

Green Energy and Intelligent Transportation: The Role of Composite Materials in Electric and Automotive Sectors

Sunil Kumar Gupta^{1*}, Asit Mohanty², Pragyan Paramita Mohanty³, M. Venu Gopala Rao⁴, Govind Singh Patel⁵

Abstract

The global transition toward sustainable mobility is accelerating, driven by mounting concerns over climate change, urban congestion, and the rapid development of green energy technologies. At the heart of this transformation lie intelligent transportation systems (ITS) and electric vehicles (EVs), which are collectively reshaping the future of modern transportation. Within this context, composite materials have emerged as key enablers, offering lightweight, durable, and energy-efficient solutions that enhance vehicle performance, range, and sustainability. This article examines the strong interconnection between green energy initiatives, smart transportation technologies, and the expanding role of composite materials in the EV and automotive sectors. It provides an overview of advanced composites such as carbon fiber-reinforced polymers (CFRP), glass fiber composites, and natural fiber hybrids, along with modern manufacturing techniques including resin transfer molding, compression molding, and additive manufacturing. These materials not only contribute to improved efficiency and safety but also support innovative vehicle architectures optimized for ITS integration. The discussion further addresses critical challenges related to recyclability, cost efficiency, and large-scale production, while evaluating the environmental impact and sustainability aspects of composite adoption. Emerging trends such as smart materials, bio-based composites, and circular manufacturing approaches are also highlighted. In conclusion, the study underscores the indispensable role of composites in shaping the next generation of sustainable transportation. By combining technological innovation with environmental stewardship, composites are driving progress toward a smarter, cleaner, and more energy-efficient mobility ecosystem.

Keywords: lightweight composites, electric vehicles, public transport, CFRP, GFRP, sustainability, mobility

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INTRODUCTION

Decarbonization of the transport sector has become a pillar in the realization of the goals of global climate neutrality and fulfilling the promises made by international treaties like the Paris Accord. Among the existing opportunities, the most promising way to substitute the traditional internal combustion engine (ICE) vehicles is the rapid growth of the electric vehicle (EV) market [1]. It is projected that EVs will become the vehicle of the future road transportation, as more stringent environmental policies are implemented, battery prices drop, and there is more environmental pressure on society to demand sustainable vehicles [2]. Governments worldwide are undertaking radical measures and giving timelines to the retirement of vehicles that consume fossil fuels and spending a lot of money in creating transport systems that do not emit any carbon-based gas [3].

One such enabling factor that is crucial towards this transition is the combination of renewable and charging infrastructure. Green energy, a set of solar, wind, hydropower, and future clean technologies, is the background on which ensuring that EVs have a minimum carbon footprint throughout their life cycle is achieved. No, the implementation of charging stations with renewable energy will not only enhance the stability of the grid, but it will also allow the energy security to be enhanced because the consumption of fossil fuel will not be promoted. At the same time, Intelligent Transportation Systems (ITS) are developing to transform the mobility ecosystems. ITS uses real-time information analytics, vehicle-to-everything (V2X) and machine learning and networked connected smart infrastructure to enhance road safety, reduce congestion and energy consumption [4–5]. Even the fact that such systems are being provided also indicates that transport electrification is coupled with operational smarts, and, therefore, the fear of range anxiety, gridlocks, and energy delivery inefficiency [6]. In this dynamic environment, composite materials are being utilized in a transformational manner as it involves EV and future generation vehicle design. The use of lightweight materials that are strong is critical in the reduction of mass of vehicles, which is directly related to long driving range, enhanced energy efficiency, and performance. Also, composites are utilized to facilitate new techniques in fabrication, such as Automated Fiber Placement (AFP), filament winding, Large Format Additive Manufacturing (LFAM), and continuous fibre 3D printing [7–8]. These high-tech processes are not only enhancing structural integrity and flexibility in design, but also offer a line of affordable and scalable production of automotives, and sustainable production.

Fundamentally, the overlap between renewable energy, smart transportation facilities, and the composite material breakthrough makes the EV industry the force that will help achieve the goals of decarbonization on a global scale. Together they constitute a sustainable, efficient and technologically viable foundation of the future of mobility.

GREEN ENERGY IN ELECTRIC MOBILITY

Renewable Energy Integration

Although the very act of transport electrification is a key milestone on the path to decarbonization, its eco-friendliness relies on the nature of the electricity that serves as the input to electric vehicles (EVs). Replacing internal combustion engine with EVs will not necessarily be beneficial to the environment unless the electricity supply remains highly dependent on fossil fuels. As such, grid decarbonization and the direct connection of renewable energy sources to EV charging infrastructure are the key to actual zero-emission mobility.

One of the most feasible options of decentralized clean energy is solar-powered EV charging stations. Vehicles can be charged using photovoltaics (PV) at charging points to charge vehicles with low transmission loss and lower the carbon intensity of electricity use. Likewise, the use of wind, hydroelectric power and new technologies like green hydrogen can further increase the range of renewable energy types that can be used by the transport sector. Vehicle-to-Grid (V2G) is another important development that will enable EVs to act not only as consumers but also as distributed energy storage units.

Two-way charging can increase grid stability, simplify renewable energy integrations, and decrease the frequency of fossil-fuel-based peaking power plants since EVs can also add electricity to the grid when the grid needs it the most, thus reducing the load on the grid. Taken together, these steps will form EVs as part of a modern and intelligent energy system [9–11].

The Table 1, compares the renewable energy options of EV charging infrastructure based on efficiency, advantages and challenges. Weather- and land-dependent but decentralized is solar PV (15–22%). Wind energy (30–45%) is intermittent, location bound, and generates a large amount of energy in windy locations. Hydropower (35–50%) is a stable, long-term source of energy with ecological and location limitations.

Table 1. Renewable Energy Options for EV Charging Infrastructure

Energy Source	Typical Efficiency	Key Advantages	Challenges
Solar PV	15–22%	Decentralized, scalable, low maintenance	Weather dependence, land use
Wind Power	30–45%	High output in windy regions, scalable	Location-specific, intermittency
Hydropower	35–50%	Stable base load, long lifespan	Ecological impact, site-dependent
Green Hydrogen	30–40% (electrolysis-to-use)	High storage potential, suitable for heavy-duty transport	High production cost, infrastructure gaps
Biomass/Bioenergy	25–35%	Carbon-neutral potential, waste-to-energy	Feedstock availability, emissions management

Green hydrogen (30–40%) can be used in storage, heavy transport, but is expensive and has poor infrastructure. Waste-to-energy and carbon neutrality require biomass (25–35%) and should be supported by feedstock availability and emission control. In general, both sources have sustainability, scalability, and practicality trade-offs.

BENEFITS FOR TRANSPORTATION SYSTEMS

Lower Carbon Footprint

Renewable-powered charging solution integration lowers significantly the lifecycle greenhouse gas (GHG) emissions of EV fleets. Unlike traditional vehicles which release carbon dioxide during their use, operation of renewable powered EVs will have minimal emissions. This equates to a significant decrease in the carbon footprint of national transportation systems, on a well-to-wheel basis, and is directly related to mitigating the effects of global climate change targets.

The Table 2, compares the GHG lifecycle emission of vehicle types. The use of fossil fuel makes conventional ICE vehicles the most emitting (180-250 g CO₂/km). Even EVs powered by a grid that is heavy on coal will emit up to 100-150 g CO₂/km, with an even lower emission of 40-80g CO₂/km with an even heavier renewable grid. Having 100 percent renewable energy also reduces EV emissions to less than 20 g CO₂/km, demonstrating that clean energy is essential to make EVs as sustainable as possible.

Cost Stability and Economic Efficiency

Renewable energy has the benefit of offering stability in pricing as compared to the instability of the global oil and natural gas markets. In large EV fleets, especially in the public transport and logistics industries, the renewable-powered charging infrastructure lowers the costs of operation and protects operators against fuel price volatility [14–15].

The economic results of renewable-powered EV-charging are presented in the Table 4. The traditional ICE fleets are expensive, volatile in terms of fuel costs, expensive to maintain, and generally expensive to own. EVs which run on grid electricity reduce the cost of maintenance and ownership and rely on grid prices. EVs powered by renewable energy have the lowest and most consistent energy prices, least maintenance, and lowest overall cost of ownership, which is economically beneficial in the long term.

Table 2. Lifecycle GHG emissions of different vehicle types.

Vehicle Type	Energy Source	GHG Emissions (g CO ₂ /km, well-to-wheel)
ICE Vehicle (Petrol/Diesel)	Fossil fuels	180–250
EV (Grid mix, coal-heavy)	Fossil-dominant grid	100–150
EV (Grid mix, 50% renewables)	Renewable-integrated grid	40–80
EV (100% renewables)	Solar/wind/hydro	<20

Enhanced Energy Security

The economic and geopolitical weaknesses related to dependence on imported fossil fuels have existed long before. Countries can enhance their energy security by diversifying energy sources by incorporating solar energy, wind energy, hydropower, and other renewable energy sources. Scaled-up renewable integration to charge EVs will minimize the risk of global oil price volatility, supply chain shocks, and other risks, and improve long-term energy security [12–13].

In the Table 3, fossil fuel reliance is compared with renewable integration in the EV sector. A fossil fuel-based economy is characterized by a high dependency on imports (60-80%), price fluctuations and high strategic risks, resulting in a poor long-term energy security. By contrast, an EV economy based on renewables decreases the import-dependence (10–20%), stabilizes prices better, reduces vulnerability, and offers greater energy security over time.

Barriers to Renewable-EV Integration

Despite the advantages, several barriers hinder full-scale integration of renewables into electric mobility systems.

Table 5, describes the main obstacles in EV renewable-energy integration. The unpredictability of solar and wind affects the dependability of the charging procedure, which can be relieved by battery, hydrogen, and V2G storage alternatives. The cost of infrastructure is high and needs to be subsidized and a partnership between the government and the commercial.

Floating solar, offshore wind, and roof PV can reduce land and resource demands in the face of limited land and resources. Absence of policy and regulation slows down execution that demonstrates the worth of unmistakable standards and preferable policies.

INTELLIGENT TRANSPORTATION SYSTEMS (ITS) AND EVS

ITS Functionalities in EV Ecosystems

The addition of Intelligent Transportation Systems (ITS) to the electric vehicle (EV) ecosystems is changing mobility by enhancing energy efficiency and improving safety, along with connectivity. ITS utilizes the best ICT (Information and Communication Technologies), real-time analysis, and interconnected infrastructure to resolve the bottlenecks in charging, traffic, and grid reliability.

Table 3. Fossil Fuel Dependence vs. Renewable Integration in EV Sector

Parameter	Fossil Fuel Dependent Economy	Renewable-Integrated EV Economy
Import Dependency	High (60–80%)	Low (10–20%)
Price Volatility	High	Stable
Strategic Vulnerability	Significant	Reduced
Long-term Energy Security	Weak	Strong

Table 4. Economic impacts of renewable-powered EV charging.

Factor	Conventional ICE Fleet	EV Fleet (Grid Electricity)	EV Fleet (Renewable-Powered)
Fuel/Energy Cost (per km)	High (volatile)	Moderate (depends on grid)	Low & Stable
Maintenance Cost	High (engine wear)	Low	Low
Total Cost of Ownership	High	Medium	Low (long-term savings)

Table 5. Key challenges in renewable energy integration for EVs.

Barrier	Impact on EV Adoption	Potential Solutions
Intermittency (solar/wind)	Charging reliability	Energy storage (batteries, hydrogen, V2G)
Infrastructure Cost	High upfront investment	Public–private partnerships, subsidies
Land/Resource Constraints	Limited expansion	Floating solar, offshore wind, rooftop PV
Policy & Regulatory Gaps	Delayed deployment	Clear standards, supportive policies

Smart Charging

Charging systems based on ITS introduce dynamic demand-response that can coordinate EV charging with renewable energy peaks (e.g., solar noon, wind surges). This will make the grid more flexible, less expensive and more renewable.

Route Optimization

ITS solutions are based on artificial intelligence-based navigation, on-demand information, and predictive information to automate the traffic flow. ITS-enabled EVs decrease battery-stress, increase energy-efficiency and fleet-logistics performance by reducing congestion and idle time.

Autonomous Driving Support

Self-driving cars do not exist without car-all-around (V2X) communication. This enhances safety, energy consumption, and movements in cities through elimination of unnecessary stop-start driving and road accidents.

The Table 6, identifies major ITS functionalities in EV ecosystems. Smart charging is the use of AI and dynamical pricing to optimize charging and minimize costs and grid stress. The route optimization of the real-time traffic and prediction AI is intended to reduce congestion and range. V2X, LiDAR, radar and cameras enable the process of autonomous driving, making the driving process smoother, safer and more efficient in terms of energy.

Composites in ITS-Ready EVs

Remote integration of materials is also a requirement to ensure the success of ITS in EVs, as well as software and communication. Composites improve the structural performance of EVs as well as facilitate the implementation of ITS technologies [15–17].

The Sensor Mounting is Lightweight

Carbon-fiber-reinforced polymers (CFRPs) and hybrid composites allow rigid but light sensor casings to LiDAR, radar, and cameras, with low aerodynamic drag and weight loads.

Electromagnetic Shielding

Graphene-enhanced polymers and carbon nanotube-based composites offer electromagnetic interference (EMI) protection to communication and navigation modules.

Integration of Structural Battery.

Multifunctional composites are energy-saving load-bearing devices that decrease redundant weight and add range - one of the enabling factors of ITS-enabled EVs.

The Table 7, describes the applications of composites in ITS-enabled EVs. FRP and hybrid composite materials with lightweight characteristic and high level of stiffness are used in sensor housing and mounts to improve efficiency and accuracy. CNT / graphene polymers deliver EMI protection to avoid loss of signal and also provide reliable ITS communication. The structural battery composites combine energy storage with the frame or body to increase space efficiency and improve range.

Table 6. ITS Functionalities in EV ecosystems

ITS Functionality	Key Technology Used	Impact on EVs	Benefits
Smart Charging	AI load balancing, dynamic pricing, renewable synchronization	Optimized charging patterns	Cost savings, reduced grid stress
Route Optimization	Real-time traffic analytics, telematics, predictive AI	Efficient route planning	Reduced congestion, better range
Autonomous Driving	V2X communication, LiDAR, radar, cameras	Smooth driving patterns	Higher safety, energy efficiency

ITS and EV Ecosystem Synergies

The integration of ITS and composites unlocks multiple system-level benefits, turning EVs into smart, sustainable, and high-performing mobility nodes within connected transportation networks.

Table 8, demonstrates the interactions between ITS, EVs and composites to gain benefits at the system-level. In smart charging, ITS manages demands and renewables and provides lightweight charger enclosures through composites to improve efficiency. To achieve autonomous driving, ITS also supports V2X and AI navigation, and composites assist sensor housings, and EMI shields to ensure safer driving that consumes less energy. The scope and price savings of fleet management is achieved by ITS real-time optimization and lightweight composite structures. Structural innovation integrates ITS energy optimization with structural batteries and conserves space and weight with an increase in range. Overall, EV cars are turning into ITS, and are reducing to smart connected mobility devices and the systems will always integrate to composite efficiency, light weighting and multifunctionality.

Composite Materials in EV and Automotive Sector

Electric vehicle (EV) design and development on composite materials have been the center of attention due to the ever-increasing trend of light weighting and sustainability in the automotive industry. The various types of composites offer a different set of mechanical, thermal, and economic trade-offs that determine their use in a particular EV application.

Carbon fiber reinforced polymer (CFRP)

CFRPs are used in high-end EV because of its high stiffness to weight ratio. The carbon fibers have high modulus, which provides high fatigue resistance, stability, and vibration damping. Instead, they are expensive and relatively energy intensive to manufacture, which presents a mass adoption challenge.

Glass Fiber Reinforced Polymer (GFRP)

GFRPs provide a reasonable balance of cost to performance, particularly in high volumes of EV manufacturing. They provide sufficient strength and resilience and are much less expensive than carbon fiber. Their recycling is emerging as an additional benefit in the sustainability rules.

Kevlar and Aramid Fiber Composites

Kevlar and aramid are ideal impact absorbing fibers and are essential in battery crash shields, safety cages and ballistic panels. Their low density, thermal stability and puncture resistance are a safety assurance of high voltage EV systems.

Table 7. Role of composites in ITS-enabled EVs.

Composite Type	ITS Application Area	Functionality	Benefits
CFRP & Hybrid Composites	Sensor housings, mounts	Lightweight, high stiffness	Maintains efficiency, improves accuracy
CNT/Graphene Polymers	EMI shielding of electronics	Prevents signal loss	Reliable ITS communication
Structural Battery Composites	Frame, body integration	Dual function: energy storage + structure	Higher range, space efficiency

Table 8. Synergies of ITS, EVs, and composites.

Area of Integration	ITS Role	Composite Role	System-Level Benefit
Smart Charging	Demand-response, renewable sync	Lightweight enclosures for chargers	Lower charging losses, higher efficiency
Autonomous Driving	V2X, AI navigation	Sensor housings, EMI shielding	Safer, energy-efficient driving
Fleet Management	Real-time optimization	Lightweight body/chassis	Higher range, reduced fleet costs
Structural Innovation	Energy optimization	Structural batteries	Space + weight savings, longer range

Hybrid Composites

Hybrid composites are made with various fibers (carbon, glass, aramid) to achieve a specific performance at the optimal cost. Auto-makers obtain the multifunctional advantages of EV vital components by laying down high-stiffness carbon layers, with impact-resistant aramid layers.

Table 9 summarizes the main composite materials used in electric vehicles (EVs) along with their key characteristics. Carbon Fiber Reinforced Polymer (CFRP) offers high strength-to-weight ratio but at a higher cost, making it suitable for chassis and body panels. Glass Fiber Reinforced Polymer (GFRP) is more economical with moderate strength, commonly used in underbody and interior components. Kevlar/Aramid provides excellent impact resistance at medium cost, ideal for crash protection and battery reinforcement. Hybrid composites combine different fibers to achieve tailored properties, supporting multifunctional and modular EV applications.

Advantages in Automotive Applications

The transition to next-generation EV platforms requires materials that simultaneously support energy efficiency, safety, durability, and design freedom. Composites provide a compelling solution.

Weight Reduction

- Reduces rolling resistance and enhances power-to-weight ratio.
- Enables downsizing of battery packs without sacrificing range.
- Contributes to vehicle agility and acceleration performance.

Crashworthiness

- Composites absorb crash energy via progressive failure mechanisms (fiber fracture, matrix cracking, delamination).
- Protects lithium-ion battery packs from high-impact deformation.
- Reduces passenger injury risk through controlled energy absorption.

Corrosion Resistance

- No galvanic corrosion issues compared to aluminum/steel.
- Better resistance in humid, coastal, and chemically aggressive environments.
- Extends lifecycle durability with lower maintenance costs.

Design Flexibility

- Facilitates optimization of aerodynamic through complicated geometries.
- Provides the possibility of fusion of sensor housings, antennas, and cooling channels.
- Supports platform of vehicles that are easy to assemble.

Table 10 highlights the key advantages of composites in EVs. Their lightweight nature enhances range and performance, while superior crash energy absorption improves passenger and battery safety. Unlike metals, composites resist corrosion, ensuring long-term durability. Additionally, their design flexibility allows modular and aerodynamic structures with reduced manufacturing complexity.

Table 9. Types of Composites in EVs and their key characteristics

Composite Type	Density (g/cm ³)	Tensile Strength (MPa)	Cost Level	EV Applications
CFRP	1.55–1.80	3500–6000	High	Chassis, body panels, battery enclosures
GFRP	1.80–2.00	1500–3500	Low–Medium	Underbody panels, interior modules, door frames
Kevlar/Aramid	1.40	2800–3600	Medium	Crash shields, battery pack reinforcement, protective panels
Hybrid Composites	Variable	Tailored (2000–5000)	Medium	Multifunctional structures, modular EV parts

Emerging trends in composite use for EVs

1. *Recyclable Composites*: Circular economy Developing thermoplastic CFRPs and GFRPs, which can be reused as a thermoplastic, is in line with the vision of the circular economy.
2. *Nanocomposite Integration*: Addition of graphene, CNTs, and nanoclays enhance thermal conductivity, EMI shielding, and mechanical strength.
3. *Structural Batteries*: Multifunctional composites, Next-generation Multifunctional composites are load-bearing structures and sources of energy.
4. *3D-Printed Composites*: Additive manufacturing allows to create customized structures and produce parts of EVs on demand.

Table 11 describes developing composite innovations in EVs. Thermoplastics can be recycled, which facilitates the disposal process, whereas nanocomposites are stronger and act as EMI shields. Structural batteries integrate energy storage and load-bearing capabilities, which consume less space, and 3D-printed composites allow development of EVs more quickly and with more customization. Composite materials is a cornerstone to EV technology, as it provides multifunctionality, lightweighting, and safety and durability. They are not limited to structural use but can also be integrated into batteries, provided with safety, and support of smart sensors. As the pressure on the sustainable, high-performance EVs increases, the combination of new high-tech composites and electrified mobility will continue to grow and shape the future of automotive engineering.

Advanced Composite Manufacturing for EVs

The blistering development of electric vehicles (EVs) demands production processes that should be both accurate, scalable, and sustainable. The hi-tech composite manufacturing methods are critical to the fulfillment of such requirements and enable the fabrication of lightweight, strong, and high-performance components with complicated geometry.

Automated Fiber Placement (AFP)

Automated Fiber Placement is a technique that involves the use of robotic heads that lay down narrow fiber tows (carbon, glass or aramid) with controlled angle, pressure and heating. This allows one to manufacture large, high-performance composite components with a high degree of repeatability and a minimum of wastage of material.

Applications in EVs

- EV chassis and roof structures.
- Aerodynamic panels.
- Battery enclosures with anisotropic strength.

Table 10. Advantages of composite materials in automotive applications.

Advantage	Role in EVs	Comparative benefit over metals
Weight Reduction	Improves range, efficiency, and acceleration	30–50% lighter than steel, 15–20% lighter than aluminum
Crashworthiness	Protects passengers & batteries	Absorbs 2–3x more energy per unit mass
Corrosion Resistance	Ensures durability & reliability	No rust, no galvanic corrosion
Design Flexibility	Enables modular, aerodynamic designs	Metals require costly machining & welding

Table 11. Emerging composite innovations for EV applications.

Innovation type	Key feature	EV benefit
Recyclable Thermoplastics	Melt & reuse capability	Sustainable end-of-life disposal
Nanocomposites	Enhanced EMI shielding, strength	Protects EV electronics, reduces weight
Structural Batteries	Dual role: storage + structure	Higher energy density, space saving
3D-Printed Composites	Rapid prototyping, custom shapes	Faster EV development cycles

Table 12 (A) demonstrates the advantages of AFP in EVs manufacturing that allow lightweight and stiff chassis, better vehicle balance with CFRP roofs, and robust enclosures of the battery that enhance crash safety.

Figure 1 shows an example of the automated fiber placement (AFP) robot head and here uninterrupted strands of fibers are being placed accurately onto a curved shape of an electric vehicle (EV) chassis. The process allows creating the lightweight and high-strength composite structures and doing it more accurately and efficiently to be used in EVs.

Filament Winding

Filament winding involves winding continuous fibers under tension over a rotating mandrel, creating hollow or cylindrical parts with high pressure resistance.

Applications in EVs and FCEVs

- Hydrogen storage tanks.
- Lightweight drive shafts.
- High-strength pressure vessels.

Table 12 (B) presents filament winding applications in EVs, such as lightweight CFRP hydrogen tanks with high pressure resistance, hybrid drive shafts for better torsional strength, and GFRP cooling ducts offering thermal stability and corrosion resistance.

Table 12 (A). Benefits of AFP in EV composite manufacturing.

EV Component	AFP Composite Material	Advantage in EVs
Chassis/Frame	CFRP, Hybrid Laminates	Optimized stiffness-to-weight ratio
Roof Structures	CFRP	Lighter roof, improved center of gravity
Battery Enclosures	CFRP, GFRP	Structural integrity + crash safety

Table 12 (B). Applications of filament winding in EV industry.

Component	Fiber/Resin Type	Key Benefit
Hydrogen Tank	CFRP/Epoxy	High pressure resistance, lightweight
Drive Shaft	CFRP/GFRP Hybrid	Improved torsional strength
Cooling Ducts	GFRP	Thermal stability, corrosion resistance

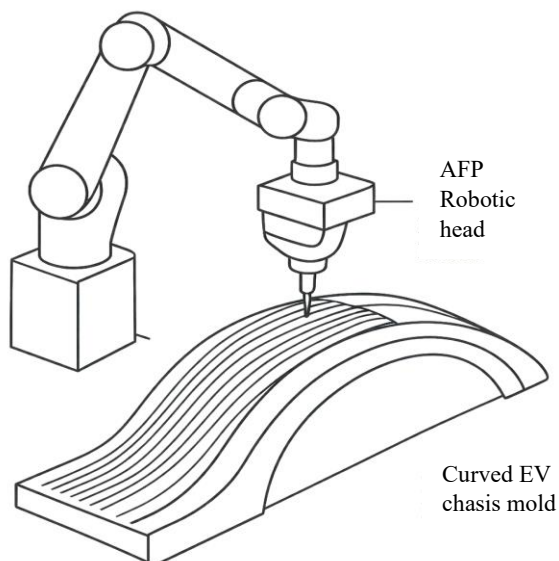


Figure 1. Schematic of AFP robotic head placing fibers on a curved EV chassis mold.

Figure 2 shows the filament winding process, where continuous fibers are wound around a mandrel to manufacture high-pressure hydrogen storage tanks with enhanced strength and durability for clean energy applications.

Large Format Additive Manufacturing (LFAM)

LFAM combines additive manufacturing with chopped fiber reinforcement to produce large EV components rapidly and economically.

Applications in EVs

- Battery trays with integrated cooling channels.
- Dashboards and interior panels.
- Prototyping and low-volume specialty EV parts.

Table 12 (C) highlights LFAM benefits in EVs, including battery trays with integrated cooling, sustainable dashboards from natural fibers, and lightweight body panels enabled by rapid prototyping.

Figure 3 compares traditional mold-based production with Large-Format Additive Manufacturing (LFAM) for EV battery trays, highlighting differences in efficiency, material usage, and design flexibility.

Table 12(C). LFAM advantages in EV manufacturing

Component	Material System	LFAM Benefit
Battery Tray	Thermoplastic + chopped CFRP	Integrated cooling features, reduced tooling
Dashboard	Natural fiber composites	Sustainable interior design
Body Panels	Thermoplastic CFRP	Rapid prototyping, lightweight

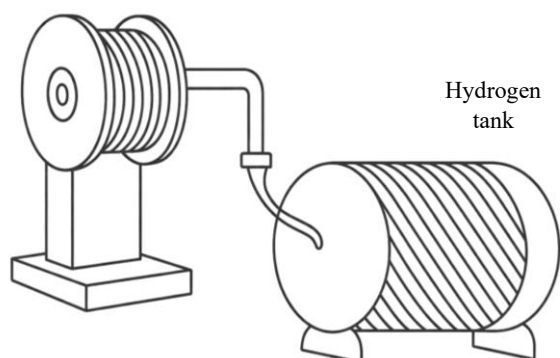


Figure 2. Illustration of filament winding process for hydrogen tank manufacturing.

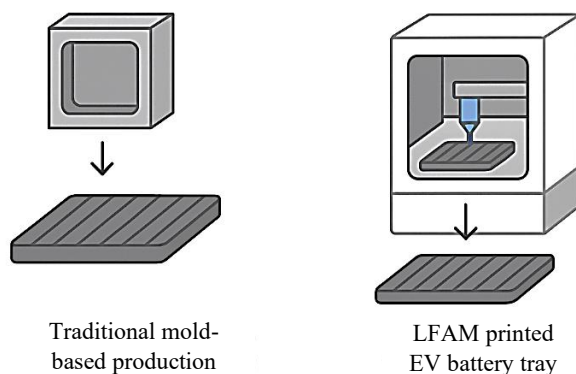


Figure 3. Diagram comparing traditional mold-based production vs. LFAM printed EV battery tray.

Large-Format Continuous Fiber 3D Printing

This is a new process which incorporates continuous fibers into 3D-printed matrices and provides mechanical performance of traditional composite materials with the flexibility of additive manufacturing.

Applications in EVs

- Crash-protection beams.
- Suspension arms and structural joints.
- Integrated load-bearing battery housing.

The contribution of continuous fiber 3D printing to EVs is depicted in Table 12 (D). It allows crash beams with high impact absorption, suspension arms with high fatigue performance and light weight battery housing that are also structural elements using CFRP and hybrid systems.

Figure 4 illustrates the integration of continuous fibers within a 3D-printed EV suspension arm, enhancing its strength, stiffness, and lightweight performance for improved vehicle efficiency.

Table 12 (E) makes comparisons between advanced composite manufacturing of EVs. Automated Fiber Placement (AFP) provides high precision but is very expensive, filament winding provides strong cylindrical components and Large-Format Additive Manufacturing (LFAM) allows very fast prototyping with strength trade-offs. Lightweight, personalized EV parts are further improved by continuous fiber 3D printing.

Table 12 (D). Continuous fiber 3D printing in EV applications.

Component	Material System	Key Benefit
Crash Beams	CFRP-Thermoplastic Matrix	High impact absorption
Suspension Arms	CFRP/GFRP Hybrid	Superior fatigue resistance
Battery Housing	CFRP-Polymer Matrix	Dual load-bearing + lightweight energy storage

Table 12 (E). Comparison of Advanced Composite Manufacturing for EVs

Process	Key Strengths	Limitations	EV Applications
AFP	Precision, anisotropic tailoring	High setup cost	Chassis, roof, enclosures
Filament Winding	Pressure resistance, durability	Limited to cylindrical parts	Hydrogen tanks, shafts
LFAM	Design freedom, rapid prototyping	Lower mechanical properties vs. AFP	Battery trays, panels

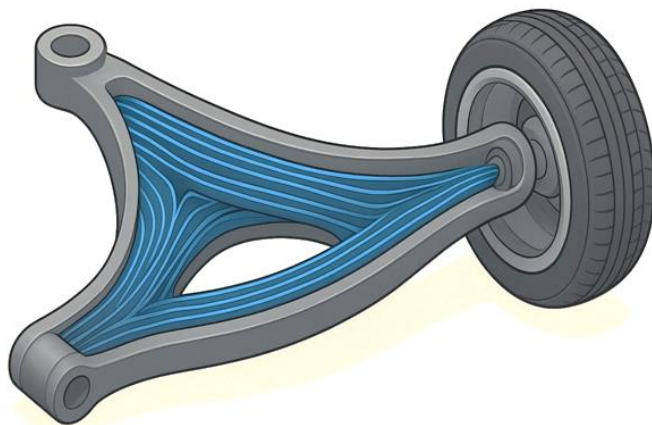


Figure 4. Visualization of continuous fiber integration in a 3D-printed EV suspension arm.

Comparative Assessment of Manufacturing Techniques

The Table 13 compares ITS-enabled transport and traditional. Conventional systems have low energy efficiency, increased risk of accidents, little integration of renewables, and high cost of operation. On the other hand, ITS-enabling transport is more efficient because of real-time routing, safer because of predictive analytics, more aligned with renewable energy, and cost-effective because of optimized operations.

Lifecycle analysis shows that metal is easier to recycle but the composite has greater efficiency benefits throughout the lifecycle, due to light weighting and corrosion resistance. Composites and metals in the automotive industry are compared in the Table 15.

Composites weigh 30–50 percent less, with significant operational energy savings and excellent durability and corrosion resistance, but have yet to be corroborated as easily as metallic composites. Other metals such as steel or aluminum are heavier and are less efficient in operation, but their recycling procedures are already established. Generally, metals can be more easily recycled but composites are more beneficial over time and service.

Table 14 summarizes the most important obstacles to composite integration in EVs and solutions to them. High prices put mass adoption in the way of low cost precursors and composite hybrids. Recycling of materials poses waste problems, which are solved by thermoplastics and chemical recycling. The limited scalability of manufacturing can be resolved through automation, i.e., AFP and LFAM, and supply chain gaps are resolved by producing more fibers and using bio-resins. In general, these solutions are designed to make composites cheaper, more sustainable, and scalable to EV applications.

Table 13. Comparison of Intelligent Transportation Systems vs. Traditional Transport

Parameter	Traditional Transport	ITS-Enabled Transport
Energy Efficiency	Low due to idle congestion	High through real-time routing
Safety	Reactive, accident-prone	Proactive with predictive analytics
Integration with Renewables	Minimal	Dynamic alignment with renewable peaks
Operational Costs	High (fuel + maintenance)	Lower (optimized operations)

Table 14. Barriers and Solutions for Composite Integration in EVs

Barrier	Impact	Potential Solution
High Cost	Restricts mass-market EV adoption	Low-cost precursors, hybrid composites
Recycling Challenges	End-of-life waste accumulation	Thermoplastics, chemical recycling
Manufacturing Scalability	Limits production rates	AFP, LFAM, automation
Material Supply Gaps	Supply chain bottlenecks	Expanded fiber production, bio-resins

Table 15. Lifecycle Assessment of Composites vs Metals in Automotive Sector

Parameter	Composites	Metals (Steel/Aluminum)
Weight	30–50% lighter	Heavier
Energy Use in Production	Moderate to High	High (especially aluminum smelting)
Operational Energy Savings	Significant (due to lightweighting)	Limited
Recyclability	Improving (thermoplastics, pyrolysis)	High, well established
Durability	High corrosion resistance	Needs coatings, prone to rust

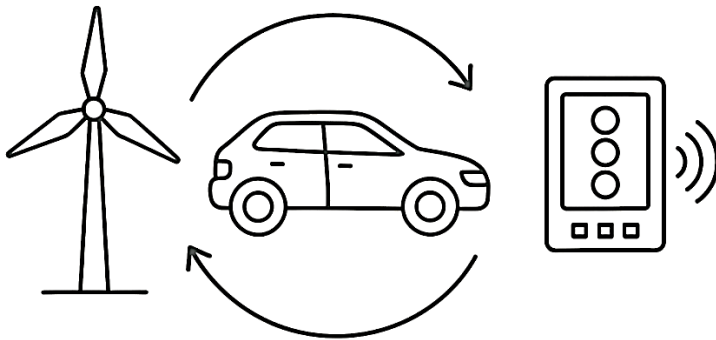


Figure 5. Synergy between renewable energy, EVs, and ITS.

This Figure 5 illustrates how renewable energy feeds EV charging, EVs interact with smart grids via V2G, and ITS optimizes traffic and charging. Together, they form a closed-loop sustainable transport ecosystem.

Sustainability and Recycling

On the one hand, advanced composites provide a performance advantage, but on the other hand, their impact on the environment and recyclability is a topical issue. Traditional thermoset composites cannot be recycled once cured, because of the irreversible chemical cross-linking between the resins and fibers. Existing studies are overcoming these shortcomings in a variety of ways:

- *Thermoplastic Composites:* thermoplastic matrices are meltable and can be readily recycled and re-melted, whereas thermosets cannot. High toughness and short production cycles also make the materials interesting in their automotive applications.
- *Then:* Both pyrolysis and Solvolysis Thermal (pyrolysis) and chemical (solvolysis) processes are under development to reclaim high quality fibers in end-of-life composite. Though they consume a lot of energy, the carbon or glass fibers could be reused in secondary applications, thus eliminating waste and reducing the need to import raw materials.
- *Bio-Based Resins:* Bio-resin refers to resin which is made using renewable materials such as plant oils or lignin and as such, no petroleum-based resins or carbon emissions are used. Fully sustainable composite systems based on bio-resins and natural fibers may be achieved in selected EV interior and semi-structural applications.

Recycling solutions are the key to ensuring that EV composite production meets the requirements of the circular economy and becomes sustainable in a real sense.

This Figure 6 shows composites enabling lightweight chassis, battery housings, and EMI-shielded sensor mounts. Their multifunctionality supports both performance and ITS connectivity.

Circular Economy Model for Composites in EVs Figure 7 shows composites from raw fiber → EV manufacturing → ITS-enabled operation → recycling via thermoplastics/pyrolysis → reintegration, enabling circular sustainability.

Challenges and Future Outlook

Although promising, composites use in EV applications has a number of challenges:

Challenges

The cost of carbon fiber production and automated manufacturing is prohibitively high: It is impossible to use carbon fiber production and automated manufacturing on a large scale in the mass-market EVs.

- *Limitations of supply of materials:* The amount of advanced fibers and resins that can be produced globally remains a constraint and can limit its widespread utilization.

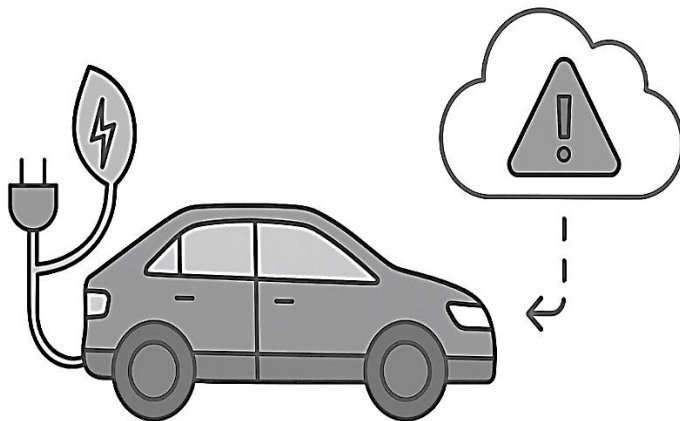


Figure 6. Composite Roles in EV design and ITS integration.

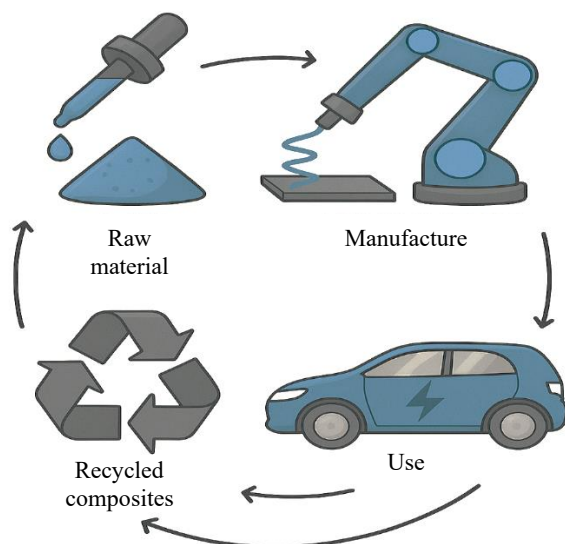


Figure 7. Circular Economy Model for Composites in EVs

Furthermore, the inability to recycle the composite waste streams with special recycling devices the way the metals and plastics can is one of the bottlenecks to sustainable use.

Future Directions

- *Artificial intelligence and machine learning:* The manufacturing system will rely on AI to detect defects, automatic optimization of the process, and predictive maintenance to ensure that the prices are maintained as low as possible and the consistency is maximized.
 - *Structural Batteries:* Some are designing composite structures that can be used as load-bearing structures, as well as energy storage systems that also perform and store mechanical functions and electrochemical functions in order to enhance the use and efficiency of space in EVs.
- Circular Economy Models: It is the recycling, remanufacturing and reuse of composite materials that will be put at the center of the formation of a sustainable EV ecosystem. With the maturity of the industry, the business models of take-back systems and component level refurbishment will evolve.

CONCLUSION

Green energy, intelligent transportation and advanced composite technologies are converging and transforming the automobile world into a different place. The composites might offer the optimal strength to weight ratios, and might be easily programmed in structure, which is essential in raising the

driving variety of EVs, performance and could possibly meet high safety criteria. The renewable energy integration gives the zero-emission of the operations, but the intelligent transport systems (ITS) give the efficiency of the operation and the certainty of the system. However, the price and recycling challenges must be addressed to make composites achieve mass acceptance in EVs on a mass-market basis. The other area that could see innovations of the composites in the future not only is the use of composites to act as lightweight structural materials, but also act as flexible building blocks in energy storage, smart sensors, and flexible vehicles. Composites will, in this way, make a radical contribution to the achievement of the vision of the sustainable, intelligent, and resilient mobility.

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