Advancements and Future Directions in Polymers for Electric Vehicle Technology

Dr. Sunil Kumar Gupta[1], Chandra Sekhar Mishra[2], Dr. Ranjan Kumar Jena[3],
Dr. Javed Khan Bhutto[4], Dr. Ashish Raj[5]
[1 &3]Professor, [2]Research scholar [4&5]Associate Professor
[1&4]Department of Electrical and Electronics Engineering, Poornima University, Jaipur, India
[2&3] Odisha University of Technology and Research
[5]Associate Professor, Department of Electrical Engineering, King Khalid University, Abha, Saudi Arabia
Email id: sunil.gupta@poornima.edu.in[1], chandrasekharmishra1106@gmail.com[2], ranjankjena@gmail.com[3]
jbhutto@kku.edu.sa[4], ashish.raj@poornima.edu.in[5]
*Author for Correspondence E-mail: sunil.gupta@poornima.edu.in

Abstract: Plastics have become important internally in automotive applications, ranging from vehicle inner components to under the hood of the car, as they are flexible and help on improving fuel economy and reducing CO_2 emissions by replacing metal. The last two years had seen a higher rate of electric car sales even though its adoption around the world was not at the same pace. There is still a doubt among the individuals about the battery life, efficiency, profitability and development of the infrastructure compared to conventional and hybrid vehicles. The use of plastics in EV design and manufacture is set to assume an ever-more-important place, presenting engineers with greater freedom of choice and the possibility of making lighter, more efficient parts. On the other hand, the investigation of bio nanocomposites seems to be perfect for eco-friendly solutions introduced at all stages of EVs lifecycle. This article's primary objective is to offer a detailed analysis of the latest innovations in polymers devoted to electric vehicle applications and to enlist the prospect of future research directions in this fast-moving field.

Keywords: Polymers, Vehicles, Plastics, Energy, Battery Operated Vehicle, Electrical Vehicle

1. Introduction

Polymers have been proved for their multiple applications, especially in the field of automotive industry due to their outstanding properties including the lightweight-to-strength ratio, corrosion resistance and glossy appearance. Through the years, their application has risen from being more decorative and luxurious to now it includes structural and semi-structural components, which replaces conventional metals such as steel and aluminum. As a result, the lighter and more fuel-efficient vehicles were developed and the consequent trend toward efficiency and environmental sustainability in the industry was born [1-5].

With the use of electric vehicles (EVs), the automotive landscape is going through a very important transformation or revolution. The trend towards the development of cleaner energy sources, including the electricity generated from renewable sources, has accelerated the shift to electric vehicles globally. Prospect predictions clearly indicate that the utilization of polymers in EVs is set for the exponential growth, especially engineering plastics and elastomers which possess the highest tendency in the change. This trend is fostered by the public awakening and governmental initiatives developing eco-friendly transport options in the Asia-Pacific region in particular [6-9].

The battery development incorporating increased energy density and capacity is another whose significance is highlighted by polymers in this sector of EVs. Nevertheless, the problem of passenger safety, cost effectiveness and the component longevity still could not be solved, so more research and development are needed. The role of weight reduction facilitated by high-performance polymers being played a significant product of fuel efficiency is undeniable [10-12].

Through the upcoming years we are experiencing development of digital technology (self-driving systems among them) that are going to completely reinvent the automobile industry. In addition, this advancement will definitely influence the way polymers and their composites are employed in automotive manufacturing, which can lead to the innovation process and higher efficiency [8-15].

This paper investigates the role of polymers in the automobiles field, but with emphasis on how they are used in EVs. It deals with the basic frameworks of the different polymers and provides the principle of composites and its sustainable use. Moreover, being a latest area of research related to use of polymers in automotive manufacturing, this topic will be presented in detail, based on a variety of sources such as industry of data sheets, company websites and reports on technology. Though not very ample academic literature is on the subject of polymers in electric vehicles; this review is an attempt to bridge the gap through the reviews of the industries pushing for the Research and Development of the subject by reviewing the information into a cohesive narrative [10-20].

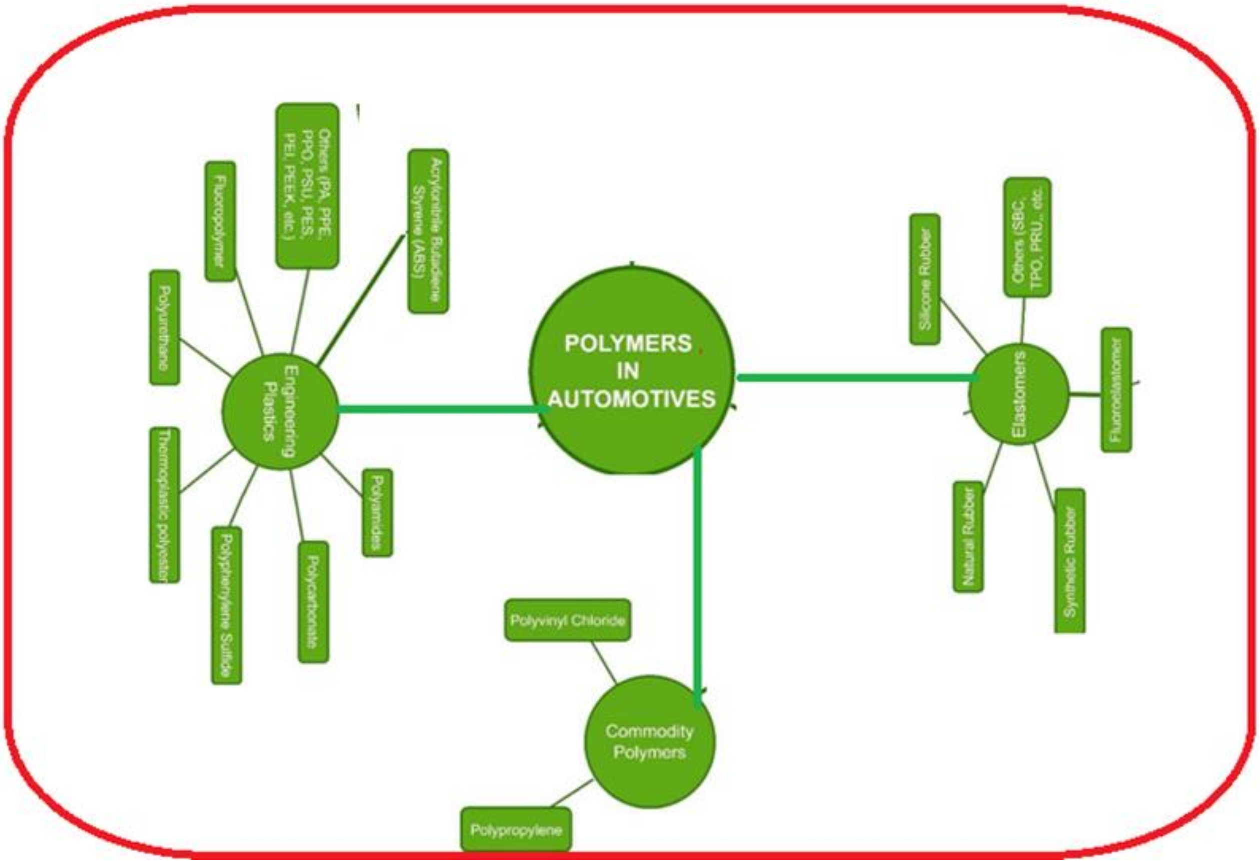

Figure 1. Classes and kinds of polymers used in Automotive parts and components.

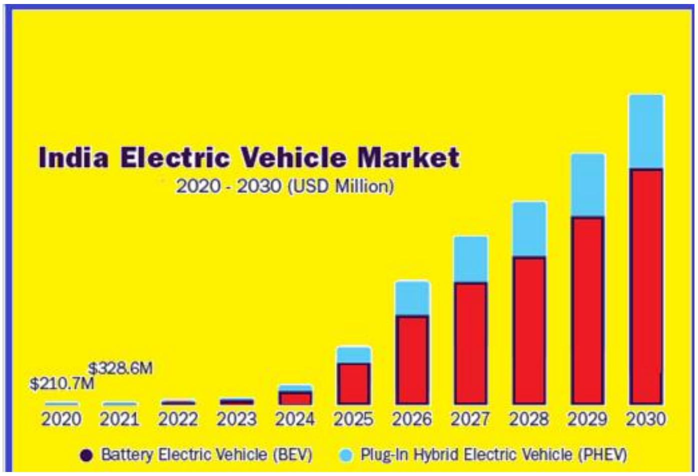

Figure 2: Indian Electrical Vehicle Market

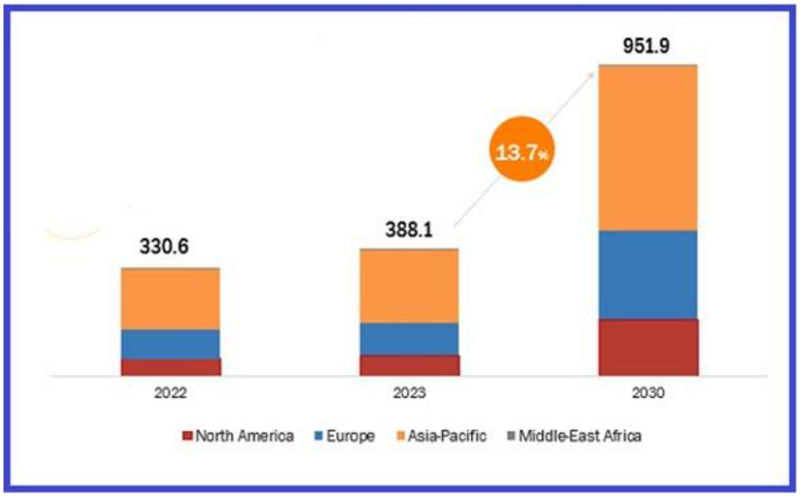

Figure 3: Electrical Vehicle Market Global Forecast (2030) (USD Billion)

2. Polymer Solutions for Automotive Components

Plastics are getting common in engineering of cars and they are giving numerous benefits such as flexibility, affordable cost, and reliability. They not only get rid of possible safety issues and enhance performance and engine efficiency but also reduce fuel consumption and air pollution. While electric vehicles may bring new problems and ones with fresh options, there is still a chance for a rise of polymer demand but only if we act smartly. Government interventions are vital for triggering off EV adoption but the price decrease is needed before such transportation may become available for the mass market. Although EVs open up possibilities in the field of lightweight polymer composite, the same serves in addressing the issues of better fuel efficiency. EVs are devoid of the engine of the ICE vehicles which are actually polymer reductions of 30% while aluminum and composites are being used more than before particularly as the primary ingredients of batteries and structural components. As the transition from internal combustion vehicles to EVs continues, the market for secondary battery structure is likely to increase considerably due to both hybrid and pure EVs shifting towards minimizing their weigh. Some part of power electronics contains vandal like inverter and chargers which offer convenience for polymer application, this phenomenon confronts ICE-related drawbacks.

Nevertheless, it is vital for EV to consider polymers by taking into account the harsh environmental conditions like fluctuations in temperature and chemical exposure that are needed for performance. In PC (polycarbonate), we see a potential for the applications of electric and electronic utilities with the heat resistance, flame retardancy, and the transparency being some of the special attributes. Interaction with both the engineering team and the product design side is hence key for polymers so that your products are with best performance, good outlook and having low energy consumption [16-25].

Plastics feature across the EV matrix, composing shields for sensors, covers, insulation materials, and charging stations, that help to expedite global electrification. Polymers that are applied to EVs can be divided into various parts under power train system and for interior and external applications, as well as lighting systems, which manifest the versatile role played by polymers [15-27].

2.1 Propulsion System and Underhood Applications

The conventional method of power supply in a car takes power from the engine and shift it to axle. While the powertrain of a conventional automobile is drawn from the engine inside, the condition of an EV is not influenced by an internal combustion engine (ICE). Manual, precision based design of EV powertrain systems tends to be difficult as it involves looking into the existing structures which were originally developed to support ICE technology. Actions aside, the energy intensity of gasoline is much higher than that of lithium ions found in the powering systems of EVs, which calls for a radically different power supply model. Table 1 visually portrays differences ICE and EV powertrain systems, a topic that will be elaborately gone through in the forthcoming section [24-32].

Table 1. Powertrain System Comparison: Internal Combustion Engine vs. Electric Vehicles

S. No.	Role	EV	ICE
1	Power Electronics	AC-DC inverter	N. A.
2	Energy Transfer	Fixed ratio gear box	Multi speed gear box
3	Energy Conversion	Electric Motor	Internal Combustion Engine
4	Energy Storage	Lithium-ion battery	HDPE fuel tank
5	Energy Input	Plug-in port with plastic housing and metallic connectors	Metallic fuel lid with plastic fuel tank cover

The various portions of electric vehicles powertrains use polymer components. These comprise of inlets, connectors, fuse boxes, specially coatings for power electronics, and power electronics themselves. Flame retarding, electrical insulation, colorability, and heat stability in the long-term are the basic material properties needed. TPU, PA, PPA, different species of polyester: PET, PBT and so on, and thermosetting polyurethane are typical examples of the current practice. On the other hand, applying electric vehicle parts, like batteries, safely within vehicle may require prerequisite protection. Lastly, the recyclability and high impact resistance of composites made of thermoplastic polyethylene terephthalate (PET) with carbon fiber (CF) and self-reinforced polypropylene (SPP) in crash testing has proven that these materials are very safe in this respect. Moreover, fracture patterns proved to be different for materials that included numerous multi-wall carbon nanotubes such as polyamide 6, as opposed to traditional materials.

Melamine resin foams and other thermoset materials lend themselves perfectly to the powertrain application due to their low weight and intrinsic flame retardance, and temperature stability being just some of the properties they have. Thermal insulators, soundproofing elements, and engine shielding components are some examples of how these supplies could improve the safety and performance of your system. Moreover, antioxidants and heat stabilizers that are present in the polymers are crucial for ensuring the long-term thermal attributes and hence the dependability in harsh automotive environments.

2.1.1. Battery

Such rules of cleaner air and less traffic jams enforce the use of batteries in world cities. The growing trend of electric vehicles (EVs) makes lithium-ion batteries the major player in markets, because they maintain good efficiency across the wide range of temperature conditions and good energy-converting capacity. Utilizations for consumer devices, cars, aviation, healthcare services, productions, energy, and telecommunications are dynamics that are growing the value of this market in the world to about USD 116.6 billion by the year 2030.

One of the fundamental methods that electric vehicles store energy is inside the lithium ion batteries which use minerals such as lithium iron phosphate, lithium manganese oxide and lithium nickel oxide ones to work better. Due to the fact chemical inertness, mechanical elasticity, and light weight of polymers make them valuable in fabrication of battery components.

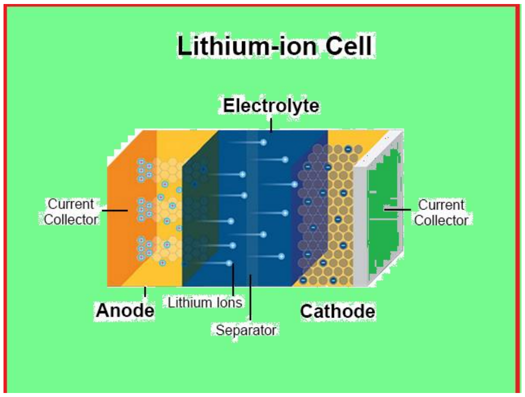

Figure 4: Lithium-ion battery

Within the confines of a lithium-ion battery, redox reactions are a fundamental occurrence. At the cathode, reduction transpires as cobalt oxide reacts with lithium ions to yield lithium-cobalt oxide (LiCoO2). This reaction can be represented by the half-reaction:

$$CoO2+Li++e-\longrightarrow LiCoO2 \tag{1}$$

Conversely, oxidation takes place at the anode, where the graphite intercalation compound LiC6 converts into graphite (C6), liberating lithium ions. The corresponding half-reaction is:

$$LiC6\rightarrow C6+Li++e- \tag{2}$$

The overall reaction, representing discharge (left to right) and charge (right to left) processes, is:

$$LiC6+CoO2\rightleftharpoons C6+LiCoO2 \tag{3}$$

Research efforts aim to enhance battery technology, focusing on cooling, energy density, and charging efficiency, with advanced polymers enabling innovative cooling system designs in EVs. Polymer-based materials also show promise in energy conversion technologies, such as organic photovoltaics and thermo-electric electrical voltage generation, offering high efficiency and cost-effectiveness.

The performance of EV batteries continues to improve, driven by advancements in energy density and cost reduction. Table 2 outlines the key features and technical requirements of EV batteries, along with the challenges associated with meeting these requirements[31].

Table-2. Key Requirements and Challenges for Batteries in Electric Vehicles. Adapted with permission.

S. No.	Battery attributes	Main Requirements	Main Challenges
1	Safety	No fire/flame/rupture/explosion	The trade-offs must be effectively managed. all given aspects one battery technology that meets Difficult to find
2	Performance	15 years	
3	Life	80 % ~SOC in 15 min	
4	Fast Charge and Power	< $100 kWh for cells	
5	Cost	> 350 Wh/kg for cells	
6	Energy Densities	> 750 Wh/L	

2.1.1.1. Polymer Binders

Polymer binders are vital in battery technology, acting as the cohesive element between components like conductive additives and active materials. Factors like polymer type, molecular weight, and solvent influence the battery's rheological properties and electrochemical stability. Binders, categorized into synthetic, natural/biopolymer, and conductive polymer types, impact the slurry's behavior and contribute to mechanical strength, adhesion, electrolyte absorption, and thermal stability.

Binders that are usually adopted include the polyvinylidene difluoride (PVDF), acrylates, polyethylene, polyimide, carboxymethyl cellulose (CMC) and even conductive polymers which include the ethylenedioxythiophene (EDOT). These binders extend the performance of batteries and new generation devices such as Li-S, Na-ion, and solid state batteries. Thus covers durability, maintenance, and stability.

Efficient separators in batteries is the fundament since they prevent short circuits and support conductive path for ionic diffusion. The materials like PE, PP, PVDF, PTFE, and Polysulfide’s offer this class improved behaviour and safety features. Sophisticatedly, polar separators from (a) polymers boost power, heat stability and distance of EVs, having the high molecular weight, chemical resistance, ease of processing and lower density [31-48].

2.1.1.2. Separator

Like the conductor, the separator is a valuable piece in the anatomy of the battery. The separator prevents direct contact between cathode and the anode, favoring proper ionic transport and preventing the thermal runaways, overcharge, and short circuits. An optimal separator in the words of Saal et al. water insulation, ion current flow, good hydrophilicity in the electrolyte, and a satisfactory ternal stability are the vital requirements for a separator.

Separators' materials vary a lot with respect to the battery type and the active component of an electrolyte. While PE and PP are the most commonly used polymers for Li-ion and Li-S batteries, they may not be the best candidates for Na-S batteries because of their lower wetting properties. Coordinating the polymeric membrane construction deals with different morphology and coating ways in order to achieve better outputs and reject safety. Besides that, the separator either carbon surface or inorganic materials are used to boost its efficiency.

Efficient separators extend battery life by preventing short circuits, achieved through methods like constructing well-defined pore structures to inhibit dendrite penetration. Advanced modifications, such as incorporating nano-Sb2O3 into membranes, enhance thermal stability and mechanical strength, enhancing battery safety. Advanced polymers like PVDF, polytetrafluoroethylene (PTFE), and polysulfides offer improved properties, boosting battery power, heat stability, and drive range for Li-ion battery-powered EVs.

2.1.1.3. Battery Module Cell Frames/Retainers/Battery Pack Top Covers

To endure the high temperatures experienced during charging and discharging cycles, the cell frames and retainers of battery modules are made of flame-resistant polymer compounds. The electrical characteristics, stability, light weight, and acid resistance of a composite made of high-impact polystyrene, 8-10% glass fiber, and polyphenylene ether (PPE) are outstanding. The aromatic ring arrangement and ether concentration of PPE determine its melting point, which in turn affects its characteristics. The use of non-halogenated flame retardants allows for thinner, lighter modules by improving stiffness and impact resistance and ensuring a UL V-0 certification. Reinforcing using glass raises both the mechanical strength and the temperature at which heat is reflected.

Material selection criteria by Lewchalermwong et al. favor acrylonitrile butadiene styrene (ABS) for upper battery mount components due to its strength, thermal and chemical resistance, and ease of processing. ABS, an amorphous terpolymer, offers superior strength, chemical and scratch resistance, and thermal stability. The combination of nitrile groups and properties from acrylonitrile and styrene ensures robustness and ease of processing, making ABS the optimal choice for battery module components.

2.1.2. Engine

The engine serves as the heart of various electrical vehicles, each employing distinct methodologies for propulsion. Whether it's the efficiency-focused electric motors of hybrids, the potent battery-driven engines of pure electric cars, or the innovative hydrogen fuel cells powering fuel cell vehicles, the diversity in engine technologies underscores the evolution and adaptation within the automotive industry towards sustainable and efficient transportation solutions

2.1.2.1. Electric Motor

Electric vehicles (EVs) rely on their electric motors, which are essential for generating power and enhancing overall performance. The design of the motor determines whether an electric vehicle is front-wheel drive (FWD), rear-wheel drive (RWD), or all-wheel drive (AWD). Housings, stator assemblies, rotors, end caps, bus rings, and connection supports are all made of polymeric materials such polyphthalamide (PPA), polyether sulphone (PESU), and long glass-reinforced PPA.

The melting temperature, chemical resistance, and tensile modulus of PPA are improved by adding aromatic diacids. To modify processability, copolymerization or longer diamines are used. In addition to having excellent flame retardancy ratings, these materials are electrically compatible, very strong mechanically, and very resistant to heat and media.

A combination of aromatic ether and sulfone linkages gives PESU exceptional heat resistance. The melting point may be lowered for processing without thermal deterioration thanks to the flexible ether groups, and the stability can be assured by the sulfonyl groups, who preserve oxidative stability by maintaining electron deficit. The alkyl groups increase the impact strength and flexibility.

2.1.2.2. Motors

Seat adjustment, automated lighting control, and door locking systems are just a few of the many important roles played by actuators in electric vehicles (EVs). Actuator materials must exhibit exceptional mechanical performance to keep up with the current trend of downsizing and improved functionality. The qualities that make the engineering plastic Ultraform® Polyoxymethylene (POM) unique include a high polymerization degree, an easy-to-process structure, and a partly crystalline structure. Ultraform® is resistant to chemicals and heat, and its co-monomers make it stable during processing. Adding mineral and glass fillers to POM amplifies its already impressive strength and stiffness, which is a result of its crystalline structure [33].

2.1.2.3. Emblems

Many parts of an electric vehicle's drivetrain, including the housings of the battery packs and gaskets for power conversion devices (such as inverters and motors), rely on sealing. The perfect material for a seal should not only be dust-free and resistant to heat and vibration, but it should also be impermeable to fluids and chemicals. When compared to ICEs, the operating speeds of electric cars are substantially higher, necessitating seals that can endure such extreme circumstances. Because electric motors spin at a greater RPM, rotary seals work especially well with them. Because of its high heat resistance and low friction, polytetrafluoroethylene (PTFE) finds widespread usage as a sealing material. The carbon-fluorine (C-F) bonds that make up PTFE's chemical structure make it thermally stable throughout a broad temperature range, which means less friction and better sealing efficiency. Superior sealing performance is offered by innovative materials as HiSpinTM PDR RT, which also contribute to lower power consumption through reduced friction [34].

2.1.2.4 Design of Steering

The steering system is comprised of the following main parts: the wheel, the coupler, the gear, the power steering pump, and the power steering hose. With its extra components including cables, sensors, actuators, motors, and electronic control units, electric power steering has recently surpassed hydraulic power steering in popularity. When it comes to electric power steering, one of the biggest obstacles is reducing weight, which has the potential to improve performance and safety. The steering wheel's central structure transfers the driver's input to the column, dampens vibration, and ensures the wheel's structural integrity. Polyurethane (PUR) foam encases die-cast aluminum or magnesium frames. Alternatively, PUR foam compound with short glass fibers or sophisticated polymer composites made using Long Fibre Injection (LFI) technology can be used in place of iron frames. New alternatives derived from bio- and carbon-fiber sources are also on the horizon. To find the best material for its steering frames, Takata ran internal research with polyamides, polypropylene, and fiber combinations [31-34].

2.1.2.5 Gears

Gears enable the transmission of power and motion in conventional ICE cars. Although originally crafted from metals, polymers now provide easier design and production methods. In addition to being noisier when in use, metal gears are typically more expensive. While transferring power, it is important to keep temperature, wear rate, noise, and vibration in mind. For formula supra cars, Chopane et al. investigated the use of plastic gears reinforced with PA 6 and 66 in rack-and-pinion steering systems. In comparison to carbon fiber-reinforced composites, these gears are more cost-effective, have lower noise levels, are less heavy, and resist corrosion better. They also have superior mechanical qualities. While lubricating contacting components, lubricants like graphite, silicon oil, molybdenum disulfide, and PTFE dissipate heat, flush dirt particles, and prevent corrosion.

The most typical materials used to make plastic gears are polyamides, fluoropolymers like PTFE and ABS, high-density polyethylene (HDPE), and polyoxymethylene (POM). Thermoplastic matrix composite gears may be made using a wide variety of fillers, processing techniques, and materials, including short and long fibers, glass mat and fabric, natural fibers, nanomaterials, and a host of other additives. Due to the greater revolutions per minute (RPM) of electric motors, electric vehicles (EVs) usually only need a single gear, unlike internal combustion engine (ICE) cars. A list of the different polymers that are utilized for gearing is shown in Table 3. Nevertheless, due to the significantly greater rpm of the electric motor, a multispeed gearbox is unnecessary in electric cars; hence, EVs are equipped with a single gear[35-39].

Table 3. Operations performed on gear components made of polymer

Material	Component	Description
Polyoxymethylene (POM)	Gear	Investigated the impact of incorporating Carbon Nanotubes (CNT) and Polytetrafluoroethylene (PTFE) on load-bearing properties and durability. The composite underwent fabrication via melt compounding with a twin-screw extruder, followed by injection molding of the gears.
Polyoxymethylene (POM)	Gear	Conducted an enhanced geometric characterization of thermoplastic gears manufactured through injection molding.
Nylon 66	Helical gear	Utilized a non-contact temperature sensor to measure surface temperature resulting from frictional interactions. Data was then correlated with friction levels. A nylon 66 helical gear was compared with a metallic counterpart to evaluate noise and vibration levels. This study was performed on two-wheelers (mopeds) as a feasibility assessment for potential replacements in lightweight vehicles.
Polypropylene Acetal Copolymer Reinforced with Graphene	Gear	Employed varying weights of graphene as filler material in acetal.
Polypropylene Acetal Copolymer Reinforced with Graphene	Spur Gear	Tested injection-molded polypropylene gears reinforced with graphene against metallic gears under different loads.

2.2. Exterior Applications

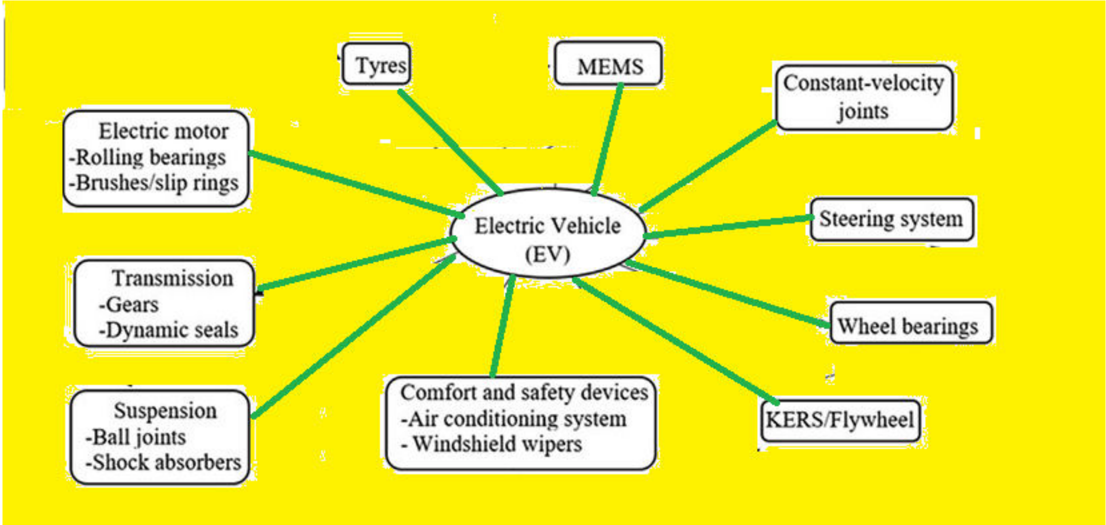

Figure 5: Electric Vehicles Components

2.2.1. Bumper

Vehicle bumpers are mounted at both front and back sides of the vehicle. They serve as the protective barriers which dissipate and reduce the forces of collision to safeguard the occupants and also operating systems of the vehicles. A rising number of EVs accounts for more attention placed on improving their safety systems. Bumpers of EVs, besides being functional, also have to show a perfect balance of performance and aesthetics while ensuring the safety of occupants and pedestrians. With a carefully conducted materials choice and structural design, future electric bumpers will be built with the state of the art technology which will raise the crash resistance level. In particular, the molded item used for front end crash impact mitigation, for example in the 2013 Fusion midsize sedan and Mondeo sedan, readily meets the safety standard criteria. This innovative approach completely does away with any extra parts being needed and uses a combination of polycarbonate (PC) and polybutylene terephthalate (PBT) providing an improved energy absorbing capacity. Ford's aiming at using its PCR materials throughout all the parts, resulting in enhancing the UV resistance and the impact strength. Pioneering energy absorber built-in to the grille landing allows for the elimination of a separate structure thus ensuring that it meets the European pedestrian protection standards. Furthermore, anti-corrosive coatings play a critical part in vehicle care and maintenance with conductive polymers and clay-polymer composites demonstrating superior qualities of enhanced durability and performance.

2.2.2. Exterior Body

Polymer matrix composites arise from the compilation of thermoplastics with other kinds of polymers. Create your own release. Write unique content without any custom. These are varying in construction, from those fashioned for sturdiness and minimizing the effect of corrosion and wear, impact, heat and weight, water absorption, of increased stiffness. Chemicals and solvents high tolerance, really rich flexibility in style and cheap production manage to provide various sort of applications for these materials. These thermoplastics are on the rise the automotive sector as in the case of EVs, in front section of vehicles. With the advent of extremely high energy consumption and prevalent heavy weights of EVs, vehicle manufacturers are looking toward weight drop as a strategy for improving efficiency and expanding the travel range on single charge. Despite the increased weight of the "space frames" of electric vehicles made of lightweight and durable material such as aluminum and steel, they are ab definite benefit. By reducing weight, improving energy efficiency and range length, the benefits of aluminum alloy may be highlighted and maintained. This may be possible through its features of a lower density. In the past, electric vehicles vehicles such as Tesla and others' initial models used aluminum for its lightweight characteristics, while Nissan's latest Leaf, for instance, adapts steel for its economical cost. The performance of vehicle in terms of quality and weight, light weight plastics have the function of increasing the range of driving between recharges. Rearview mirror housings, wheel wheel covers, and door handles are some the external applications that use a lot of polymers such as acrylonitrile styrene acrylate (ASA), Polycarbonate/ Acrylic/ABA, and filled nylon composites. There are characteristics such as the mouldability option, the energy dissipation function, the durability, and a high luster level which make ABS the material of choice. The mechanical properties of the polypropylene composite material and the affordability of glass fiber as well as natural fiber composites in the automobile sector is making them much sought-after. Using the envisioned blending of the thermoplastic engineering resin and the glass fiber-reinforced thermoplastic resin leads to the creation of newer materials with higher performance indicators.

2.2.3. Tires

Electric vehicles (EVs) come in the spotlight with the idea of introducing the smart cars era. It is here that we can research on high-tech tires that play an integral role in driving the vessels towards emission-free and environmentally second-to-none future. EVs do have an advantage since they are very quiet, fuel expenses are nothing, and they require less maintenance. While their heavy batteries can be a benefit, yet it requires extra tires and has become an obstacle, so careful selection is necessary to achieve efficiency, braking, as well as mileage. Tires are originally manufactured from rubber, whether derived from natural or artificial rubber, with carbon black as well as sulfur being fundamental ingredients. The trend of the environmental friendly materials like the solution polymerized styrene butadiene rubber (SSBR) and silica can be seen in EV tire designing that reduce the rolling resistant and ensure fuel efficiency without any performance reduction. Specialized tires developed specifically for EVs, for instance Eco Contact, integrate the values of sustainability, durability and lowest rolling resistance to contribute to the totality of the mileage and efficiency across different road conditions.

2.2.4. Comfort and Safety Devices

The transition from internal combustion engine (ICE) vehicles to electric vehicles (EVs) heralds significant technological advancements, yet it also introduces potential safety concerns stemming from the proliferation of high-power electrical components within vehicles. While EV systems are designed with safety in mind, their unique characteristics may present specific safety considerations distinct from traditional vehicles. Currently, existing standards and regulations do not comprehensively address EV safety, reflecting the dynamic nature of this emerging technology and the gradual introduction of new models. Public perception of EV risks, such as high voltage and chemical batteries, can influence acceptance, despite similar inherent risks in ICE vehicles which may not be as readily apparent to everyone.

Windshield wipers improvement is one of the TAs for assessing the latest developments in the automotive sphere. Initially, this function was operator-driven or manual however, with electric-powered wipers, visibility even during the worst conditions is now assured. While EPDM - ethylene propylene diene monomer synthetic rubber - is widely used in wiper blades because of its good performance to hardening and weathering, natural rubber is still the frequent choice due to its excellent elasticity. The core of co-extrusion molding (a manufacturing technique) is the combination of natural rubber with EPDM (an environmental-friendly elastomer) with the aim to enhance the overall performance. Other challenges include providing adequate soundproofing coverage and making sure that the sound deadening is even. The firms such as Valeo use various technological solutions like graphitized coatings.

The safety of EVs can be enhanced with features that deal with attitudes as EVs get less audible with decreased vehicle sound. Noise emitters that are electronic, in the same way, as ultrasonic frequency emitters, are meant to give audible warning to pedestrians about the presence of EVs. This reduces the likelihood of accidents, especially to visually impaired individuals. Further, the application of innovative technology as laser beam windscreen wipers supports a future option over conventional systems. Laser wipers offer dynamism and precision in the sense that they use AI algorithms to sense the windshield and remove debris without any human assistance, thus, using fast-moving wiper blades will be of no use.

2.3. Interior Applications

2.3.1. Dashboard

The dashboard serves as a crucial component in modern vehicles, providing essential information to the driver, including speed limits, maintenance alerts, and vehicle status. Marques et al. proposed a flexible dashboard concept for EVs, reflecting advancements in smart dashboard technology. These flexible dashboards offer customizable digital displays, allowing drivers to monitor vehicle speed, battery status, mileage, and advanced driving systems such as traction control and anti-lock braking. Additionally, flexible dashboards can be reconfigured to accommodate changes in vehicle subsystems or aesthetic preferences, enhancing user experience and customization options. The use of plastics in automotive dash-boards is summarized in Table 4 [39-42].

Table 4. Common polymeric materials used in dashboards and associated interior use Reproduced with permission

Material	Features/Properties	Applications/Enhancements
Styrene Maleic Anhydride (SMA) Copolymers	Exhibits superior heat resistance compared to traditional polystyrene. Can be strengthened with glass fibers for increased heat resistance and with rubber to prevent brittleness.	Various grades available, including general purpose, high flow, blow molding, and low gloss, offering versatility in processing and creating diverse surface finishes.
ABC Blend	Offers ease of processing and enhanced heat deflection temperature. Capable of producing various surface types.	Available in different grades for specific applications, such as general purpose, high flow, blow molding, and low gloss, providing flexibility in manufacturing and achieving desired surface characteristics.
Acrylonitrile Butadiene Styrene (ABS)	Possesses high impact strength and toughness due to polybutadiene, with excellent chemical stress cracking resistance from acrylonitrile. Easily processed.	Versatile material with adjustable ratios of acrylonitrile, butadiene, and styrene, suitable for various applications including pillars, instrument panels, and door panels.
Chloride Polyurethane	Exhibits high impact strength at low temperatures and stiffness at high temperatures, preventing deformation.	Utilizes polyether polyols for door panels and energy-absorbing polyurethane foam for pillars and door panels, enhancing passenger safety during side impacts.
Polyvinyl	Offers a favorable price-to-property ratio and flame retardancy.	Blended with ABS to create sheets for instrument panel covers, providing both cost-effectiveness and fire resistance.
Thermoplastic Olefin (TPO)	Boasts low gloss and density, high flexibility, stiffness, and toughness.	Easily injection molded into various components for instrument panel assemblies and used as skin for PP foam construction, offering both aesthetic appeal and structural integrity.
Polypropylene (PP)	Features high thermal resistance, superior to polyethylene (PE), and is cost-effective.	Maintains uniformity throughout vehicle interiors by utilizing the same base material for parts like pillar covers, instrument panels, and door panels. PP's resilience to temperature variations ensures durability in diverse environments.

2.3.2. Energy Storage Systems

Electric vehicles (EVs) replace traditional fuel tanks with battery packs, emphasizing environmental sustainability and reduced fuel costs without compromising performance. However, EVs face challenges such as longer recharge times compared to fuel-powered vehicles, prompting research into advanced technologies like lightweight hydrogen fuel tanks. Historically, high-density polyethylene (HDPE) has been the primary material for fuel tanks, with surfaces fluorinated to enhance barrier properties against volatile gases. Fluorination involves treating plastics with fluorine compounds to create strong, stable bonds, improving resistance to chemicals and enhancing structural integrity. Some countries are exploring hydrogen fuel cell technology to reduce reliance on foreign oil and battery materials, with hydrogen fuel cell electric vehicles (FCEVs) offering zero emissions and environmental benefits. FCEVs store energy as hydrogen and convert it into electricity through fuel cells, emitting only water as a by-product. While the market for FCEVs is limited, technological advancements and production expansion are underway to meet growing demand in select markets.

Results and Discussions

The use of polymers in electric vehicle (EV) technology is rapidly evolving, driven by the need for lightweight, durable, and efficient materials that enhance the performance and sustainability of EVs. In this detailed analysis, we will explore the types of polymers used in EV technology, their applications, recent advancements, market trends in India, and future directions. We will also delve into graphical representations of market growth, distribution of polymers, technological advancements, projected market demand, and investments in research and development (R&D).

Table 5: Types of Polymers Used in EV Technology

Polymer Type	Characteristics	Common Applications
Polypropylene (PP)	Lightweight, durable	Battery casings, interior panels
Polyamide (PA)	High strength, thermal resistance	Engine parts, cable insulation
Polycarbonate (PC)	Impact resistance, transparency	Headlights, windows
Polyethylene (PE)	Chemical resistance, flexibility	Wiring insulation, seals
Polyurethane (PU)	Versatility, cushioning	Seats, insulation panels

Table 5 lists the primary types of polymers used in EV technology, highlighting their characteristics and common applications. Polypropylene (PP) is valued for its lightweight and durable properties, making it ideal for battery casings and interior panels. Polyamide (PA) offers high strength and thermal resistance, suitable for engine parts and cable insulation. Polycarbonate (PC) is known for its impact resistance and transparency, used in headlights and windows. Polyethylene (PE) is appreciated for its chemical resistance and flexibility, often used in wiring insulation and seals. Lastly, polyurethane (PU) is versatile and provides cushioning, used in seats and insulation panels.

Table 6: Applications of Polymers in EV Components

EV Component	Primary Polymer Used	Benefits
Battery Casings	Polypropylene (PP)	Lightweight, durable
Wiring and Insulation	Polyethylene (PE)	Chemical resistance, flexibility
Interior Panels	Polypropylene (PP)	Durable, cost-effective
Exterior Panels	Polyamide (PA)	High strength, thermal resistance
Seats and Cushions	Polyurethane (PU)	Comfort, versatility

Table 6 provides a closer look at the specific applications of polymers in various EV components. Battery casings predominantly use Polypropylene (PP) due to its lightweight and durable nature. Polyethylene (PE) is primarily used for wiring and insulation because of its chemical resistance and flexibility. Interior panels often use Polypropylene (PP) for its durability and cost-effectiveness. Exterior panels benefit from Polyamide (PA) due to its high strength and thermal resistance. Seats and cushions typically use Polyurethane (PU) for its comfort and versatility.

Table 7: Recent Advancements in Polymer Technology for EVs

Advancement	Description	Impact on EV Technology
High-Temperature Resistant Polymers	Enhanced polymers that withstand higher temperatures	Improved safety and efficiency
Conductive Polymers	Polymers with improved electrical conductivity	Better performance in electronic components
Lightweight Composite Materials	Composite polymers reducing overall vehicle weight	Increased range and efficiency
Recyclable Polymers	Development of easily recyclable polymers	Environmental sustainability
Enhanced Durability Polymers	Polymers with increased lifespan and durability	Reduced maintenance costs

Table 7 outlines recent advancements in polymer technology for EVs. High-temperature resistant polymers can withstand higher temperatures, improving safety and efficiency. Conductive polymers offer better electrical conductivity, enhancing the performance of electronic components. Lightweight composite materials reduce the overall weight of the vehicle, increasing range and efficiency. The development of recyclable polymers contributes to environmental sustainability. Enhanced durability polymers have an increased lifespan, leading to reduced maintenance costs.

Table 8: Market Trends of Polymers in EV Technology in India

Year	Market Size (in Billion USD)	Growth Rate (%)
2020	1.2	15
2021	1.5	25
2022	1.9	27
2023	2.4	30
2024	3.0 (Projected)	25 (Projected)

Table 8 shows the market trends of polymers in EV technology in India from 2020 to 2024. The market size has steadily increased, from 1.2 billion USD in 2020 to a projected 3.0 billion USD in 2024. The growth rate has also seen an upward trend, peaking at 30% in 2023. This trend indicates a robust market for polymers in the Indian EV sector, driven by increasing demand for advanced and sustainable materials.

Table 9 highlights future directions and potential developments in polymers for EVs. The development of biodegradable polymers aims to create eco-friendly materials that contribute to environmental sustainability. Advanced composite materials with better strength-to-weight ratios can increase efficiency and range. Smart polymers with self-healing properties can extend the lifespan of components and reduce maintenance. The integration of nanotechnology in polymers can enhance properties and introduce new functionalities. Innovations in cost-effective production techniques can reduce manufacturing costs and increase adoption.

Table 9: Future Directions and Potential Developments in Polymers for EVs

Future Direction	**Potential Developments**	**Expected Benefits**
Biodegradable Polymers	Development of eco-friendly biodegradable polymers	Environmental sustainability
Advanced Composite Materials	New composites for better strength-to-weight ratio	Increased efficiency and range
Smart Polymers	Polymers with self-healing properties	Increased lifespan and reduced maintenance
Nanotechnology in Polymers	Integration of nanotechnology for enhanced properties	Improved performance and new functionalities
Cost-Effective Production Techniques	Innovations in production to reduce costs	Lower manufacturing costs and increased adoption

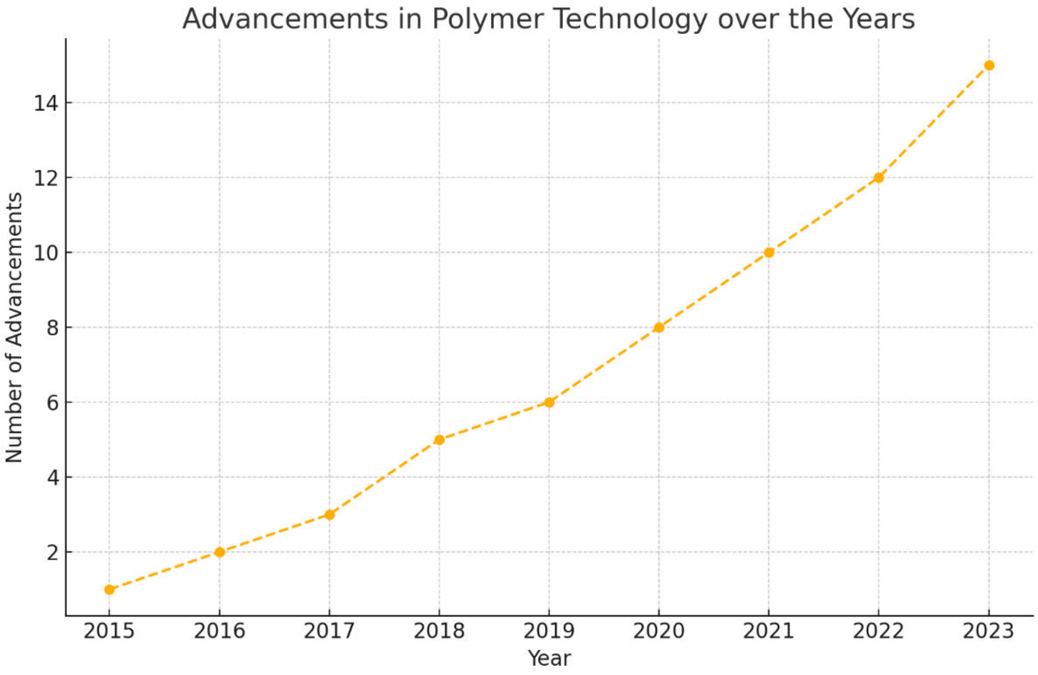

Figure 6. Advancements in Polymer Technology over the Years

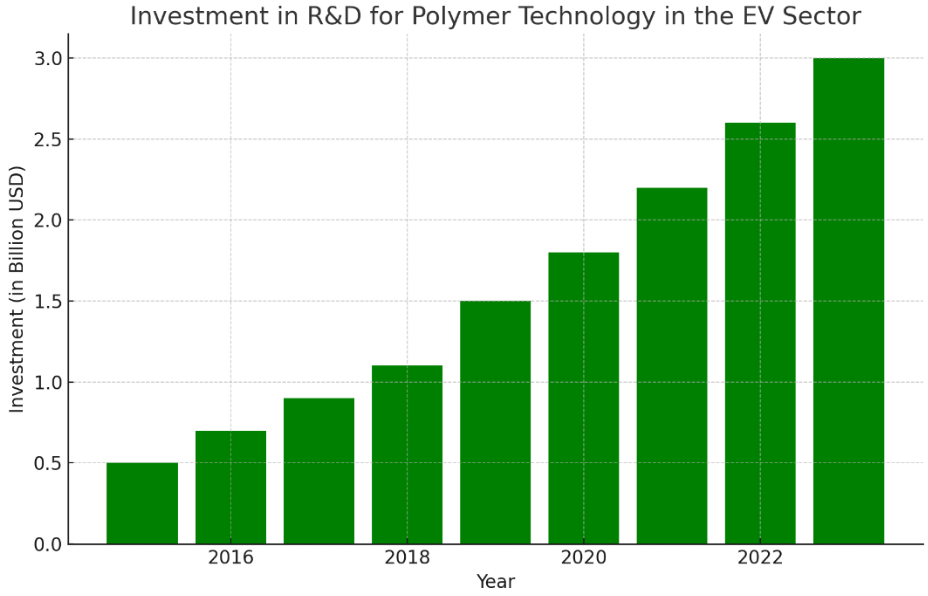

Figure 7. Investment in R&D for Polymer Technology in the EV Sector

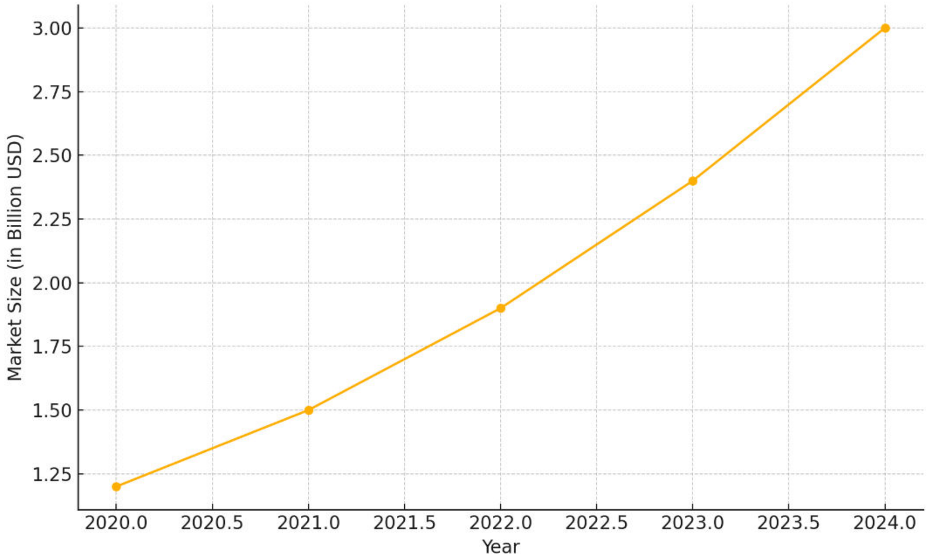

Figure 8. Market Growth of Polymers in EV Technology

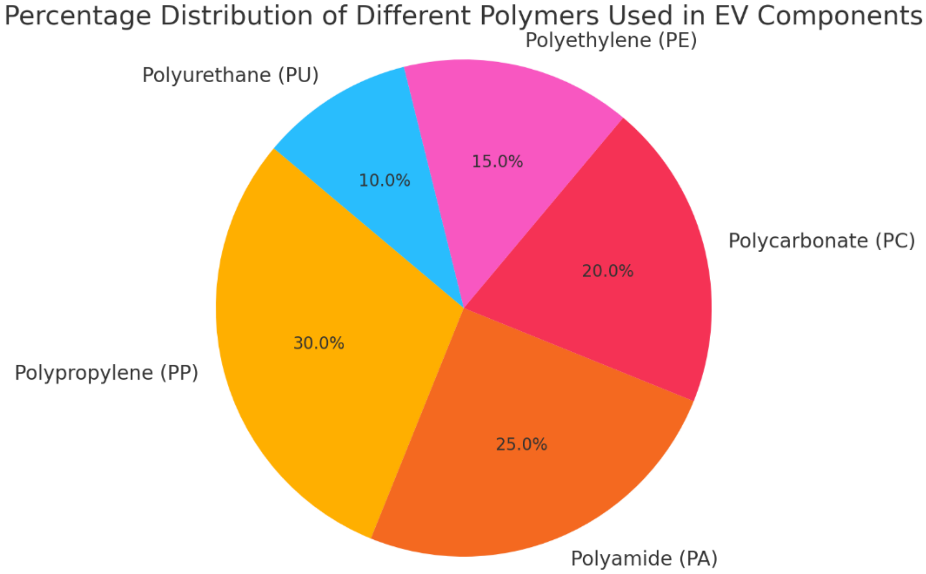

Figure 9. Percentage Distribution of Different Polymers Used in EV Components

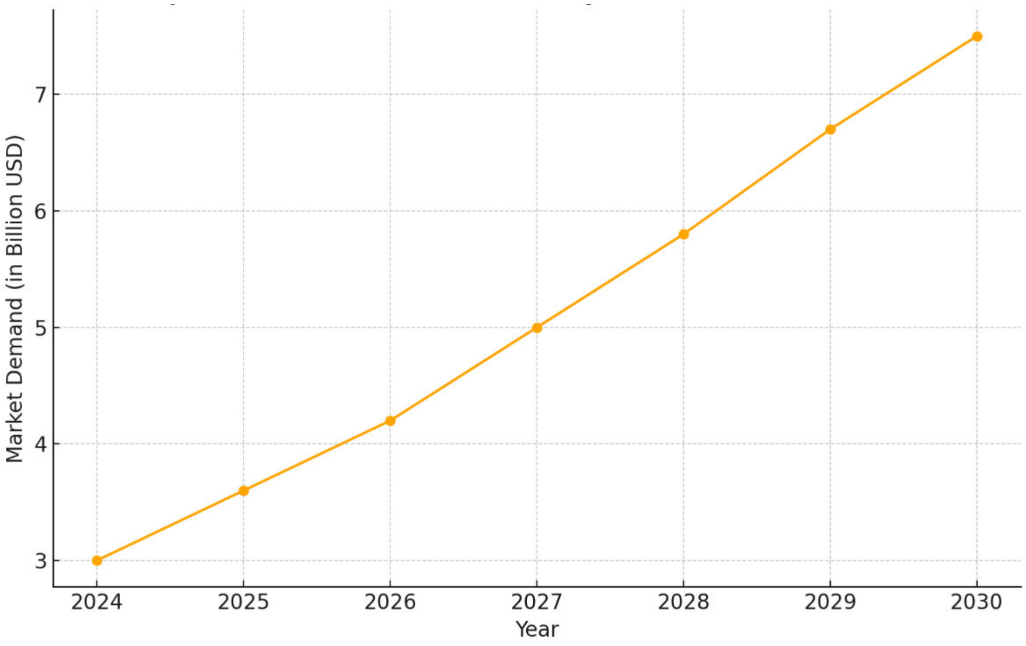

Figure 10. Projected Market Demand for Polymers in EVs (2024-2030)

Figure 8 shows the market growth of polymers in EV technology from 2020 to 2024. The market size has grown significantly, from 1.2 billion USD in 2020 to a projected 3.0 billion USD in 2024. This growth is indicative of the increasing demand for advanced polymer materials in the EV sector, driven by technological advancements and the push for more sustainable and efficient vehicles.

Figure 9 illustrates the percentage distribution of different polymers used in EV components. Polypropylene (PP) accounts for 30% of the usage, followed by Polyamide (PA) at 25%, Polycarbonate (PC) at 20%, Polyethylene (PE) at 15%, and Polyurethane (PU) at 10%. This distribution reflects the varying applications and properties of these polymers, highlighting their importance in different aspects of EV technology.

Figure 6 depicts the advancements in polymer technology over the years, from 2015 to 2023. The number of advancements has steadily increased, indicating continuous innovation in the field. This trend showcases the commitment to improving polymer materials, making them more suitable for the demanding requirements of EV technology. The advancements include improvements in thermal resistance, electrical conductivity, durability, and recyclability, among others.

Figure 10 projects the market demand for polymers in EVs from 2024 to 2030. The demand is expected to grow from 3.0 billion USD in 2024 to 7.5 billion USD in 2030. This projection reflects the anticipated increase in EV production and the ongoing advancements in polymer technology. The growing demand for polymers is driven by the need for lightweight, durable, and efficient materials that enhance the performance and sustainability of EVs.

Figure 7 shows the investment in R&D for polymer technology in the EV sector from 2015 to 2023. The investment has increased significantly, from 0.5 billion USD in 2015 to 3.0 billion USD in 2023. This trend indicates a strong focus on innovation and development in polymer materials, aimed at improving the performance and sustainability of EVs. The increased investment is expected to drive further advancements and create new opportunities in the EV market.

The analysis of polymers in electric vehicle technology highlights the critical role these materials play in the advancement and sustainability of EVs. The tables provide a detailed overview of the types of polymers used, their applications, recent advancements, market trends, and future directions. The graphs visually represent market growth, the distribution of different polymers, technological advancements, projected market demand, and investments in R&D, providing a comprehensive understanding of the current and future landscape of polymers in EV technology.

Polymers such as Polypropylene (PP), Polyamide (PA), Polycarbonate (PC), Polyethylene (PE), and Polyurethane (PU) are crucial in EV technology due to their unique properties. These materials offer lightweight, durability, high strength, thermal resistance, impact resistance, chemical resistance, and versatility. These characteristics make them ideal for various applications in EVs, from battery casings and wiring insulation to interior and exterior panels, seats, and cushions.

The application-specific use of polymers is driven by the need to enhance the performance, efficiency, and safety of EVs. Polypropylene (PP) is commonly used for battery casings and interior panels due to its lightweight and durable nature. Polyethylene (PE) is preferred for wiring and insulation because of its chemical resistance and flexibility. Polyamide (PA) is used in exterior panels for its high strength and thermal resistance, while Polyurethane (PU) is favored for seats and cushions due to its comfort and versatility.

Recent advancements in polymer technology are focused on improving the thermal resistance, electrical conductivity, durability, and recyclability of these materials. High-temperature resistant polymers enhance safety and efficiency, conductive polymers improve the performance of electronic components, lightweight composite materials increase range and efficiency, recyclable polymers contribute to environmental sustainability, and enhanced durability polymers reduce maintenance costs.

The market for polymers in EV technology in India has seen significant growth, with the market size increasing from 1.2 billion USD in 2020 to a projected 3.0 billion USD in 2024. The growth rate has also shown an upward trend, peaking at 30% in 2023. This growth is driven by the increasing adoption of EVs, advancements in polymer technology, and the push for more sustainable and efficient vehicles.

Conclusion

The advancements and future directions of polymers in electric vehicle technology are critical for the growth and sustainability of the EV market. Polymers provide distinct properties that improve the performance, efficiency, and safety of EVs, making them essential in various components. The continuous innovation and development in polymer technology, coupled with increasing market demand and investment in R&D, are driving the evolution of EVs towards more sustainable and efficient solutions.

The information provided in this research paper offers a comprehensive overview of the current status and future prospects of polymers in EV technology. They highlight the importance of these materials, the advancements being made, the market trends, and the potential developments that will shape the future of the EV industry. As the demand for EVs continues to grow, the role of polymers will become increasingly significant, driving further innovations and improvements in the technology. The future of polymers in EV technology lies in the development of biodegradable polymers, advanced composite materials, smart polymers, and the integration of nanotechnology. These innovations aim to create eco-friendly materials, improve the strength-to-weight ratio, introduce self-healing properties, and enhance performance and functionalities. Additionally, cost-effective production techniques are expected to lower manufacturing costs and increase adoption.

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