement for electrical power grows with the deployment of many recharge stations. Drawing excessive power from the grid can result in an overload, which in turn can cause a range of power quality issues, including but not limited to voltage control problems, voltage fluctuation, peak demand problems, dependability, and load forecasting. The issues have a detrimental impact on the system's efficiency and can even result in significant harm to the batteries. This poses a significant obstacle to the progression and proliferation of electric vehicles and their charging systems. Consequently, a diverse range of techniques have been formulated to tackle these concerns, comprising:

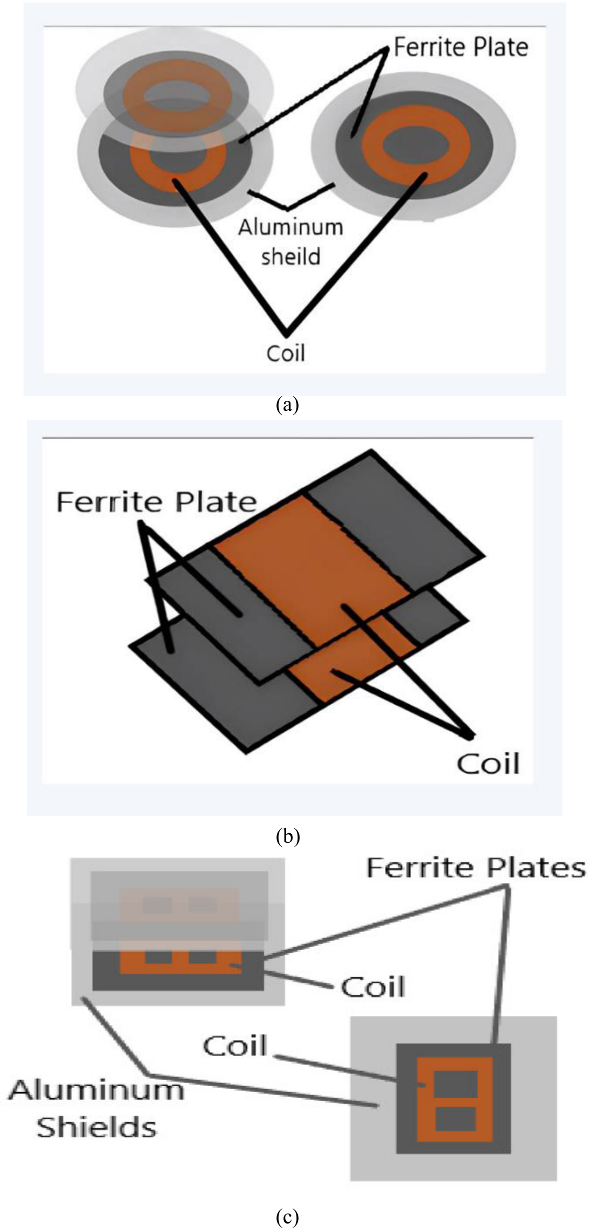

FIGURE 4. **a. Coil system of the circular systems. b. Coil system of the solenoid structure. c. Coil system of bipolar structure.**

A. SMART GRID TECHNOLOGY

The deployment of intelligent grid systems can alleviate the issue of unorganized electricity provision and augment dependability to a certain extent. establishing a communication link between the grid and the user has facilitated efficient load monitoring in specific regions, as enabled by the smart grid. The deployment of a smart grid has the potential to guarantee the secure functioning of the power grid. This is achieved by installing remote terminal units at each feeder, which transmit information regarding any fault conditions and power usage at each feeder. This methodology can provide preliminary data to the power grid regarding the load, ensuring seamless power generation and mitigating any potential reliability concerns [59], [79].

B. RENEWABLE ENERGY TECHNOLOY

Fossil fuels are widely recognized as the leading contributor to environmental degradation, while simultaneously serving as the predominant source of electricity generation on a global scale. More electrical power is needed as more EVs are adopted. Therefore, using these fossil fuels again in a new way to meet demands, is not a prudent choice. The greatest solution for recharging EVs is to use renewable energy sources because they minimize grid demand and carbon emissions. Installing solar power systems at the residential level is considered the most straightforward and optimal method for obtaining electricity. To alleviate the direct strain on the power grid, it is possible to install solar panels on the rooftops of public electric vehicle charging stations, commercial establishments, corporate buildings, and other sites that offer ample surface area [80], [81].

C. VEHICLE TO GRID (V2G) TECHNOLOGY

Maintaining a balance between active power and frequency is crucial for preserving the integrity of the power system, as overloading and underloading can result in frequency mismatch problems that can diminish system performance. Hence, it is advisable to employ a bidirectional energy transfer mechanism, wherein the power grid supplies electricity to the car, and the automobile, during its idle state, returns electricity to the grid. The technology commonly referred to as V2G, which stands for vehicle to grid, is an alternative nomenclature for this innovation. Additionally, it's important to consider the potential impact of V2G on battery degradation. The frequent charge and discharge cycles inherent in V2G operations can accelerate battery wear, impacting its longevity and efficiency. Therefore, a comprehensive evaluation of battery health under V2G conditions, including factors such as cycle life and capacity fade, is crucial to assess the long-term viability and sustainability of V2G technology [82], [83], [84].

D. VEHICLE TO VEHICLE TECHNOLOGY (V2V) TECHNOLOGY

Vehicle-to-Vehicle (V2V) communication, while enhancing road safety and traffic management, encounters challenges in the context of charging infrastructures. The primary issue lies in ensuring that EV charging stations support the uninterrupted operation of V2V systems, which demand a consistent power supply for optimal functionality. The variability in charging station capabilities, in terms of power output and connectivity, can hinder the effectiveness of V2V communications. Moreover, as V2V technology progresses towards supporting autonomous vehicles, the demand for fast-charging infrastructure escalates. Ensuring that these infrastructures can accommodate the rapid charging needs without compromising the performance of V2V systems poses a technological challenge that warrants attention [85], [86].

E. VEHICLE TO HOME (V2H) TECHNOLOGY

The implementation of Vehicle-to-Home (V2H) technology presents unique challenges in the context of current EV charging infrastructures. The foremost challenge lies in enabling the bidirectional flow of energy between the vehicle and the home. Most existing EV charging stations are designed for unidirectional charging, thus requiring significant upgrades to support V2H capabilities. There is also a need for smart energy management systems within homes to effectively utilize the energy supplied by EVs. These systems must be capable of dynamically balancing energy needs between home consumption and EV charging demands. Moreover, the integration of V2H technology requires the development of smart grid infrastructures that can accommodate the additional load and energy flow from EVs to homes, while maintaining grid stability and efficiency [87], [88].

Lithium batteries are composed of multiple cells interconnected in a series and parallel configuration to form a module. These modules are then linked in a series to construct a battery pack. The major difficulty right now is to quickly and effectively charge these batteries. Several charging methods include: Constant Current; Constant Current Charging Scheme; Constant Voltage Charging Scheme; and Multistage Charging Scheme. Given India's trajectory towards sustainable development, it is imperative to implement electric vehicle charging stations (EVCS) and electric vehicles (EVs) promoting environmentally conscious transportation. One crucial component influencing a nation's growth is its transportation system. To implement EVCS in developing nations, several rules and standards are presented that have the potential to bring about a radical shift in the automotive industry. By switching to 100% electric cars, the environment could substantially increase. It will significantly aid in creating a healthy future. Authorities must first install extra fast-charging stations that use green energy sources in order to put them into place. Numerous research projects are currently being carried out to improve the system as a whole [55].

We have so far discussed the problems associated with power grids and their compatibility with the popularization of EVs. However, when considering electric versions of heavy vehicles like trucks and buses, the issues created become even more challenging. According to CALSTART's study and analysis, the market for medium- and heavy-duty electric trucks has promises and issues. In contrast to electric vehicles designed for light-duty purposes, electric trucks and buses offer distinct prospects and obstacles. The present investigation characterizes the E-Truck and bus sector as encompassing plug-in electric vehicles with medium and heavy-duty capabilities (i.e., GVWR > 6,001 lbs.). Despite its recent inception, this industry is expanding and garnering interest from various companies throughout the country. E-trucks and vehicles are currently used to transport goods and individuals in California and throughout the United States. Plug-in Hybrid Electric Vehicles (PHEV) offer several benefits, including the ability to travel without producing any emissions, greater operational flexibility, and simplified and expedited charging infrastructure installation requirements. While short-range Battery Electric Vehicles (BEVs) can be rapidly charged to operate continuously without prolonged interruptions for charging, long-range BEVs offer greater flexibility in vehicle deployment since they are not restricted to charging infrastructure along their routes. Implementing of a charging infrastructure for electric trucks and vehicles is expected to impact the power grid. Technology selection involves making trade-offs among different operational expenses, grid demand, and car operation requirements [89]. Proterra and BYD are the leading manufacturers of battery-powered buses in the United States, having delivered 110 and 102 buses, respectively. The transit bus market is expected to witness a three-fold increase in the number of battery electric and fuel cell hydrogen buses by 2016, with a projected market share of 20% by 2030. To achieve the ambitious objective of deploying 12,000 zero-emission buses by 2030, as stipulated in the Electric Drive Strategic Plan of the Federal Transit Administration, a swift escalation in the sales of zero-emission buses is imperative. Recent statements indicate that the industry is experiencing appropriate expansion. In response to a consistent increase in demand, Proterra is currently constructing a secondary establishment in California. Additionally, BYD has set a target of delivering a maximum of 200 electric buses to the United States in 2015 [90]. The prevalence of single-family residences in California poses a difficulty in devising strategies for managing utility loads for individual electric vehicles. In contrast to light-duty electric vehicles, the charging requirements for newly developed electric trucks and buses may exhibit a significant increase, however, the process of planning for utility load can be comparatively less complex. A limited cohort of enthusiastic and cooperative truck and bus fleets can facilitate the implementation of E-Trucks and Buses in California and other regions. The participation of truck and bus fleets in the E-Truck & Bus notification program is a viable means of promoting the utilization of charging facilities. This initiative enables the fleets to notify electric utilities of newly established charging locations, thereby ensuring the grid's stability, reliability, and safety [91]. Even though an E-Bus or E-Truck has much larger batteries and charges faster than many light-duty electric vehicles, they take the same amount of electricity and consume the same amount of energy. A comprehensive inquiry is necessary to fully comprehend the impacts of charging E-Trucks and buses, and this investigation must include:

1. The impacts on utility distribution grids.
2. Extra infrastructure is required to support them.
3. Costs associated with upgrading fleet facilities, charging infrastructure, and utility.

The primary drivers of interest in electric vehicles among truck and bus fleets are operating and maintenance costs, among other factors. In contrast to conventional gasoline-fueled automobiles, electric vehicles also incur costs. To ensure that fleets can widely adopt E-Trucks and Buses, it's vital to revise the existing regulations of the public utility commission. This revision should incorporate the need for market reform and cost reduction regarding the charging and operation of E-Buses and Trucks. The primary directive for fleets that operate vehicles and buses is to provide efficient and reliable service to their customers. As a result, E-Trucks and Buses often adhere to predetermined schedules that align with passengers' commuting or working hours of. Real-time pricing has been proposed as a potential replacement for time-of-use (TOU) pricing to enhance the integration of variable energy sources into the system. The implementation of real-time pricing may facilitate the adoption of electric trucks and buses by certain fleets. However, this pricing strategy may also pose challenges for these fleets in terms of accessing reduced or negative energy costs. Demand charges are considered the most effective way to enable utilities to recoup their capital costs while also sending a price signal that promotes market innovation and fiscally sound alternatives. The following improvements are desired for the charging infrastructure:

- Typically, automobiles necessitate recharging at their current location, whether a yard or a conveyor line, which may far from the existing utility service drop. Excavation, conduits, cabling, and repaving may be needed to connect electricity to the spot where cars are parked.
- Every bus stop, distribution spot, and vehicle yard is distinctive. Furthermore, estimating the cost of the necessary charging infrastructure, the age of the electric infrastructure, and the possible electric capability is challenging.
- The duration of an infrastructure improvement project can vary from a few days to up to one year, contingent upon several factors. It is not possible to operate vehicles during the period when fleets are awaiting updates.
- Without utility support, it is challenging to study charge data, comprehend electricity prices, and identify strategies to save expenditures.
- Not all electric utilities actively support the deployment of electric cars by truck and bus fleets and offer useful advice.
- Because charging methods vary widely, there are questions regarding whether future car models can use the current infrastructure.

Four prospective technical alternatives exist range extenders, smart charging, on-site electricity production, and energy storage. The implementation of intelligent charging systems has the potential to enhance grid integration through the optimization of electric vehicle charging and the establishment of charging infrastructure that can accommodate a greater number of vehicles at a reduced cost, while simultaneously enhancing service reliability for fleets. Range extenders, energy storage, and on-site generating are being actively researched by several of the companies we spoke with as potential technological solutions that could lessen the grid effects of charging. To effectively address industry concerns, expand and improve industry stakeholder forums. Obtain a comprehensive load analysis for E-Trucks and buses. To help fleets and create jobs for specialist E-Truck and Bus project administrators. To lower operating costs for e-trucks and buses, secure current low carbon fuel standard credits. Maintain your support for electrifying trucks and buses with grants, incentives, and tax credits. Finance research initiatives aimed at developing technology that will allow for further electrification. Adapt utility pricing structures to hasten the electrification of buses and trucks at the lowest possible cost. Change the Public Utilities Commission's current practice to lower the cost of the equipment needed to charge e-trucks and buses [91].

VI. ENVIRONMENTAL CHALLENGES POSTED BY EVs

The quality of ecology is improved when EVs are used instead of ICE automobiles. EVs can be seen as ecologically beneficial because they are battery-powered and have no exhaust pipes. When ICE burns petroleum, poisonous gases are released into the sky, harming humans, and the ecosystem. However, greenhouse gases are also released during the process of producing energy for EV recharge. Emissions of greenhouse gases into the atmosphere cause global warming. The operating concept of electric vehicles is built around using electrical energy, reducing the need for petroleum. Therefore, the impact of energy storage systems in electric cars on the atmosphere is minimal. However, pulmonary, cognitive, and respiratory problems could arise during the creation and handling of energy storage devices and during the decomposition of electrochemical batteries. Therefore, when building energy storage devices, especially batteries, safety measures must be considered [3].

Understanding and recognizing any possible environmental impacts of generating energy because electric vehicles don't emit any particulate matter. The cells in an EV must be refilled once the battery capacity has been depleted, which can be done at the charging station. Local power networks produce the electricity needed to recharge EVs, but doing so results in sizable emissions of carbon dioxide into the atmosphere. It was also concluded that the total grams of CO2 created rose when more energy (kWh) was utilized. It is also possible to assert that the CO2 emissions are influenced by how much energy each EV uses to charge, which impacts overall energy usage. Because of the cumulative CO2 emissions during an EV's lifespan, there will be obvious changes in the ecosystem [92]. Because of this, EVs do not have negative emissions throughout their life cycle, but the total environmental impact can be reduced with advancements in manufacturing methods and alternative energy sources. In many regions worldwide, heavy vehicles are a major contributor to immense greenhouse gas emissions. One study that had the entire state of California as its sample size, found that medium- and heavy-duty vehicles use around 20% of all gasoline and emit 9% of the state's greenhouse gases. There is a significant possibility to cut emissions and fuel usage with e-trucks and buses [91], [93].

Disposing of Li-ion batteries is another big challenge the EV industry faces. Suppose the disposed batteries are not properly treated and processed. In that case, random discarding can lead to severe and dangerous environmental issues due to various toxic components present in them and sometimes even heavy metals. A solution to this problem is the recycling of these used-up batteries. Recycling can help cut down on life-cycle costs and aid in retrieving some precious materials, which, if left unchecked and disposed of carelessly can be extremely hazardous to the environment. Lithium is a highly limited resource we have. And, at the current rate of use and predicted increase in demand in the future, it is likely we may face actual possible depletion of materials like cobalt and lithium, which are crucial materials used to manufacture Li-ion batteries. Their exhaustion can lead to severe price hikes in their market value and result in making Li-batter technology more expensive, making EVs less affordable and accessible to the masses. This is all the while such crucial resources present in used up Li batteries are disposed of carelessly without undergoing recycling or any kind of proper treatment. This adds to hastening the depletion of precious resources and negatively impacts our environment and its ecosystem. Currently, only 10% of Li batteries are undergoing proper recycling, while the rest are improperly handled and ultimately end up in landfills. This can lead to the spilling of toxic materials and heavy metals like Cu, Co, Cr, Mn, Pb, Ni, etc., which can pollute the surrounding ecosystem and bio-life, including ours. Recycling lithium batteries can help reduce their production's negative environmental influence by around 10-30%. Recycling is also seen to reduce dependence on some freshly mined natural resources and greenhouse gas emissions by up to 50%. But the lack of simple, effective, and efficient recycling methods is one of the major issues we face today. Additionally, a significant number of battery kinds have cobalt, copper, and nickel concentrations that are too excessive. The ecotoxicity of lithium-ion batteries is significantly increased by the presence of lead and thallium in some of them. Other materials used in Li-ion batteries include lithium manganese oxide and lithium cobalt oxide, both of which have been shown to have long-term chronic impacts on some groups of crustaceans [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104], [105], [106], [107]. Currently, either direct, pyrometallurgical, or hydrometallurgical methods are used to recycle Li-ion batteries. To reclaim and improve the cathode material for use in creating new batteries, direct recycling techniques are physical and non-destructive processes that don't involve adding chemicals to the material's structure [108], [109]. Pyrometallurgical methods rely on exposure of already used battery materials to high temperatures for a prolonged time, allowing us to reduce the metal oxides formed by the battery materials to metals that can be separated and extracted in the form of metallic alloys. Acids are used in hydrometallurgical processes to dissolve ionic species from battery debris, generating solutions that contain metal ions that can be collected by solvent extraction or precipitation [109], [110]. All these methods have their advantages and disadvantages, which are elaborated in table-2 below. The extracted material can then be used again in further Li-ion battery production. In addition to recycling, another way of reducing the negative environmental impact of Li-ion batteries is to replace the toxic components present in them using non-toxic and bio-degradable materials. This was particularly investigated in one study focused on producing an organic Li-ion battery. In these batteries, the electrodes were made using a di-lithium benzene-diacrylate biomaterial. This material is soluble in water and less toxic. This also helps avoid using solvents like DMF and NPM, which we use in the treatment of electrodes in present-day conventional Li-ion batteries [111].

Precious materials can be recovered from Li batteries via recycling. However, there are still a lot of limitations and environmental hazards associated with the recycling process. Because of this, the creation of organic Li-ion batteries may help to lessen the negative effects of Li-ion batteries on the ecosystem. The development of organic Li-batteries will make this recycling process much safer and less hazardous to the environment; yet another way of avoiding wastage of batteries and materials is giving a battery a second life in addition to its primary application. The Li-ion batteries will still have about 75–80% of their initial high capabilities after the first life cycle is over. So, even after a cell is depleted and is no longer feasible for use for its primary application, it can still be used in other places where the cells having extremely low efficiencies are not a problem. This can extend their time on active duty for several more charging and discharging cycles before we have no choice but to break it down and recycle them for materials [109]. The life cycle of a Li-ion battery is depicted in Figure 5.

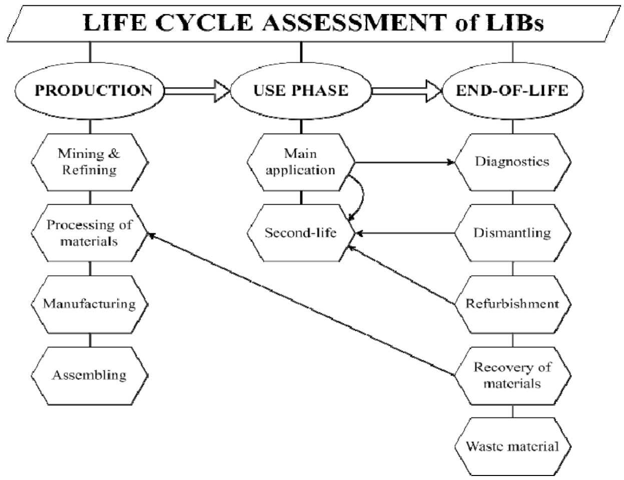

FIGURE 5. Life-cycle assessment of Li-ion batteries.

VII. EV TECHNOLOGY-FUTURE

With the world today moving towards cleaner, greener, and more energy-efficient concepts, the popularization of EVs is inevitable. As it has the potential to become one of the cleanest transport means. However significant developments in the field of EV technology and related fields have to be made to make this a reality. And, as an effort to strive towards this goal, we can expect extensive research to be done on the following:

- How can government policies be formulated in a way that facilitates a smooth transition from Internal Combustion Engine Vehicles (ICEVs) to Electric Vehicles (EVs), without causing any negative impact on other industries?
- How can Electric Vehicle technology be efficiently integrated into public transportation systems, and how can it be promoted to increase its usage?
- With the popularization of EVs, will come a very rapidly growing energy demand, and diverting fossil fuels we would otherwise use for ICEVs will not help us in reducing our carbon footprint. So, the future will see extensive research done to integrate renewable energy sources into power grids to meet these energy demands, or their integration into EVs for achieving passive constant charging even while using the vehicle, as long as there is sunlight. This can take a significant burden off the power grids.
- Improvement in battery technology will be made, to deliver better range and make EV-technology more safe, flexible, and efficient. As a result, we will be able to witness the development of unique anode materials or electrolytes for Li-batteries, as well as the creation of solid-state batteries and batteries that replace Li-ions with Na or K-ions to improve their safety, energy storage, and efficiency. All these developments can make battery technology more robust, affordable, and safe. Thus, promoting the transition to EVs.
- In the landscape of EV technologies, hydrogen fuel cell vehicles (HFCVs) present a compelling alternative to traditional battery electric vehicles (BEVs). HFCVs offer unique advantages, leveraging hydrogen as a sustainable fuel source, unlike the concerns surrounding elements in BEV batteries like lithium and cobalt. HFCVs excel in refueling time and range, making them ideal for long-distance travel and heavy-duty use. However, challenges persist in hydrogen production and infrastructure, underscoring the need for ongoing research and development to fully harness their potential alongside BEVs for a sustainable EV future.
- And with developments in the production of organic Li-batteries, along with safe and efficient repurposing and recycling of Li-batteries, EV-technology will become much greener and cleaner.
- Popularization of EVs will also make it necessary to develop charging infrastructure. With the implementation of a wide-spread charging station

TABLE 2. Comparison of various Li-ion battery recycling processes [105], [109].

TABLE 2. *(Continued.)* Comparison of various Li-ion battery recycling processes [105], [109].

	Direct Recycling	**Pyro-metallurgical**	**Hydro-metallurgical**
Type of method	Physical	Chemical	Chemical
Requirements	Physical Stimuli	High Temperature	Acids or other Precepting agents
Recovered materials	Active materials	Raw materials	Raw materials
Advantages	• Eco-friendly • Specificity is high • Non-destructive • Preserves important structure of cathode • Almost all battery components, including anode and foils, can be reclaimed. • Compatible with LFP batteries • Highly efficient about energy • Easy for industrial waste recycling	• High amount of recycling • Totally free of solvents • Adaptive to any battery chemistry and setup • No need for mechanical pre-treatment • Metal recovery rate is high • Reliable technology • May be carried out with the aid of current pyrometallurgical tools.	• The rate of recycling is high • Recovery of a wide variety of metals is done • Usable with batteries of any composition and setup • Versatility in methods for recovery and separation for targeting certain metals • Recovery rate is high • High product purity and so can be used for cathode precursors • Highly efficient with regard to energy • Negligible atmospheric pollution
Dis-Advantages	• Non-specific • Not permitted to process the various cathode elements simultaneously. • There is a need for detailed mechanical pre-treatment and separations. • When recovered material is presented to the market, it might not perform as well as virgin material or get outdated. •Combining cathode components might make the product that is recycled less valuable. • Procedures for regeneration still need to be created • Not scalable to a commercial level	• Demand for temperatures of high value • To efficiently reclaim materials, additional techniques might be required. • LFP batteries cannot be treated • Gas clean-up costs will be high in order to prevent harmful air pollution. • Capital and energy-intensive • Additional refining is required to convert metal alloys made using the smelting process into elemental metals.	• Process is quite complex • Toxic reagents are used • Battery cells need to be broken up which could lead to safety issues • Acid disintegrates the cathode structure. • A large amount of process waste must be handled by being recycled or disposed of. • For lithium iron phosphate (LFP) batteries, it is not cost-effective • Recovery of anode materials is negligible • Expensive running costs
Assessment of efficiency	Resynthesized cell efficiency	Recovery rate	Recovery rate

network and integration of smart grid, intelligent transport system technology, renewable energy technology, home-to-grid technology, vehicle-to-home technology, vehicle-to-grid technology, grid-to-vehicle technology, and vehicle-to-vehicle technology, into our exiting power grids, we will be able to execute concepts like dynamic charging and complete vehicle automation, etc., successfully. This means that autonomous cars with virtually unlimited driving ranges, which are zero-emission are not so far away.

EVs today are not completely emission-free when you consider the production stages and the disposing stages. But with advancements in technology being carried out in the above pointed directions we will come closer to a much cleaner and greener future.

VIII. CONCLUSION

EVs represent the trajectory of today's automotive industry. Given pressing environmental issues such as global warming, ozone layer depletion, and the health risks they pose, reducing our carbon footprint has become imperative. The transport industry is one of the greatest contributors to the increasing global carbon footprint that mankind leaves. Thus, aiding the transition of vehicles from IC engines to EVs can help us be more energy efficient and consume fewer fossil fuels which are already running towards fast depletion. As a result, greatly reduce our carbon footprint and avoid many impending global disasters. However, this transition is neither smooth nor swift, presenting numerous challenges. Numerous areas within the EV industry require extensive research and advancements including the manufacturing of EVs, the materials used in making EVs, the simplification of the complex systems that drive the EV technology, the improvement of batteries used by EVs, the improvement and rework of power grids to make them flawlessly compatible with EV charging, economic challenges the introduction of EVs will bring, etc. Challenges include potential economic disruptions, technological barriers to EV adoption, and emerging environmental concerns tied to the EV industry. Review like this one is very important to identify these challenges in order to start figuring out solutions that can be implemented for the smooth transition into the era of EVs.

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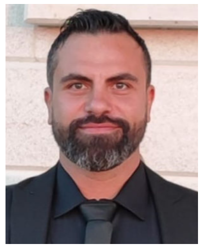

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