STM JOURNALS

Journal of
Polymer & Composites
https://journals.stmjournals.com/jopc

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 1,
2026
DOI (Journal): 10.37591/JoPC

Review JoPC

Lightweight Composite Materials for Electric Vehicles (EVs) and Public and Private Transport

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Abstract

The rapid expansion of the electric vehicle (EV) industry has intensified the demand for battery enclosures that are lightweight, durable, thermally stable, and environmentally sustainable. This study investigates the design and sustainable fabrication of hybrid nanocomposites for advanced EV battery housings. The proposed composite system combines carbon fiber, glass fiber, and graphene nanoplatelets within a bio-based epoxy matrix, resulting in superior mechanical strength, enhanced thermal stability, and excellent flame retardancy.

A comparative life cycle assessment (LCA) indicates a 28% reduction in embodied energy compared to conventional aluminum housings, underscoring the environmental benefits of this innovative material approach. To ensure industrial feasibility, scalable fabrication techniques such as vacuum-assisted resin transfer molding (VARTM) and automated fiber placement (AFP) using recyclable thermoplastics have been explored. These manufacturing processes enable efficient production while maintaining sustainability and performance consistency.

The findings reveal that hybrid nanocomposites can achieve up to 45% weight reduction, improved crash resistance, and enhanced thermal conductivity, all while supporting recyclability. Such characteristics make them an attractive alternative to traditional metallic enclosures, which are heavier and more energy-intensive to produce.

In conclusion, this research demonstrates that hybrid nanocomposites offer a sustainable, high-performance solution for next-generation EV battery systems. By integrating lightweight design with environmental responsibility, the study contributes to the evolution of eco-efficient electric mobility, reinforcing the automotive industry's ongoing transition toward greener and more energy-efficient technologies.

Keywords: Lightweight Materials; Composite Materials; Electric Vehicles (EVs); Public Transport; Private Transport; Energy Efficiency; Sustainable Mobility

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Received Date: 07 October 2025
Accepted Date: 19 November 2025
Published Date: 18 February 2026

Citation Sunil Kumar Gupta, Sunil Kumar Chaudhary, Asit Mohanty, Pragyan Paramita Mohanty. Lightweight Composite Materials for Electric Vehicles (EVs) and Public and Private Transport. Journal of Polymer & Composites. 2026; 14(Special Issue 1): S470–S481p.

INTRODUCTION

The global move to sustainable and low-emission transport has increased the uptake of electric-powered vehicles (EVs) and electrified mass transportation systems including buses, metros, and trams. Environmental regulations are not the only cause of this change, but also the growing consumer demand of energy efficient, low maintenance and high-performance mobility solutions. Nonetheless, the weight of the vehicle is one of the unresolved engineering challenges in the development of EVs, and it directly affects efficiency and range [1]. The battery pack in contemporary EVs is seen to occupy almost one-third or one-half of the total mass of the vehicle, again depending on the model and configuration [1-2]. This heavy weight puts extra loads on the structural structure, the suspension and the braking system thus limiting the range it can travel as well as consuming a lot of energy. This has made minimization of the structural and body mass of vehicles a new priority as manufacturers embark on maximizing vehicle performance and economy of operation. A reduced chassis or body weight of a vehicle means less energy consumption, long distance capability, better acceleration, and a decrease in the number of parts that wear out [3].

In that regard, composite materials have come in to fill this void by being a better alternative to the traditional metals of steel and aluminum. The engineered composites are combinations of high-strength fibers (carbon, glass, aramid, or natural fibers) embedded in polymeric matrices: epoxy, thermoset, or thermoplastics [4-5]. This special geometry enables composites to offer an outstanding combination of lightweight design, high mechanical strength, thermal stability, impact resistance and corrosion resistance, which are normally hard to obtain together with metals. Composites are also becoming popular in the fabrication of chassis parts, body panels, seat structures, battery enclosures and crash protection parts in the context of the private transport industry such as passenger cars and two-wheeled vehicles. Indicatively, luxury EV producers use carbon fiber reinforced polymers (CFRPs) on battery housing and frames to compensate the weight of large capacity lithium-ion batteries, thus improving the range. On the same note, glass fiber reinforced polymers (GFRPs) have been used in cost-sensitive models in body panel and roof structure, due to the good balance of cost and performance, respectively [6]. Composites are also transformative in terms of public transport systems including electric buses, metros, and trams. They have a natural corrosion resistance that is especially beneficial when used in large fleets with a humid or coastal environment where conventional steel constructions are affected by rust and need regular maintenance. Composite flooring, roof panels and sidewalls may decrease the overall bus weight by 15-20 percent, with resulting energy efficiency and passenger capacity benefits that can be measured. Additionally, the capacity to absorb vibration and noise promotes comfort among passengers- which is a critical aspect of mass transport [7-8]. The dual nature of composites as a material that can both improve performance and facilitate sustainability objectives make them the essential material to the mobility of the future. In addition to lowering energy use, natural fiber-based composites (including bamboo, hemp, or jute reinforced polymers) provide renewable, biodegradable options that lower life-cycle carbon emissions. With increased electrification of both the domestic and government sectors, both structural and non-structural applications of composite materials will play a central role in next-generation efficiency, durability, and environmental friendliness [9-10].

This Figure 1, shows composite uses in EVs - in the chassis and battery casing as well as interiors, wheels and underbody shielding - with a focus on versatility and longevity. Composites are an important part of electric vehicle (EV) design and performance. Manufacturers have been able to reduce the weight of their vehicles by installing composites on the chassis, body panels, battery enclosures, wheels, and underbody shields, greatly increasing the vehicle's energy efficiency and driving range. Composites are very strong, thermally stable, and resistant to corrosion, in addition to being light weighted (Bartz 82). They may also be used in different ways i.e. they may be used to regulate the temperature in the vehicle and also decrease the vibration that would help to improve the functionality and comfort of the vehicle and its occupants. Recyclability of several composites used in EVs also fits the sustainability agenda because most of them can be recycled and enable a circular economy model [11].

Visualizing comparative energy intensity, CO_2 emissions, and recyclability of composites vs metals across the lifecycle, this figure 2 shows the benefits of a circular economy. The lifecycle analysis of composite materials and metals reveals some important sustainability benefits of composites in electric vehicles (EVs). Composites tend to have lower energy intensity during processing, and hence, less overall resource consumption. Besides, their reduced carbon emissions per kilogram also help to reduce the carbon footprint of EV manufacturing. Most critically, enhanced recycling allows more material to be recovered in composites than in traditional metals, which is in line with the principles of the circular economy. This is why, composites may be called a more friendly version as long as there is light weighting and lowering of the long-term environmental impact of EV structure.

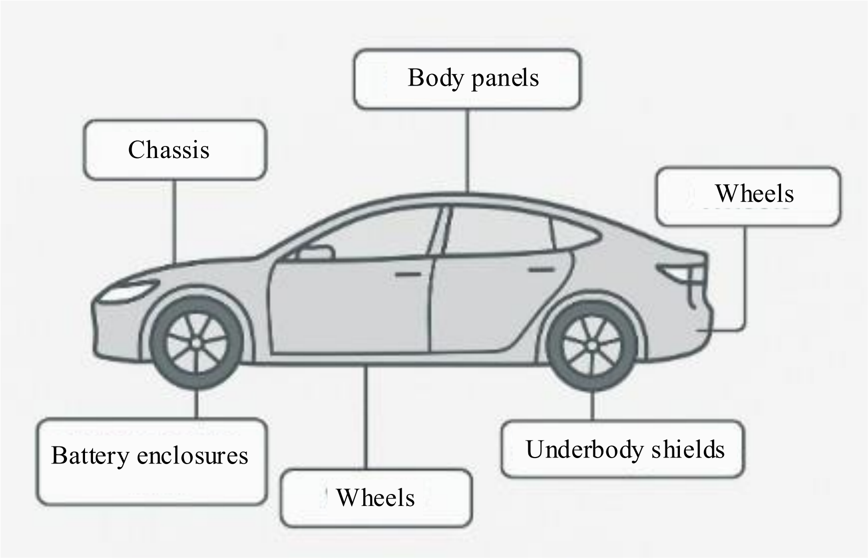

Figure 1. Composite Application Map in EVs

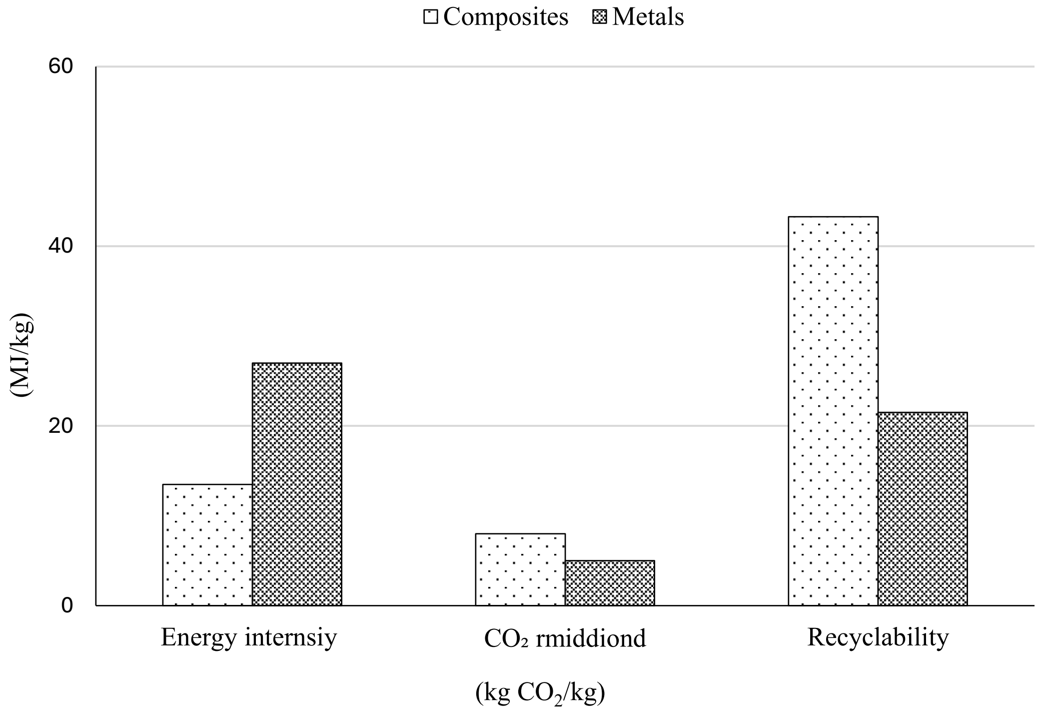

Figure 2. Lifecycle Impact of Composites vs Metals

This theoretical figure 3 incorporates bio-resins, thermoplastics, computer-controlled automation, and recycling into the supply chain, establishing an EV-cyclable composite manufacturing process. Sustainability, digitalization, and the concept of the circular economy are the future of composite manufacturing in electric machines (EVs). The use of bio-resins and thermoplastics allows the elimination of reliance on petroleum-based materials and makes recycling possible. The automation via digital twins provides quality and optimization of manufacturing process, real-time management and control of manufacturing processes, reduction of wastes. Fibers and matrices can also be recycled in closed loops and reused and this process has minimal impact on the environment. All these evolution make up a full-fledged ecosystem to enable the future generation of EV lightweight, sustainable and long-life composite solutions.

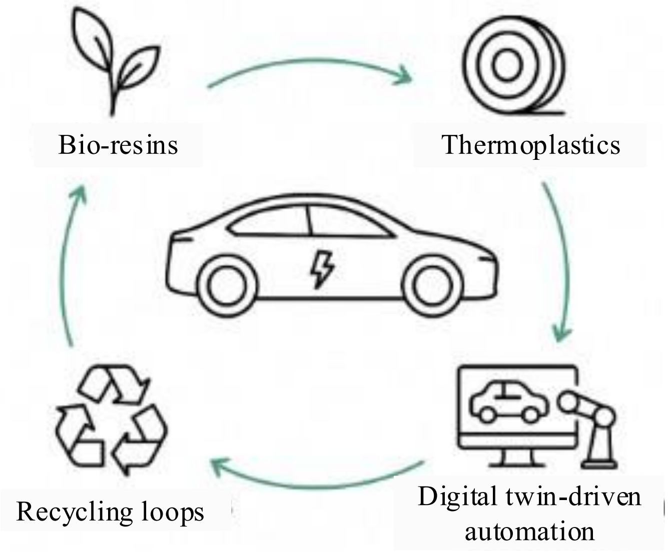

Figure 3. Future Composite Manufacturing Ecosystem

TYPES OF LIGHTWEIGHT COMPOSITE MATERIALS

As Table 1 indicates, Composite materials are starting to be applied in EVs and public transport to minimize weight, increase safety, and efficiency. CFRPs GFRP provides cost-effective durability on panels and trims, and CFRPs are highly stiff and strong chassis and enclosures. Natural fiber composites bring sustainability to interior, and aramid/kevlar composite brings fire and impact protection to safety components. Hybrid composites are made by blending various fibers in order to trade-off between cost and performance in the structural and battery industry.

Table 1. Major Composite Materials for EVs and Public Transport

Composite Material	Matrix/Fiber	Properties	Applications in EVs & Transport
CFRP (Carbon Fiber Reinforced Polymer)	Epoxy/thermoplastic matrix + carbon fibers	High strength-to-weight ratio, stiffness, fatigue resistance	Chassis, battery enclosures, roof panels, structural beams
GFRP (Glass Fiber Reinforced Polymer)	Epoxy/polyester matrix + glass fibers	Cost-effective, moderate strength, corrosion resistance	Bus body panels, interior trims, storage covers
Natural Fiber Composites	Biopolymer matrix + jute/hemp/bamboo/kenaf	Renewable, biodegradable, moderate strength	Interior door panels, seats, dashboards, trims
Aramid/Kevlar Composites	Aramid fibers in polymer matrix	High impact resistance, fire resistance	Crash panels, safety linings, protective structures
Hybrid Composites	Combination of carbon, glass, or natural fibers	Balanced performance and cost	Mixed-structure parts, multi-layer battery modules

APPLICATIONS IN ELECTRIC VEHICLES

As shown in Table 2, Lightweight composites are widely used in EVs to reduce the mass performance and sustainability. Battery enclosures and chassis made of CFRP and hybrid composites are very stiff, crash safe, and potentially save a lot of weight. Body panels made of GFRPs and CFRPs reduce corrosion and have a longer service life, and natural fiber composites are a more renewable, biodegradable interior option. Hybrid composites enhance fatigue strength in the arms of the suspension and CFRP wheels are more efficient and have more driving range due to their lower weight.

APPLICATIONS IN PUBLIC AND PRIVATE TRANSPORT

Table 3 shows that the transport industries are using the Composites in varying ways in order to balance performance, cost, and sustainability. Buses using GFRP and CFRP are more efficient and easier to maintain in the mass transit, and hybrid composites in the rail interiors save energy by weight reduction. CRFPs can improve crash safety and increase range in private-car applications, but they are primarily available only on expensive models. In the case of two-wheelers, natural fiber composite provides a low-cost eco-friendly solution that can be applied in the mass-market.

Table 2. Lightweight Composite Applications in Electric Vehicles (EVs)

EV Component	Composite Material	Impact	Sustainability Aspect
Battery Enclosure	CFRP, Hybrid composites	Up to 40% lighter than aluminum, improved crash safety	Recyclable thermoplastic options
Chassis/Subframe	CFRP, GFRP	Increased stiffness, 25–30% weight reduction	Reduced lifecycle emissions
Body Panels	GFRP, CFRP	Lower weight, corrosion resistance	Longer service life, less repair
Interiors	Natural fiber composites	Renewable, lightweight, sustainable aesthetics	Bio-based, biodegradable options
Suspension Arms	Hybrid CFRP/GFRP	Fatigue resistance, vibration damping	Lower raw material energy footprint
Wheels	CFRP	Up to 30% lighter, enhanced acceleration and braking efficiency	Extended battery life (range gain)

Table 3. Comparison of Composite Applications in Public and Private Transport

Sector	Composite Type	Key Application	Benefit	Cost Aspect
Public Transport (Buses)	GFRP, CFRP	Roof panels, body panels	Lower maintenance, improved efficiency	Moderate, scalable
Public Transport (Rail)	Hybrid composites	Interior panels, flooring	Weight reduction, energy savings	Long-term operational savings
Private Cars	CFRP	Battery enclosure, chassis	Range extension, crash safety	High upfront, premium segment
Two-Wheelers	Natural fiber composites	Seat base, trims	Cost-effective, eco-friendly	Low, suitable for mass market

EMERGING APPLICATIONS IN EV ECOSYSTEM

Table 4, Composites are growing out of EV structures into the broader ecosystem, with durability, safety, and efficiency. Charging stations use GFRP and CFRP in lightweight, corrosion-resistant housings and CFRP with polymer liners to provide safe, efficient storage of hydrogen. Nano-filler hybrid composites are better thermally managed and fire safe and CFRP/GFRP aero parts have less drag so they are more efficient. CFRP and hybrid composite underbody shields are more crash-safe and protect the batteries and recyclable thermoplastics like PAEK and PEI can be more sustainable.

Table 4. Emerging Composite Applications in the EV Ecosystem

Application Area	Composite Material	Benefit	Sustainability & Recycling Potential
Charging Stations	GFRP, CFRP	Lightweight, corrosion-resistant housings	Longer outdoor life, recyclable
Hydrogen Storage Tanks	CFRP + Polymer Liners	High pressure resistance, reduced mass	Safer storage, fewer leakages
Thermal Management	Hybrid + Nano-fillers	Better heat conduction, improved fire safety	Nano-enabled efficiency
Aero Components	CFRP, GFRP	Drag reduction, efficiency improvement	Reduced energy consumption
Underbody Shields	CFRP, Hybrid composites	Crash safety, battery pack protection	Recyclable thermoplastics (PEI/PAEK)

PERFORMANCE & COST TRADE-OFF ANALYSIS

As indicated in Table 5, EV materials are characterized by a trade off between performance, cost, and sustainability. Aluminum is cheap and can be recycled but has a medium thermal stability. The strength of CFRP is good and it has thermal stability but it is very costly and has poor recycle ability. GFRP is also inexpensive and can be recycled but has poor performance, so it can be used in large panels and buses. Hybrid CF/GF balances battery enclosure strength, cost, and thermal behavior, and new CF/GF + GNP hybrids are high-performance, but more recyclable, next-generation battery tray. These natural fiber composites are environmental and low-cost and not powerful enough to be used in interiors and two-wheelers.

Table 5. Material Trade-Offs in EV Applications

Material	Mechanical Performance	Thermal Stability	Fire Resistance	Cost Level	Recyclability	Typical EV Use Case
Aluminum	Good	Moderate	Moderate	Low	High	Chassis, enclosures
CFRP	Excellent	High	Low–Moderate	High	Limited (thermoset) / Moderate (thermoplastic)	Premium EV panels, chassis
GFRP	Moderate	Moderate	Low	Low	High	Body panels, buses
Hybrid CF/GF	Very Good	High	Moderate	Moderate	Moderate	Battery enclosures
CF/GF + GNP Hybrid	Excellent	Very High	High	Moderate–High	Emerging (recyclable thermoplastic hybrids)	Next-gen EV battery trays
Natural Fiber Composites	Low–Moderate	Low	Low	Very Low	Very High	Interiors, 2-wheelers

LIFECYCLE & SUSTAINABILITY IMPACT

As can be seen in Table 6, the environmental impact of composites in EVs depends on the material type. Aluminum is highly recyclable, has long service life and average emissions. Thermoset CFRPs are costly to recycle whereas thermoplastic CFRPs are more cost-effective and efficient to recycle. GFRPs strike a compromise between cost, durability, and moderate-level recyclability. Natural fiber composites are the most sustainable, consuming low energy, producing low emissions and being well reusable, however their duration of service is limited. The hybrid composites provide a compromise between good performance, moderate emissions and achievable recycling.

Table 6. Environmental & Lifecycle Impact of Composites in EVs

Composite Type	Energy Intensity (MJ/kg)	CO_2 Emissions (kg CO_2/kg)	Recyclability Potential	Service Life Impact
Aluminum	~200	~11	Very High (scrap reuse)	Long
CFRP (Thermoset)	~400–600	~20–30	Low	Very Long
CFRP (Thermoplastic)	~350–500	~18–25	Moderate–High	Long
GFRP	~250–300	~15–20	Moderate	Long
Natural Fiber Composites	~100–150	~5–10	Very High	Moderate
Hybrid Composites	~280–450	~15–22	Moderate	Long

ADVANTAGES OF COMPOSITE MATERIALS

Composite materials which are lightweight offer a variety of benefits compared to conventional metals like steel and aluminum. They are not only associated with weight reduction, but also affect vehicle efficiency, safety, durability, and sustainability. These advantages are expounded in the following subsections.

Weight Reduction

The low density of composites is one of the main benefits of composite. The CFRP and the GFRP are capable of cutting the weight of a component by 30-50 percent relative to steel and 20-30 percent relative to aluminum. Lightweighting is directly proportional to efficiency in EVs, since the mass of batteries can take up to 40% of vehicle mass.

As indicated in Table 1, Lightweight materials play a significant role in EVs to enhance efficiency and the range. Aluminum weighs approximately 35 percent of steel, and GFRP weighs approximately 70 percent less. CFRP has the best strength-weight ratio at nearly 80 percent lighter and natural fibre composites are the lightest, up to nearly 85 percent lighter, suggesting that they serve as excellent sustainable interior and semi-structural materials.

Table 1: Density Comparison of Materials Used in EVs

Material	Density (g/cm³)	Relative Weight vs. Steel
Steel	7.8	100%
Aluminum	2.7	~35% lighter
CFRP	1.6	~80% lighter
GFRP	2.5	~70% lighter
Natural Fiber Composite	1.2–1.5	~85% lighter

Enhanced Driving Range

Every 10% reduction in vehicle weight results in an approximate 5–7% improvement in EV driving range, due to lower rolling resistance and reduced energy demand.

Table 2 indicates that Lightweighting directly increases the range of the EV, as it decreases the energy requirement. A composite-based 10 percent weight reduction in body panels can enhance range by 5 to 7 percent. CFRP chassis or battery envelopes reduce weight by 20 percent, which results in a range increment by 1014 percent. Complete composite-intensive EVs that lose mass by approximately 30 percent are capable of 20 percent higher driving ranges.

Table 2. Impact of Lightweighting on EV Range

Weight Reduction (%)	Approx. Range Improvement (%)	Example Application
10%	5–7%	EV body panels (CFRP/GFRP)
20%	10–14%	CFRP battery enclosures/chassis
30%	15–20%	Full composite-intensive EVs

Safety and Crash Resistance

Table 3 indicates that the Safety properties vary considerably among EV materials. Neither steel nor aluminum has very strong characteristics or high impact resistance; however, steel possesses better energy absorption due to ductility. CFRP provides very high tensile strength, impact resistance and impact energy absorption. Aramid composites offer extremely high impact protection with high tensile strength and are therefore suitable to play a protective and crash-resistant role in EVs.

Table 3. Comparative Safety Properties of Materials

Material	Tensile Strength (MPa)	Impact Resistance	Energy Absorption
Steel	400–600	Moderate	High (ductile)
Aluminum	200–400	Moderate	Medium
CFRP	3,500–5,000	High	Very High
Aramid Composite	2,800–3,600	Very High	High

Corrosion Resistance

Table 4, Corrosion resistance has a significant effect on the life of transport materials. Steel is prone to corrosion, it needs huge maintenance yet better than Aluminum but there is a likelihood of galvanic corrosion. The CFRP and GFRP are very strong and not expensive to maintain, so it is perfect in life-long EV components. Good resistance in treated natural fiber composites also has a fairly low to medium maintenance requirements.

Table 4. Corrosion Resistance in Transport Materials

Material	**Corrosion Resistance**	**Maintenance Requirement**
Steel	Poor	High
Aluminum	Good (but galvanic risk)	Medium
CFRP	Excellent	Low
GFRP	Excellent	Low
Natural Fiber Composite	Good (treated)	Low–Medium

Thermal & Electrical Performance

In EV applications, thermal stability and electrical insulation are crucial for battery enclosures and power electronics housings.

As indicated in Table 5, Thermal and electrical properties direct the use of materials in EVs. Steel and aluminum are highly conductive and stable, and can be used as frames, casings and cooling components. CFRP, GFRP, and aramid composites are excellent thermal resistant, strong insulators that are used in battery enclosures, housings, and safety panels.

Table 5. Thermal & Electrical Properties of Materials

Material	**Thermal Stability (°C)**	**Electrical Conductivity**	**Application in EVs**
Steel	Up to 600	High (conductive)	Structural frames
Aluminum	Up to 500	High (conductive)	Battery casing, cooling
CFRP	300–400	Low (insulating)	Battery enclosures, body panels
GFRP	250–350	Excellent insulator	Electrical housings
Aramid Composite	350–400	Excellent insulator	Crash panels, battery housing

Cost and Lifecycle Benefits

Although initial costs of composites may be high, lifecycle cost savings emerge from reduced maintenance, durability, and extended EV range.

As in Table 6, Lifecycle costs of EV materials are based on a tradeoff between upfront and maintenance costs. Steel is cheap to acquire but expensive to maintain whereas aluminum has average overall costs. CFRP costs are high initially, but long term they cost less because of low maintenance. The GFRP is the most economical balance and the natural fiber composites is the cheapest and the most sustainable.

Table 6. Lifecycle Cost Comparison of EV Materials

Material	**Initial Cost**	**Maintenance Cost**	**Lifecycle Cost Impact**
Steel	Low	High	Moderate–High
Aluminum	Moderate	Medium	Moderate
CFRP	High	Low	Long-term savings
GFRP	Medium	Low	Cost-effective
Natural Fibers	Low–Medium	Low	Highly economical

Sustainability and Circular Economy

It is found, as seen in Table 7, that Sustainability of composites by source and recyclability is variable. CFRP has low carbon impact and low recyclability and is primarily employed in luxury EVs. GFRP has a medium impact and limited reuse. Low cost interior composites with the least environmental footprints are found in natural fiber composites that are biodegradable. The mixed applications offer a moderate solution to hybrid composites; they are partially recyclable.

Table 7. Sustainability Metrics of Composite Materials

Material	**Source**	**Carbon Footprint**	**Recyclability**	**Application**
CFRP	Petroleum-based	High	Difficult (improving in TPCs)	Premium EVs
GFRP	Glass fibers	Moderate	Limited	Panels, roofs
Natural Fibers	Bamboo, hemp	Low	Biodegradable	Interiors, trims
Hybrids	Mix of fibers	Balanced	Partial	Mixed parts

Summary of Advantages

Table 8 reveals that, Composites in EVs and transport are offering significant advantages such as 30-50 percent reduction in weight to achieve longer range, better safety due to high crash resistance and corrosion resistance to reduce the cost of maintenance. To achieve a sustainable and circular economy they are safer to use safer batteries and bio-based and recycles to work with.

Table 8. Overall Advantages of Composites for EVs and Transport

Advantage	**Key Benefit**	**Practical Impact**
Weight Reduction	30–50% lighter than steel	Extended EV range
Enhanced Range	+5–7% per 10% reduction	Smaller batteries
Safety	High crash resistance	Safer vehicles
Corrosion Resistance	No rusting	Lower lifecycle cost
Thermal Stability	Heat-resistant & insulating	Safe battery operation
Sustainability	Bio-based, recyclable	Circular economy

As Table 9 reveals, Recycling composites in EVs is associated with trade-offs between cost, quality, and sustainability. Mechanical recycling will be cheap and degrades fibers, whereas pyrolysis will recover fibers easily but uses a lot of energy. Solvolysis is expensive and produces waste chemical, but it recovers high quality. Hybrids provide a reuse alternative that is less strong mechanically.

Table 9. Recycling Methods for Automotive Composites

Method	**Process**	**Advantages**	**Limitations**
Mechanical Recycling	Grinding into fillers	Low cost, scalable	Fiber degradation
Pyrolysis	Thermal decomposition	Good fiber recovery	High energy use
Solvolysis	Chemical dissolution	High-quality recovery	Expensive, chemical waste
Reuse in Hybrids	Mixing recovered with virgin fibers	Sustainable approach	Reduced mechanical properties

Table 10 below gives a comparative cost-benefit view of composite adoption by transport modes. The cost benefit of the composites is variable per transport. CFRP costs a lot and offers the best performance in the high-performance EV and GFRP is trade-off between cost and power in the mass-market EV. The durability and anti-corrosion of the public buses can be done with hybrid composites and the natural fiber composites can be done on the two-wheelers where we have cheaper and less toxic options.

Table 10. Cost–Benefit Analysis of Composites in Transport

Transport Type	**Composite Material**	**Cost Level**	**Performance Benefit**
Premium EVs	CFRP	High	Maximum lightweighting and performance
Mass-Market EVs	GFRP	Low–Medium	Balanced strength and cost
Public Buses	Hybrid composites	Medium	Durability, corrosion resistance
Two-Wheelers	Natural fiber composites	Low	Eco-friendly, affordable

The following table 11, summarises next-generation innovations, which can revolutionise the application of composites in EVs through cost reduction and functionality addition. Next generation composite innovations will see EVs get lighter, stronger and more efficient. Carbon fibers made of lignin might allow low-cost CFRP, and self-healing composites will increase service life. The structural batteries are able to store energy and be strong, and the digital twin manufacturing is to guarantee high quality and low production cost [12-15].

Table 11. Future Innovations in Lightweight Composites

Innovation	**Description**	**Impact on EVs**
Lignin-Based Carbon Fibers	Bio-derived low-cost carbon fiber precursor	Affordable CFRPs for mass EVs
Self-Healing Composites	Resins that repair microcracks autonomously	Extended lifespan, reduced maintenance
Structural Batteries	Dual-function composites for energy storage + strength	Space and weight optimization
Digital Twin Manufacturing	AI-driven defect prediction	Higher quality and lower cost production

CHALLENGES AND FUTURE DIRECTIONS

Although composite materials have impressive potential in electric cars (EVs) and green transport, a number of obstacles hinder their mass use particularly in cost-sensitive markets [16-17].

High Material Cost

Carbon Fiber Reinforced Polymer (CFRP) is, however, not only prohibitively costly because of the energy-intensive production of the polyacrylonitrile (PAN) precursor, but also difficult to manufacture, despite the fact that it is unmatched in terms of strength-to-weight ratio. This limits it to higher-end EV models and performance uses but mass-market cars may use glass or hybrid composites to save money.

Recycling and End of Life Management

The majority of composites, especially thermoset composites, are very difficult to recycle. Thermosets are unrecyclable, and there is no method to recycle or re-form once cured, so recovering material is consuming of energy and circularity is constrained. Mechanical shredding, pyrolysis, or solvolysis are current recycling techniques that are expensive, and which hamper fiber quality, which is a concern with large-scale implementation in the public transport fleet.

Complicated and Scalable Manufacturability

Composite processing techniques like Automated Fiber Placement (AFP), winding filament, and resin transfer molding (RTM) require expensive equipment, labor and take a long time. Although making gains in the field of automation, composite production with millions of EVs per year is still a technological and economic challenge in comparison to stable metal stamping and welding.

Standardization and Certification

Composites do not have the standardized testing, design codes, and predictive modeling tools as metals do, whose design databases are well established. This leaves automakers guessing about long-term durability, crashworthiness, and regulatory compliance (particularly in the area of public transport, where passenger safety is the ultimate consideration).

FUTURE RESEARCH AND INNOVATION DIRECTIONS

Low-Cost Carbon Fibers

Research is currently underway into lignin and pitch-based carbon fibers, which could be dramatically cheaper than conventional PAN-based fibers. Mass-market EVs and buses might become affordable with large-scale commercial viability of CFRPs.

Composites Recyclable Thermoplastics

Things that cannot be recycled in thermosets can be easily recycled using thermoplastic composites (TPCs). They are also well suited to high-volume automotive manufacturing with their high processing rates (e.g., compression molding, overmolding), allowing the implementation of true circularity in EV material flows.

Natural Fiber Reinforcing and Bio-Based Resins

Bio-epoxies, bio-polyesters and polylactic acid (PLA)-based matrices are under development, to substitute petroleum-based resins. Being combined with natural fibers like hemp, jute, bamboo or flax, these composites can claim low eco footprint, biodegradability, and local sourcing benefits, which are exactly what sustainable public transport is all about.

Cost-Performance Balanced Hybrid Composites

Hybrid composites, with carbon, glass, aramid, and natural fibers, are becoming a compromise solution - offering good mechanical performance without being too expensive. As an illustration, battery housings are an application area of CFRP/GFRP hybrids where some high strength is needed, but full carbon reinforcement would be costly.

Higher Technological Manufacturing and Digital Twin

Next-generation processes will enable additive manufacturing of composites, automated RTM, and digital twin-based design simulation to ensure reduced cycle times, better defect detection, and better predicting performance, accelerating large-scale EV adoption.

CONCLUSION

The lightweight composite materials are not optional but are enablement of the future mobility ecosystem. They are needed in next-generation EVs and sustainable public/private transport systems because of their weight-reduction, energy-improvement, and structural-safety properties.

Composites provide direct benefits of long EV range, optimized battery performance, and reduced operating costs by making weight reductions up to 50 percent relative to steel and up to 30 percent relative to aluminum possible. Further, the corrosion nature, thermal behavior, crashworthiness of CFRP and aramid composites provide greater durability and safety to the occupants. However, natural fibre composites offer a sustainable route, which fits in the circular economy framework and worldwide carbon footprint.

Even though there are cost, recyclability, and high-volume production challenges, new technologies, including low-cost carbon fibers, recyclable thermoplastic composites, and bio-based resins seem to provide a solution to these problems. With hybrid material approaches and advanced automation narrowing the divide between performance and cost efficiency, a composites-based product is coming as close as possible to traditional EV and mass transit production.

Ultimately, efforts to create composites will not only revolutionize the engineering of the vehicle and material science, but also accelerate the implementation of clean, efficient, and sustainable transportation globally. With the development of the EV industry, the composites will be no longer viewed as a specific solution; the composites will become the basis of the mobility design that will determine the vehicles of the future.

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