

The Paradigm Shift in Electric Vehicle Architectures: A Comprehensive Review of Emerging Solid-State Batteries, 800V+ Networks, Silicon Carbide Power Electronics, and Software-Defined Zonal Frameworks

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Abstract

—Electric Vehicle (EV) systems are transitioning through an unprecedented technological evolution, moving away from early-stage iterations that merely hybridized or substituted internal combustion engine (ICE) components. Driven by the imperative for extreme volumetric efficiency, ultra-fast charging capability, and native structural security, modern electrified mobility is being fundamentally rewritten across electrochemical, power-electronic, and computational vectors. This paper provides an exhaustive, rigorous review of the state-of-the-art technological transformations shaping the global EV landscape as of 2026. We systematically dissect the engineering architectures of solid-state batteries (SSBs) featuring sulfide- and oxide-based solid electrolytes, analyze the structural advantages of Cell-to-Chassis (CTC) mechanical integration, and detail the thermodynamic and high-voltage kinetics of 800V/900V operational spines. Furthermore, we evaluate the bandgap physics underpinning Wide-Bandgap (WBG) Silicon Carbide (SiC) Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) and their quantified reduction in dynamic switching losses over conventional Silicon Insulated-Gate Bipolar Transistors (Si IGBTs). On the computational plane, this paper traces the disintegration of legacy distributed Electronic Control Units (ECUs) in favor of centralized Software-Defined Vehicle (SDV) zonal computing paradigms running predictive artificial intelligence loops for real-time multi-system thermal and energy optimization. To validate these assertions, a comprehensive twenty-parameter comparative analysis is conducted against both first-generation EVs and conventional ICE technologies. Finally, we map the systemic engineering bottlenecks—including high-voltage partial discharge propagation, microstructural solid-state interfacial impedance degradation, and functional safety constraints—revisiting the primary research horizons necessary to anchor the next decade of zero-emission transportation infrastructure.

Keywords—Solid-State Batteries, Cell-to-Chassis (CTC), Wide-Bandgap Semiconductors, Silicon Carbide (SiC) Inverters, 800V High-Voltage Infrastructure, Software-Defined Vehicles (SDV), Zonal Computing Architecture, Predictive Artificial Intelligence.

I. INTRODUCTION

The global transport sector is undergoing its most radical transformation since the transition from equine-based mobility to the internal combustion engine (ICE) at the dawn of the twentieth century. Early-wave electric vehicle (EV) engineering was primarily defined by adaptation constraints, where conventional passenger vehicle platforms were heavily retrofitted to accommodate low-voltage battery packs, rudimentary electric motors, and extensive distribution networks of legacy harnessing. These initial configurations succeeded in proving the fundamental market viability of

pure electric drivetrains but suffered from deeply integrated compromises, including restricted gravimetric energy densities, prolonged charging latencies, extensive parasitic thermal losses, and severe packaging inefficiencies caused by distributed computing architectures.

As the industry moves through 2026, a structural paradigm shift has materialized, separating modern electric mobility from its historical precursors. Automakers and advanced academic laboratories are completely discarding the design patterns of the early electrification wave, opting instead for integrated, clean-sheet architectures engineered exclusively around high-voltage solid-state electrochemistry and software-defined framework controllers. The design imperative has pivoted from simple range parity with fossil-fuel platforms to the realization of absolute hyper-efficiency, active structural vehicle integration, and instantaneous bidirectional power flow.

The contemporary state of EV design is fundamentally multi-disciplinary, defined by major leaps across three distinct but interlocking physical domains. In the chemical domain, volatile liquid electrolytes are giving way to solid-state matrix structures, while cell packaging has transitioned to Cell-to-Chassis (CTC) structural integration that treats the battery array as an explicit load-bearing shear element. In the power-electronic domain, standard Silicon-based insulated-gate bipolar transistors (Si IGBTs) are rapidly obsolete, replaced by Wide-Bandgap (WBG) Silicon Carbide (SiC) MOSFETs operating within ultra-high-voltage 800V/900V electrical networks. Concurrently, in the cyber-physical domain, legacy vehicle architectures comprising over 100 isolated Electronic Control Units (ECUs) are replaced by software-defined zonal computing frameworks managed by cloud-connected, predictive AI networks.

This comprehensive review provides a structured engineering analysis of these emerging technologies, evaluating their dynamic superiority over conventional fossil-fuel and first-generation electric platforms. Section II breaks down the structural mechanics and chemical formulations of modern solid-state and cell-to-chassis systems. Section III explores high-voltage network kinetics and Wide-Bandgap semiconductor inversion maps. Section IV analyzes centralized zonal computation and AI energy management profiles. Section V presents a formal, twenty-parameter comparative baseline, followed by techno-economic evaluations in Section VI. Critical engineering bottlenecks and systemic boundaries are scrutinized in Section VII, culminating in an authoritative operational outlook in Section VIII.

II. NEXT-GENERATION ELECTROCHEMICAL STORAGE AND STRUCTURAL INTEGRATION

A. Solid-State Electrolytes and Dendrite Propagation Mitigation

Conventional lithium-ion batteries rely on volatile organic liquid electrolytes to facilitate lithium-ion transport between intercalation anodes and transition-metal oxide cathodes. While highly optimized, these liquid systems are bound by a rigid volumetric ceiling and carry severe safety vulnerabilities, including high flammability and risk of catastrophic thermal runaway under mechanical puncture or electrical overcharge conditions. Next-generation Solid-State Batteries (SSBs) eliminate organic solvents entirely, substituting them with solid ceramic, polymer, or glass electrolyte matrices.

The leading solid-state electrolyte candidates are split into two primary chemical categories: sulfide-based matrices (such as $\text{Li}_{10}\text{GeP}_2\text{S}_{12}$ and $\text{Li}_2\text{S-P}_2\text{S}_5$ structures) and oxide-based configurations (such as garnet-type $\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$, commonly designated as LLZO). Sulfide electrolytes exhibit extraordinary ionic conductivities at room temperature, frequently exceeding 10^{-2} S/cm, which rivals or exceeds that of standard liquid formulations. However, they are highly sensitive to moisture, requiring sophisticated cleanroom scaling to prevent the formation of toxic hydrogen sulfide gas. Oxide-based LLZO systems possess superior mechanical hardness and exceptional chemical stability against pure lithium metal anodes, though they require high-temperature sintering steps that introduce microscopic void structures during manufacturing.

A critical engineering barrier in SSB development has been the formation of localized metallic lithium dendrites—microscopic, crystalline fingers that nucleate on the anode surface and propagate through the solid electrolyte during high-rate charging phases, eventually creating an internal short circuit. Modern 2026 architectures mitigate this phenomenon by applying high-precision uniaxial stack pressures (typically 1 to 5 MPa) across the cell assembly via structural tension springs embedded in the module enclosure, interspersed with sub-micron 2D carbon or silver-carbon

(Ag-C) composite interlayers. These interlayers lower the interfacial resistance and promote perfectly uniform lithium plating, allowing gravimetric energy densities to surge past 450 Wh/kg while maintaining a near-zero fire risk profile.

B. Cell-to-Chassis (CTC) Mechanical Integration

The physical layout of EV battery packs has historically followed a strict modular hierarchy: individual electrochemical cells were wire-bonded and housed inside protective plastic modules; multiple modules were subsequently bolted together inside an isolated, heavy aluminum pack casing; and this entire assembly was fastened to the vehicle's lower chassis. This redundant approach resulted in an unfavorable volumetric packing efficiency, with inactive structural material (enclosures, thermal boundary plates, internal brackets) accounting for over 40% of the total pack mass.

Modern architectures bypass these intermediate structural envelopes entirely via Cell-to-Chassis (CTC) integration. In a CTC framework, the individual high-capacity cells are arrayed and bonded directly into the structural lower floor pan of the vehicle frame. The upper cover plate of the battery pack serves concurrently as the primary floor of the passenger cabin. By transforming the battery pack from a passive mass penalty into an explicit load-bearing shear plate, CTC increases the overall torsional rigidity of the vehicle chassis by up to 60%.

This structural consolidation frees up significant vertical and longitudinal packaging volume, allowing for either a 15% increase in total cell count within identical vehicle footprints or a dramatic lowering of the vehicle's center of mass to optimize aerodynamic and lateral cornering stability. The elimination of modular brackets, intermediate wire harnesses, and separate enclosure plates additionally drops aggregate vehicle mass by roughly 8% to 12%, directly boosting real-world driving efficiency.

III. HIGH-VOLTAGE NETWORKS AND ADVANCED POWER ELECTRONICS

A. Thermodynamic and Kinetic Optimization of 800V/900V High-Voltage Spines

The early era of modern electric vehicles operated almost universally on 400V direct-current (DC) electrical architectures. While adequate for lower-power passenger cars, 400V infrastructure incurs substantial thermal challenges when subjected to high power throughputs, such as those demanded during ultra-fast DC charging maneuvers (>350 kW). According to Joule's Law, the rate of thermal heat dissipation P_{loss} inside a vehicle's wiring harness and power delivery path is directly proportional to the square of the electrical current I :

$$P_{loss} = I^2 \cdot R \quad (1)$$

where R is the internal mechanical resistance of the copper conductor lines. To deliver 360 kW of power under a 400V constraint, the system must pull an enormous current of 900 Amperes. This extreme current demands thick, heavy copper cabling and massive liquid cooling jackets to prevent the vehicle's thermal management system from melting under heat loads.

By doubling the operating voltage spine to 800V or 900V, the required electrical current is exactly halved to 450 Amperes for the same 360 kW power output. Because current is squared in the thermal dissipation equation, cutting current by 50% yields a profound 75% reduction in total heat losses throughout the high-voltage bus lines. This enables the cross-sectional area and physical mass of the vehicular wiring harness to shrink significantly, while allowing the battery pack to safely accept maximum high-rate charging inputs. Consequently, the standard 10% to 80% state-of-charge replenishment time is compressed down to a highly competitive 10 to 15 minutes, neutralizing a primary bottleneck to mass public EV adoption.

B. Silicon Carbide (SiC) Wide-Bandgap Semiconductors vs. Silicon IGBTs

The primary power inverter represents the electronic heart of the EV powertrain, tasked with converting direct current from the high-voltage battery pack into multi-phase alternating current (AC) to drive the traction motor. For decades, traditional Silicon Insulated-Gate Bipolar Transistors (Si IGBTs) served as the standard switching semiconductor component. However, Silicon is a narrow-bandgap material, possessing an electron bandgap energy of roughly 1.1

electron-volts (eV). This tight physical boundary restricts the maximum operating temperature, voltage breakdown limits, and switching frequencies of the device.

Modern premium powertrains substitute legacy Si devices with Silicon Carbide (SiC) Wide-Bandgap semiconductors, which boast a wide bandgap energy of 3.2 eV. This wider physical atomic threshold allows SiC MOSFETs to withstand critical electrical fields that are nearly ten times greater than those of pure Silicon. Consequently, SiC chips can execute ultra-high pulse-width modulation (PWM) switching frequencies exceeding 20 kHz, completely eliminating audible frequencies while drastically reducing dynamic switching losses by up to 70%.

Furthermore, SiC exhibits an exceptional thermal conductivity of 4.9 W/cm·K, compared to a meager 1.5 W/cm·K for conventional Silicon. This superior thermal profile minimizes the physical packaging size of the inverter's liquid cooling plates and allows the entire power electronics block to shrink by up to 50% in volume and mass. Squeezing these switching losses out of the system directly expands overall inverter efficiency to over 99.2%, translating to a permanent 5% to 7% increase in total vehicular driving range from an identical electrochemical energy source.

IV. CENTRALIZED COMPUTING AND SOFTWARE-DEFINED VEHICLE (SDV) TOPOLOGIES

A. Deconstruction of Legacy Distributed ECUs to Zonal High-Performance Computing

Conventional automotive electrical systems are built upon a heavily fragmented, distributed computing model. As new features were added over successive vehicle generations (e.g., anti-lock brakes, power windows, radar arrays, climate control), engineers added independent Electronic Control Units (ECUs) to execute each localized function. This uncoordinated methodology resulted in luxury vehicles carrying over 100 distinct, single-purpose ECUs sourced from diverse tier-1 suppliers, communicating over slow, congested Controller Area Network (CAN) topologies. This created a massive assembly nightmare, adding up to 5 kilometers of copper wiring harnesses weighting over 70 kg per vehicle.

Modern EVs dismantle this distributed model entirely, migrating toward a highly integrated 'Zonal Architecture' governed by a centralized Software-Defined Vehicle (SDV) framework. The vehicle is partitioned into a small number of physical spatial quadrants (e.g., Front-Left, Front-Right, Rear-Left, Rear-Right). Each quadrant features a single, localized 'Zonal Gateway' hub that aggregates all nearby sensor data, actuator connections, and lighting arrays into a single spatial hub.

These zonal hubs compress the raw analog signals and route them over high-speed, deterministic gigabit Automotive Ethernet lines to a centralized computing matrix comprising two or three high-performance Central Processing Units (CPUs) running real-time hypervisor operating systems. This central core virtualizes the individual functions within isolated software containers. By deconstructing the legacy ECU network, the absolute length of vehicular wiring is reduced by over 75%, and aggregate harness mass drops by up to 40 kg, dramatically streamlining factory assembly complexity and paving the way for seamless, over-the-air (OTA) cloud firmware flashing across all structural vehicular systems.

B. Predictive AI for Real-Time Thermal and Energy Management Optimization

With computational resources consolidated inside a centralized high-performance processing matrix, next-generation vehicles can deploy advanced neural networks and predictive machine learning models to manage real-time power flows. In legacy architectures, energy management was rigidly deterministic, operating via simple rule-based thresholds (e.g., if battery temperature exceeds 45°C, activate cooling fans). This reactive approach is highly inefficient when subjected to highly dynamic environmental and driving profiles.

Modern predictive AI controllers continuously ingest high-fidelity data streams from multiple sources simultaneously: onboard GPS route plans, active forward-looking ADAS cameras, localized terrain topography maps, real-time traffic congestion analytics, and external meteorological forecasting. If the AI model determines that the vehicle is navigating a 20-kilometer high-speed highway stretch followed immediately by a dense urban grid, it will preemptively cool down the battery pack slightly using the vehicle's refrigerant heat-pump loop during the high-speed cruise phase.

This predictive pre-conditioning ensures the battery rests precisely at its absolute thermodynamic efficiency window the exact moment it transitions into heavy stop-and-go regenerative braking cycles within the urban core. Concurrently, the AI model adjusts the duty cycles of the cabin climate control and motor switching frequencies down to the millisecond, compressing cumulative energy consumption by an additional 12% to 18% over uncoordinated rule-based control frameworks.

V. SYSTEMIC COMPARATIVE ANALYSIS: EMERGING EV TECH VS. CONVENTIONAL LEGACIES

To establish an authoritative, data-driven foundation for evaluating the tech transitions detailed in this review, a formal cross-comparison must be executed across all core propulsion paradigms.

Table I establishes a comprehensive engineering baseline, contrasting twenty (20) distinct mechanical, electronic, thermal, and computational parameters across Conventional ICE Powertrains, First-Generation EVs (circa 2020), and Next-Generation Emerging EV Technologies (2026+).

Engineering Parameter	Conventional ICE Technology	First-Generation EV Tech	Next-Gen Emerging EV Tech
Primary Energy Density	Extremely High (Fuel (~12,000 Wh/kg))	Low (Liquid Li-ion (~240 Wh/kg))	High (Solid-State Cell (>450 Wh/kg))
Peak System Thermal Efficiency	30% – 42% maximum	85% – 92% (Silicon IGBT Inverter)	95% – 98.5% (SiC Wide-Bandgap Line)
Charging / Fuel Latency (10-80%)	3 – 5 minutes (Liquid fueling)	40 – 60 minutes (400V DC system)	10 – 15 minutes (800V/900V SiC infrastructure)
Drivetrain Moving Parts Count	Over 2,000 active mechanical parts	Roughly 100 – 150 moving pieces	Under 40 mechanical components (Axle-integrated)
Inverter Switching Losses	Not Applicable	High (Silicon IGBT dynamic loss base)	Extremely Low (~70% reduction via SiC MOSFETs)
Battery Pack Structural Role	Not Applicable	Dead weight mass inside basic frame	Load-bearing structural pan (CTC Integration)
Vehicle Torsional Rigidity	Baseline index standard (Frame-bound)	Moderate reinforcement bounds	Up to 60% increase via CTC plate integration
Computing Architecture	Fragmented (100+ isolated single ECUs)	Distributed sub-modules (30-50 ECUs)	Centralized Zonal Architecture (2-3 Main CPUs)
Wiring Harness Mass / Length	High (Up to 5 km length, ~70 kg mass)	Moderate (3 km length, ~50 kg mass)	Ultra-low (<1 km length, <20 kg total mass)
Thermal Runaway Profile	Moderate risk (Liquid fuel volatility)	High risk (Liquid electrolyte flammability)	Near-Zero (Solid-state non-flammable base)
Energy Management System	Basic lookup tables inside localized ECU	Reactive rule-based firmware codes	Predictive AI Neural Networks with cloud sync
Regenerative Braking Capacity	0% (All kinetic energy lost as heat)	Moderate (Single-axle limits, ~60% cap)	Full multi-wheel bidirectional regen (>90% capture)

Low-Temperature Energy Loss	Minimal (Engine waste heat runs cabin)	Severe (30%-40% loss via resistive heat)	Negligible (<10% loss using intelligent heat-pumps)
Transient Torque Response Latency	200 – 500 ms (Turbo-lag, gear shifting)	10 – 20 ms (Silicon gate delay lines)	<2 milliseconds (High-frequency SiC loops)
Over-The-Air (OTA) Capability	None (Requires physical workshop linkage)	Restricted (Infotainment/TCU updates only)	Comprehensive (Full flash across all Zonal nodes)
Acoustic / NVH Penetration	High (Continuous mechanical combustion)	Low (High-frequency motor whining sounds)	Silent (High-switching SiC sits outside audio band)
Vehicle Floor/Cabin Packaging	Poor (Intrusive exhaust and driveshaft tunnels)	Moderate (Flat floor but high battery shelf)	Optimal (Ultra-thin flat skateboard chassis profile)
Parasitic Auxiliary System Drag	High (Belt-driven alternators and pumps)	Low (Isolated DC-DC step down converters)	Zero (100% Demand-responsive software loops)
Environmental Life Cycle Footprint	Severe continuous tailpipe greenhouse gases	High upfront carbon debt (Cell assembly line)	Minimized (Longer cell life, clean circular assembly)
Total Drive Autonomous Range	600 – 800 km on typical tank	300 – 500 km maximum on full charge	800 – 1,100 km on advanced Solid-State array

VI. TECHNO-ECONOMIC AND LIFECYCLE ENVIRONMENTAL ANALYSIS

A rigorous technical evaluation of emerging EV technologies must expand beyond pure bench efficiency to assess systemic economic scalability and cradle-to-grave lifecycle parameters. First-generation EVs, despite their environmental benefits over ICE systems, incurred a major upfront carbon debt during the extraction, refining, and manufacturing phases of traditional liquid lithium-ion cell packs. The high concentration of rare-earth elements within permanent magnet traction motors (such as Neodymium, Dysprosium, and Terbium) and cobalt-heavy cathodes further complicated global supply-chain vulnerabilities.

Emerging 2026 technologies fundamentally improve this lifecycle profile. The transition to solid-state chemistry allows for the broad deployment of high-capacity, cobalt-free Lithium Manganese Iron Phosphate (LMFP) or pure lithium-metal architectures. By eliminating the mass-heavy module casings and copper wiring clusters via Cell-to-Chassis integration, the upfront manufacturing carbon footprint of the vehicle frame is reduced by 25% to 33% relative to a first-generation EV. When integrated into an electrical grid dominated by renewable energy inputs, a next-generation SSB vehicle achieves full carbon payback within less than 15,000 kilometers of operational driving, compared to 40,000 kilometers for early-era liquid-ion variants.

From an economic Total Cost of Ownership (TCO) perspective, the consolidated zonal architecture and ultra-low mechanical parts count deliver structural cost mitigations. The near-complete elimination of secondary electronic components and fluid-cooling lines reduces warranty claims by a projected 45%. Furthermore, the exceptional longevity of solid-state matrices—which frequently retain over 90% of their operational capacity after 3,000 full high-rate charge-discharge cycles—guarantees that the battery outlasts the physical service life of the vehicle chassis, paving the way for secondary grid-storage asset reutilization without intensive chemical recycling.

VII. SYSTEMIC ENGINEERING BOTTLENECKS AND FUTURE RESEARCH HORIZONS

A. High-Voltage Partial Discharge and Insulation Breakdown

The migration to 800V and 900V operational spines introduces severe sub-system challenges within the vehicle's electrical insulation profiles. At ultra-high voltages, power electronic components encounter the phenomenon of Partial Discharge (PD)—localized electrical breakdowns that occur within microscopic air voids trapped inside the insulation layers surrounding the stator windings of traction motors and primary busbars. Under the rapid switching frequencies executed by Silicon Carbide inverters (>20 kHz), the continuous application of high voltage-rise rates (dv/dt exceeding $10 \text{ kV}/\mu\text{s}$) accelerates the degradation of organic resin insulation.

This electrical stress induces premature dielectric breakdown, triggering destructive internal short circuits long before the vehicle reaches its intended design lifecycle. Current global research is intensely focused on developing advanced inorganic nano-composite insulation matrices, implementing localized geometric field-grading rings, and developing high-fidelity, real-time high-frequency PD detection sensors to flag insulation micro-cracking prior to a systemic failure event.

B. Microstructural Interfacial Impedance Degradation

While solid-state electrolytes offer stellar theoretical performance, they introduce a challenging physical boundary condition: high interfacial impedance. Unlike a liquid electrolyte that flows effortlessly into every microscopic crevice of a porous electrode to ensure seamless atomic contact, a solid-state electrolyte relies on solid-to-solid microscopic contact interfaces. During successive charge and discharge operations, the volume of the anode and cathode materials undergoes continuous expansion and contraction.

This persistent microscopic breathing induces intense mechanical stress, causing delamination and the formation of localized microscopic voids at the interface between the active material and the solid electrolyte matrix. Once contact is severed at these points, localized current densities spike wildly across the remaining contact points, accelerating lithium dendrite nucleation and degrading overall cell capacity. Overcoming this requires extensive research into self-healing compliant polymer-ceramic hybrid electrolytes and atomically engineered buffer layers capable of flexing dynamically under high-rate cycling configurations.

C. Cybersecurity Protocols in Zonal, OTA-Heavy Fleets

The structural shift to Software-Defined Vehicles governed by centralized zonal CPUs linked to external cloud networks completely redefines the automotive threat matrix. In legacy vehicles, hacking an infotainment module was isolated from the vehicle's driving dynamics because the critical safety networks (brakes, steering) ran on completely separate, air-gapped CAN lines. In a modern SDV, the central computing block virtualizes all systems within a single hardware block connected to the internet for continuous OTA firmware optimization.

This structural consolidation introduces the catastrophic risk of a malicious actor penetrating the vehicle's wireless telemetry and injecting corrupt code directly into safety-critical containers, such as the active steer-by-wire or drive-torque routines. To satisfy ISO 26262 ASIL-D functional safety limits, modern architectures must pioneer multi-layered hardware-enforced security enclaves. These involve real-time public-key cryptography (PKI) handshakes embedded within Hardware Security Modules (HSM), isolated secure boot protocols, and algorithmic intrusion detection networks running continuously at the zonal gateway level to intercept anomalous data streams instantaneously.

VIII. CONCLUSION

The emerging technologies defining the 2026 electric vehicle ecosystem represent a historical breakthrough in transportation engineering, completely severing the remaining design links to the internal combustion era. The synthesis of solid-state electrochemistries with structural Cell-to-Chassis integration effectively solves the dual historical bottlenecks of energy density ceilings and volatile thermal safety profiles. Concurrently, doubling electrical distribution

spines to 800V+ networks powered by high-frequency Silicon Carbide Wide-Bandgap semiconductors compresses charging latencies to match conventional liquid fueling intervals while maximizing dynamic powertrain efficiency.

On the computational plane, the virtualization of distributed ECUs into software-defined zonal high-performance computing centers enables predictive artificial intelligence to optimize energy pathways down to the millisecond. While profound technical hurdles remain active research priorities—specifically high-voltage insulation partial discharge degradation, microstructural interfacial impedance delamination, and software cybersecurity vulnerabilities—the systemic superiority of these integrated architectures is undeniable. The modern electric vehicle has successfully evolved from a heavily compromised mechanical appliance into a highly intelligent, hyper-efficient, and structurally unified cyber-physical ecosystem, solidifying its position as the undisputed foundation of global sustainable mobility.

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