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MAY 2026

RESEARCH BRIEF

Ecosystem & Value Chain Map of Electric Vehicle (EV) Battery Systems & Advanced Battery Materials

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Cypris Research Brief | For: Open Access
May 29, 2026

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Executive Summary

This Research Brief maps the electric vehicle (EV) battery systems and advanced battery materials ecosystem by defining the key participant segments and showing how materials, components, and value move through the supply chain. The analysis covers the full pathway from raw material extraction and refining through precursor and active-material production, electrolyte and separator development, cell manufacturing, battery pack assembly, vehicle integration, and end-of-life recycling. The findings highlight value-chain dependencies and handoff points as well as and identify structural forces shaping the ecosystem. These include critical mineral supply constraints, geographic concentration in processing and manufacturing, original equipment manufacturer (OEM) vertical integration, and the growing role of recycling in reducing upstream dependency.

Analyst Opinion

The EV battery value chain has become a strategic manufacturing system that influences vehicle cost, performance, production scalability, and supply-chain resilience. Battery value is shaped well before pack integration, beginning with mineral availability, refining capacity, precursor and active-material production, electrolyte and separator performance, and cell manufacturing quality. As a result, vehicle electrification depends on both downstream OEM execution and the ability of upstream and midstream participants to deliver qualified materials at scale. The most strategically exposed handoff points are the conversion steps where raw minerals become battery-grade inputs, because bottlenecks in refining, precursor production, cathode active material, anode active material, or cell capacity can limit downstream vehicle output.

The ecosystem remains functionally segmented, even as leading OEMs, cell manufacturers, and materials companies increasingly integrate across selected parts of the value chain. This creates a structural tension between specialization and integration. Specialized suppliers remain essential as battery performance depends on deep materials and process innovation. At the same time, OEMs and large battery producers are moving closer to upstream inputs, cell production, and recycling pathways to reduce exposure to supplier disruption, regional concentration, and chemistry-specific constraints. The result is not a simple shift toward full vertical integration, but a more selective model in which companies control the most strategically sensitive handoff points while relying on partners for scale, technology, or regional access.

Another key highlight is that the EV battery value chain is becoming more circular, regionalized, and technology-contingent at the same time. Recycling and refining are beginning to reframe end-of-life batteries as future feedstock. Additionally, solid-state and other next-generation chemistries may further alter where value concentrates by elevating the importance of electrolyte, separator, lithium-metal anode, and specialized cell manufacturing capabilities. For ecosystem participants, a central strategic issue is therefore not only where they sit in the current value chain, but whether their capabilities control a durable bottleneck, enable resilience across regions, or remain relevant as battery chemistries and manufacturing architectures evolve.

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Ecosystem Segment Breakdown

This section breaks the EV battery ecosystem into its major upstream, midstream, and downstream segments and illustrates how each group contributes to the movement of materials, components, and value across the supply chain. Each segment is defined in terms of its functional role and capabilities. Together, these subsectors form an interconnected system where each stage depends on the quality, capacity, and coordination of the preceding and following stages.

Raw Materials

Raw materials sit in the **upstream** layer and include mined or extracted lithium, nickel, cobalt, manganese, and graphite that later become battery-grade chemical inputs for EVs (**Figure 1**). Their functional role is to provide the mineral base for cathodes, anodes, electrolytes, and current collectors, often through mining, brine extraction, concentration, and early-stage refining. Participant types include lithium producers, nickel and cobalt miners, manganese processors, graphite miners, and mineral refiners such as Albemarle, SQM, Tianqi Lithium, Ganfeng Lithium, and diversified mining groups. This stage supplies critical minerals that enable battery production and supply constraints in this layer can affect every later stage of the value chain.

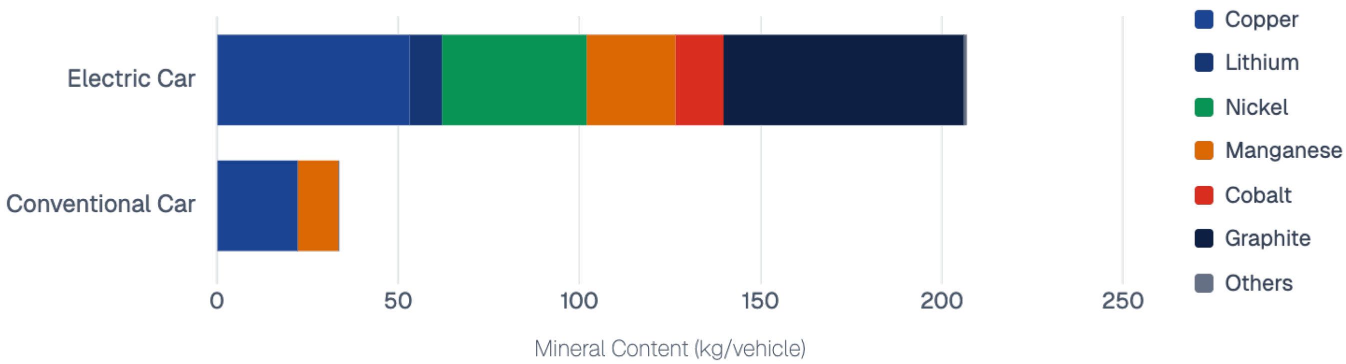

Figure 1: Estimated mineral content per vehicle for electric and conventional cars showing that EVs require substantially greater mineral inputs with ~207 kg total compared to 34 kg for a conventional vehicle. (Data Source: IEA - The Role of Critical Minerals in Clean Energy Transitions)

Precursor & Active Materials (Cathodes/Anodes)

Precursor and active-material production sits in the **midstream** layer and involves converting refined minerals into engineered battery materials such as precursor cathode active material (pCAM), cathode active material (CAM), and anode active material (AAM). This segment determines much of a battery cell's energy density, cost, durability, charging behavior, and chemistry pathway (e.g., lithium iron phosphate, nickel manganese cobalt, nickel cobalt aluminum, and emerging high-voltage materials). Participant types include cathode specialists, anode producers, chemical processors, and materials companies such as BASF Battery Materials, LG Chem, Posco Future M, Umicore, Novonix, Ryzon Materials, Nichia, Stratus Materials, and Sila Nanotechnologies. Overall, this stage turns raw minerals into battery-grade powders and engineered materials that cell manufacturers use to build electrodes.

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Cell Components (Electrolytes/Separators)

Electrolytes and separator materials are produced in the **midstream** layer and supply the internal materials that allow ions to move safely between electrodes while preventing short circuits (**Figure 2**). The electrolyte, whether liquid, gel, polymer, or solid-state, conducts lithium ions between the anode and cathode. The separator physically keeps the electrodes apart while allowing ion transport through electrolyte-filled pores. Participant types include electrolyte formulators, lithium salt suppliers, separator-film producers, ceramic-coating developers, polymer membrane companies, and solid-state electrolyte innovators. Global participants include separator suppliers such as Celgard, Toray, SK IE Technology, ENTEK, UBE, SEMCORP, and Senior, as well as electrolyte suppliers such as Mitsubishi Chemical, soulbrain MI, Capchem, Tinci Materials, Central Glass, and Solvay. This segment enables charge movement in the battery while reducing the risk of direct electrical contact.

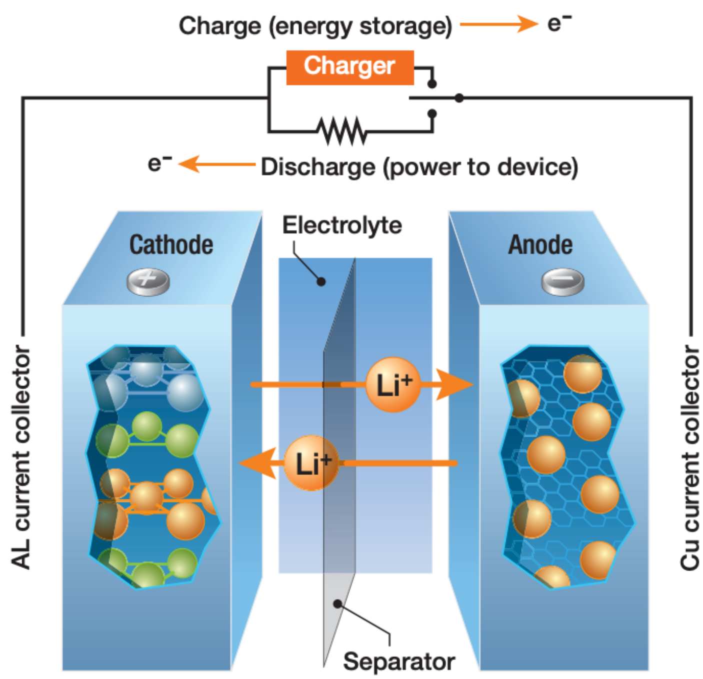

Figure 2: Lithium-Ion Battery Charge/Discharge Diagram (Image Source: Pall Corporation)

Battery Cell Production

Battery cell production **connects the midstream and downstream** layers, where electrodes, electrolytes, separators, current collectors, and casings are assembled into battery cells in cylindrical, prismatic, or pouch formats (**Figure 3**). This segment performs electrode coating or dry processing, calendaring, slitting, stacking or winding, electrolyte filling, formation, aging, testing, and quality control. Participant types include dedicated cell manufacturers and vertically integrated battery producers such as CATL, QuantumScape, SES, LG Energy Solution, Panasonic Energy, and Samsung SDI. In this stage, battery materials and components are turned into the individual rechargeable units that store and release energy.

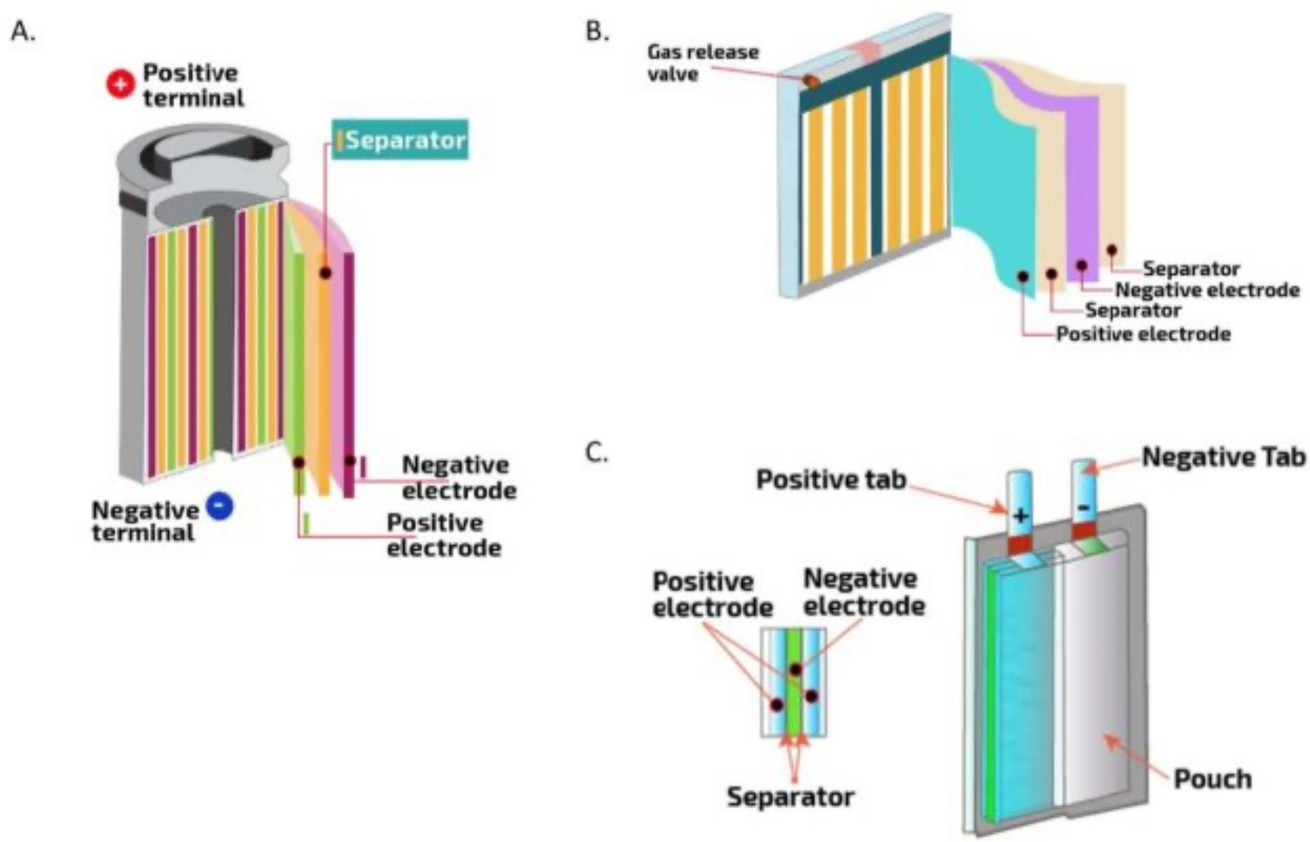

Figure 3: Battery Cell Formats - (A) Cylindrical, (B) Prismatic, and (C) Pouch (Image Source: EPA Lithium-Ion Battery Recycling)

Battery Pack Assembly & Integration

Battery pack assembly sits in the **downstream** layer and combines individual cells into modules or packs with battery management systems, thermal management, electrical interconnects, structural housing, sensors, safety systems, and software controls.[1, 2, 3] This segment makes cells usable inside vehicles by managing temperature, voltage, state of charge, safety, power delivery, durability, and serviceability. Participant types include pack integrators, battery management system suppliers, thermal management providers, power electronics firms, and automotive manufacturer in-house battery teams. Some companies active across this segment include Webasto, Bosch, BorgWarner, Proterra, and Forvia.

Electric Vehicle (EV) Manufacturing

Electric vehicle manufacturing operates in the **downstream** layer, where original equipment manufacturers (OEMs) integrate battery packs into passenger vehicles, commercial vehicles,

[1] Youyou Gao et al., "A Comprehensive Review of Thermal Management for Electric Vehicles: Subsystem Technologies, Integrated Architectures, and Advanced Controls," *Journal of Energy Storage* 151 (March 2026): 120263.
[2] Umar Shafique Awan et al., "Understanding Batteries Integration in EV Structure: Trade-Offs and Optimization," *Journal of Energy Storage* 148 (February 2026): 120289.
[3] Saroj Paudel et al., "Design, Prototyping, and Integration of Battery Modules for Electric Vehicles and Energy Storage Systems," *Electricity* 6, no. 4 (2025): 63.

buses, two-wheelers, micromobility platforms, and other electrified mobility products. This includes vehicle platform design, pack installation, powertrain integration, crash protection, charging architecture, thermal strategy, software calibration, warranty management, and supplier coordination. Participant types include automotive OEMs, commercial vehicle manufacturers, micromobility producers, and vertically integrated automakers such as Tesla, BYD, Rivian, Nio, Lucid Motors, General Motors, Ford, Toyota, Volkswagen Group, Hyundai Motor Group, and others.

Recycling & Refining

Recycling and refining **span downstream and upstream** layers because end-of-life batteries are collected from vehicles, packs are dismantled or processed into black mass, and recovered materials can re-enter the value chain as refined inputs for new cathode, anode, or precursor production (**Figure 4**). This segment's functional role includes collection, diagnostics, second-life screening, mechanical preprocessing, hydrometallurgical recovery, pyrometallurgical recovery, direct recycling, and refining into battery-grade materials. Participant types include recyclers, refiners, second-life battery integrators, black-mass processors, and closed-loop materials companies including Redwood Materials, Ascend Elements, SK Tes, Umicore, Cirba Solutions, and government-funded recycling programs such as ReCell. At this stage, value is recovered from used batteries to reduce waste and create a secondary supply of critical materials.

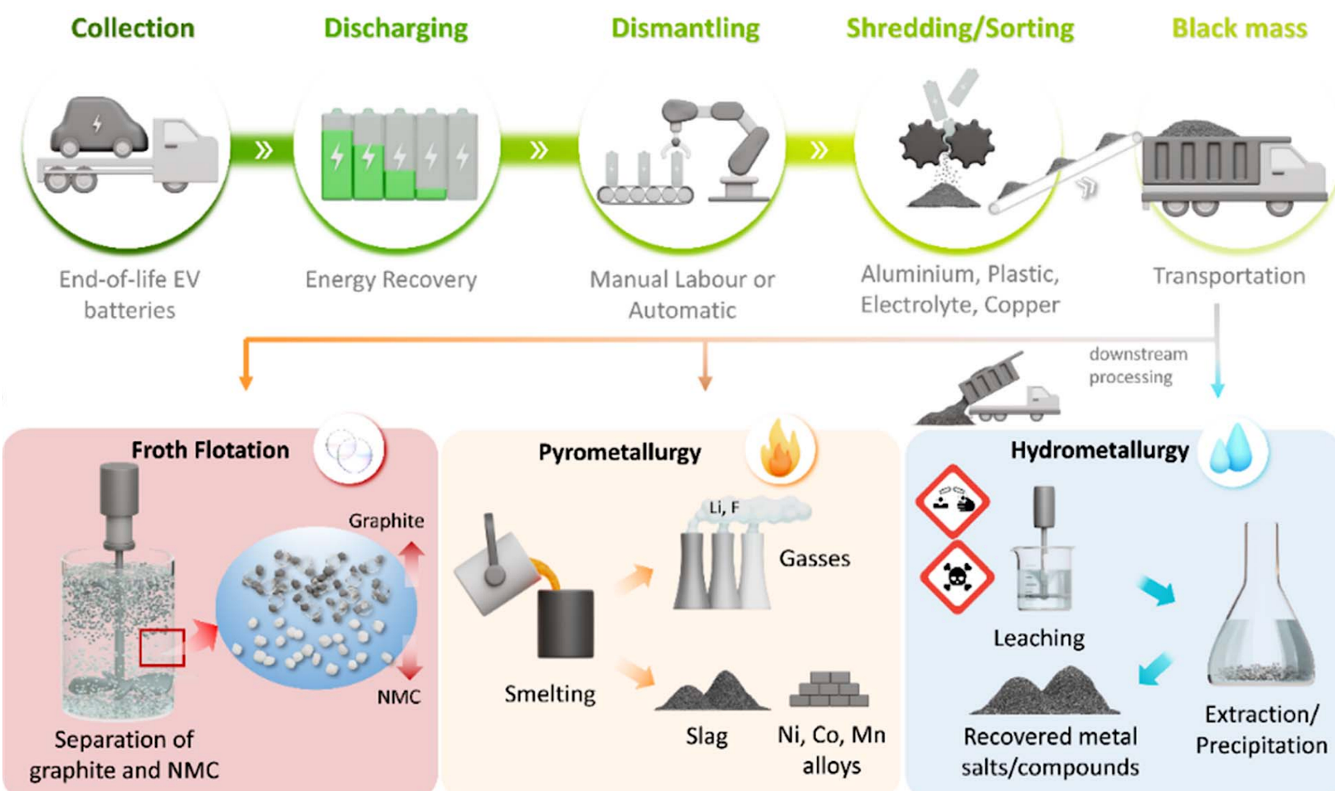

Figure 4: Typical EV Battery Recycling Process (Image Source: Lei et al. (2025))

Value Chain Architecture

The EV battery value chain is a multi-stage system where each segment depends on the prior stage delivering materials in the right chemical form, quality, and volume. Upstream suppliers extract lithium, nickel, cobalt, manganese, and graphite, but those materials usually cannot move directly into cell production (**Figure 5**). These minerals must first be processed into battery-grade chemicals such as lithium carbonate or hydroxide, nickel sulfate, cobalt sulfate, manganese sulfate, or purified graphite. In 2021, the US Federal Consortium for Advanced Batteries outlined a National Blueprint for Lithium Batteries including a battery supply-chain boundary that reflects this sequence, covering material mining, processing, cathode precursor production, cathode production, and battery assembly. Overall, advanced batteries involve complex, multi-tiered supply chains that include minerals extraction and processing, industrial chemicals, engineered materials, downstream manufacturing, transportation, and logistics.

Within the value chain, the main handoff points occur when refined materials move into precursor cathode active material, cathode active material, and anode active material production, then into cell manufacturing, pack assembly, and vehicle integration. Cathode and anode material producers define much of EV battery chemistry and performance, while cell manufacturers combine active materials with electrolytes, separators, current collectors, binders, and additives to produce cylindrical, prismatic, or pouch cells. Pack integrators then add the battery management system, thermal management, safety systems, enclosure, wiring, and controls that make cells usable in vehicles. EV manufacturers complete the downstream handoff by integrating the battery pack into the vehicle platform, where range, charging behavior, safety, software control, and warranty performance are managed. Rising EV adoption increases pressure across this architecture, with the International Energy Agency (IEA) reporting that EV battery demand reached more than 750 gigawatt-hours in 2023, up 40 percent from 2022.

Key bottlenecks sit in the conversion steps between raw materials and usable battery inputs, especially battery-grade refining, precursor production, cathode and anode material manufacturing, and cell production. Limited refining capacity can constrain the chain even when mined supply is available, because battery makers need high-purity qualified inputs rather than raw minerals. Precursor and active-material production can also become a chokepoint because each chemistry, such as nickel manganese cobalt, nickel cobalt aluminum, lithium iron phosphate, or advanced solid-state pathways, requires specific materials, processing expertise, and qualification.[4] Geographic concentration tends to amplify these risks as China dominates much of the battery supply chain, including battery mineral processing, cathode and anode material production, battery cells, and electric vehicle production. At the battery's end-of-life, recycling helps close the loop by returning recovered raw materials back into refining and production, but recycled outputs still require further processing before they can re-enter the supply chain.[5]

[4] Anthony L. Cheng et al., "Electric Vehicle Battery Chemistry Affects Supply Chain Disruption Vulnerabilities," *Nature Communications* 15, no. 1 (2024): 2143.
[5] Yanyan Zhao and Gurpreet Kaur, "The Future of Recycling for Critical Metals: The Example of EV Batteries," *Geosystems and Geoenvironment* 4, no. 2 (2025): 100376.

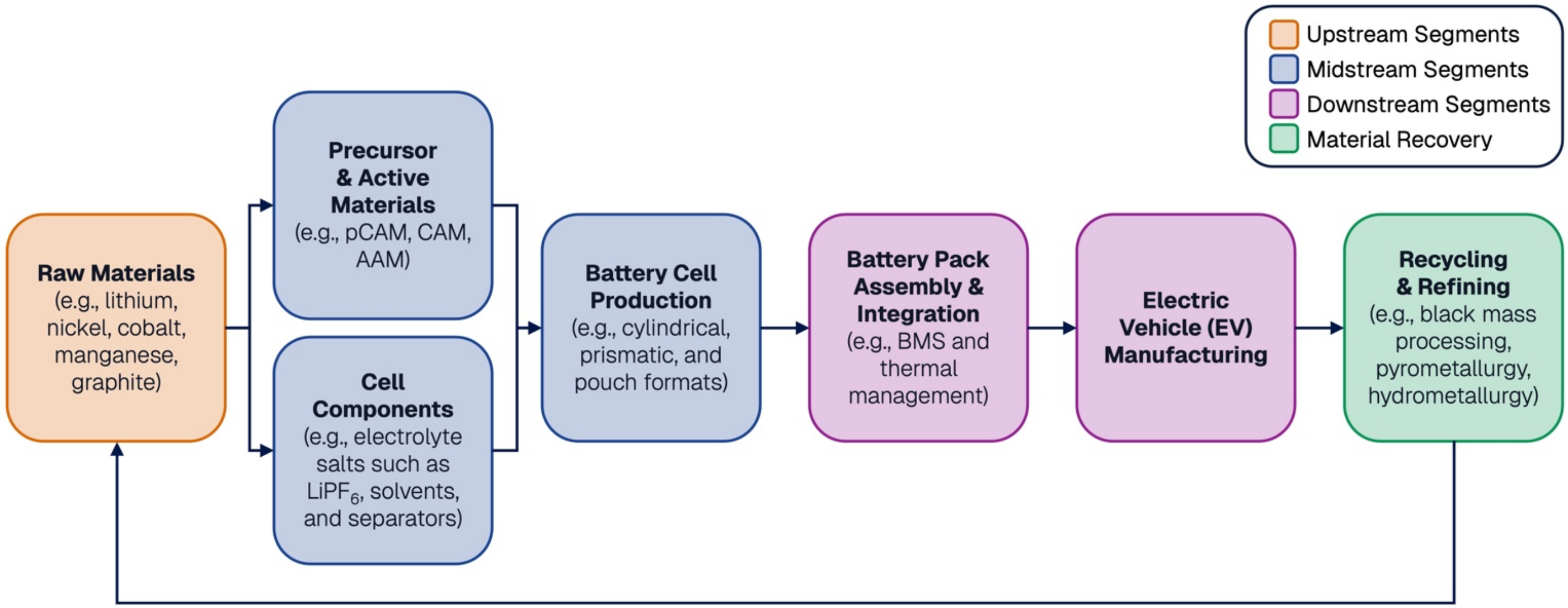

Figure 5: EV Battery Systems Ecosystem Value Chain

Player Landscape Map

The player landscape map organizes the EV battery ecosystem by functional role, separating upstream materials specialists from midstream active-material, electrolyte, separator, and cell-production participants, then downstream pack integrators, vehicle manufacturers, and end-of-life recyclers (**Figure 6**). Within the EV value chain structure, raw and refined mineral inputs move into processed materials and components, then into cells, packs, vehicles, and recovery pathways. Materials specialists sit closest to supply security and chemistry performance because cathode, anode, electrolyte, and separator inputs determine much of a battery's cost, performance, and manufacturability, while cell producers convert those inputs into standardized battery formats that can be integrated into modules and packs. Pack integrators occupy the bridge between cells and vehicles by combining cells with battery management, thermal management, safety, and structural systems before original equipment manufacturers integrate packs into vehicle platforms. Recycling and refining form a circular back-end segment as recovered battery materials can reduce dependence on primary critical minerals and feed refined inputs back into the upstream and midstream supply chain.

Figure 6: EV Battery Systems Player Landscape

Note: The companies shown in the landscape are a representative set and are not exhaustive of the full global ecosystem. Some companies operate across multiple parts of the value chain; however, each company logo is shown in only one illustrative segment for clarity.

Emerging vs. Established Players

The EV battery ecosystem continues to be shaped by a structural divide between participants that have achieved commercial scale and those pursuing step-change innovations in chemistry, architecture, or process (**Table 1**). Established scale players compete primarily on manufacturing throughput, geographic diversification, and multi-format production capability. For instance, CATL alone held 39.2% of global EV battery market share in 2025. A parallel group of established specialist companies such as POSCO Future M, Toray, and Webasto anchor specific supply-chain layers through deep process expertise and long-standing OEM qualification, without seeking to span the full value chain. At the other structural pole, vertically integrated participants such as BYD, Tesla, and Toyota collapse multiple stages under a single entity. Notably, BYD manufactures approximately 75% of its vehicle components in-house, including cells, motors, power electronics, and semiconductors, giving it supply-chain insulation and cost advantages that horizontally organized competitors cannot easily replicate. Similarly, Toyota is investing in in-house solid-state battery development through subsidiaries and partnerships with Idemitsu Kosan and Sumitomo Metal Mining and targeting commercialization by 2027-2028.

In contrast, emerging participants are more often defined by the potential to restructure how value-chain layers operate. For example, QuantumScape's solid-state ceramic separator could simultaneously displace conventional liquid electrolytes and polymer separators if it scales successfully. In the recycling segment, ReCell Center at Argonne National Laboratory, while not a commercial entity, is advancing direct cathode recycling methods that could lower manufacturing costs by 5-30% compared to virgin cathode production.

Table 1: Established vs. Emerging Players in the EV Battery Ecosystem

Player Type	Typical Operation	Differentiating Characteristics	Company Highlights
Established Scale Players	Operate at commercial scale across critical minerals, active materials, cell production, vehicles, or recycling	Manufacturing scale, supplier qualification, and ability to manage multi-stage supply chains	CATL; LG Energy Solution; Panasonic Energy
Established Specialists	Focus on a defined supply-chain layer, such as active materials, separators, electrolytes, thermal systems, or pack components	Process know-how, reliability, safety performance, and integration with cell or vehicle platforms	POSCO Future M; Toray; Webasto
Emerging Chemistry Innovators	Develop next-generation materials or cell architectures, often before full mass-market EV deployment	Breakthrough chemistry, higher energy-density targets, solid-state or lithium-metal designs, and silicon anode performance	QuantumScape; SES; Sila Nanotechnologies

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Player Type	Typical Operation	Differentiating Characteristics	Company Highlights
Emerging Circularity & Recycling Players	Build closed-loop recovery, refining, and battery-material re-entry pathways	Focus on reducing primary mineral dependency, recovering critical minerals, and linking end-of-life batteries or scrap back into materials production	Redwood Materials; Ascend Elements; ReCell
Vertically Integrated Participants	Span multiple value-chain stages, often combining materials access, cell production, pack integration, vehicle manufacturing, or recycling partnerships	Control over handoff points, reduced supplier exposure, and tighter linkage between battery strategy and vehicle platforms	BYD; Tesla; Toyota

Ecosystem Trends & Structural Forces

The EV battery value chain is shaped by structural forces that affect where value is created, where supply-chain risks concentrate, and how participants coordinate across upstream, midstream, and downstream stages. Material cost volatility, regional concentration in processing and manufacturing, OEM vertical integration, recycling-driven material recovery, and solid-state battery development all influence how minerals, components, technologies, and capabilities move through the ecosystem. Together, these trends point to a more strategically managed battery supply chain, where control over materials, processing capacity, and next-generation technologies becomes increasingly important to long-term competitiveness.

Critical Minerals Supply

Critical minerals remain a structural pressure point because battery supply chains rely on materials whose prices can move sharply as new supply, inventory, demand expectations, and policy conditions change. The IEA reports that battery minerals experienced major price declines in 2023 after two years of sharp increases, with lithium spot prices falling 75% and cobalt, nickel, and graphite prices falling 30%-45%. These markets are continuously framed as turbulent and this volatility matters because raw-material and refined-material costs influence procurement strategy, supplier contracting, and the economics of cathode, anode, and cell production, even when lower prices can temporarily reduce battery cost pressure. The IEA also notes that demand for key transition minerals is tied to clean-energy deployment, including EV batteries, so material exposure remains embedded in the value chain even as chemistries shift and supply expands.

Geographic Concentration

EV battery production remains geographically concentrated across several key steps, especially for midstream and cell-manufacturing activities in China. In a recent Global EV Outlook report, the IEA states that China represents nearly 90% of global installed cathode active material (CAM) manufacturing capacity and more than 97% of anode active material (AAM) manufacturing

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capacity, making precursor and active-material processing a major concentration point before cells are produced. Battery cell manufacturing is also concentrated, with industry reporting indicating that China accounted for about 80% of global battery cell production in 2024, while the United States, European Union, Korea, and Japan accounted for most of the remainder. This concentration creates structural dependency across the value chain because OEMs and cell manufacturers may diversify final assembly locations while still depending on upstream refining, cathode active material, anode active material, and precursor capacity concentrated in fewer regions (**Figure 7**).

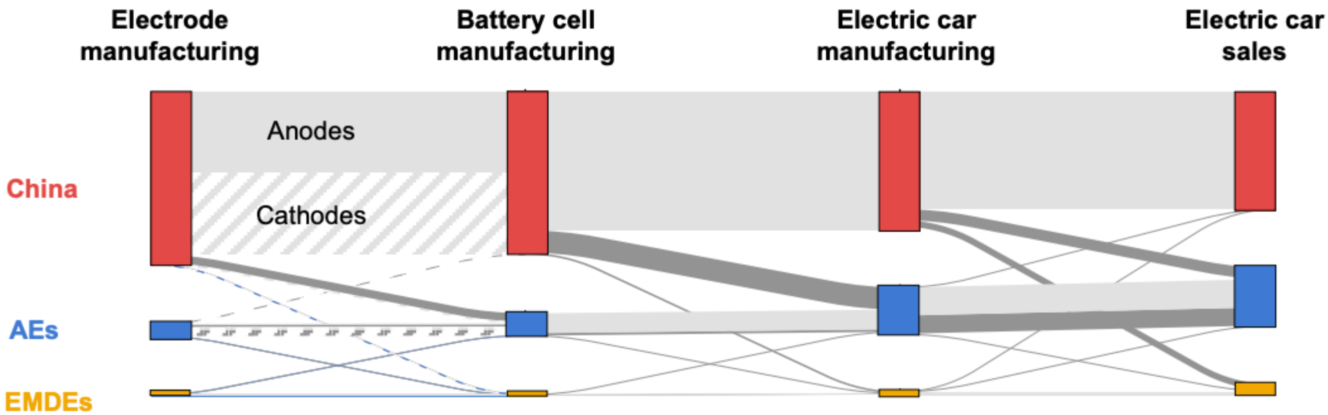

Figure 7: 2025 Global Manufacturing and Trade Flows of EVs, lithium-ion batteries, and key components across China, Advanced Economies (AEs), and Emerging Markets and Developing Economies (EMDEs) (Image Source: IEA Global EV Outlook 2026)

OEM Vertical Integration

EV OEMs are increasingly using vertical integration, joint ventures, licensing, and long-term material agreements to gain more control over battery supply, though strategies vary by company and region. For instance, Volkswagen's PowerCo states that vertical integration is a key lever for reliable and competitive battery cell production and describes an ambition to integrate steps from mining to production and recycling. General Motors uses a partnership model through Ultium Cells, a joint venture with LG Energy Solution that mass-produces battery cells to support GM's North American EV assembly capacity. These examples demonstrate that OEM integration does not always mean full ownership of every step along the value chain. In practice, vertical integration may combine direct control over selected capabilities with strategic partnerships for cell technology, cathode materials, chemistry development, or manufacturing scale.

Battery Material Recycling

Battery recycling and refining are beginning to reshape upstream dependencies by creating secondary sources of lithium, nickel, cobalt, graphite, and other battery materials. The U.S. Department of Energy's ReCell Center describes advanced battery recycling as a way to reduce reliance on foreign sources of battery materials. Separately, Argonne National Laboratory notes that direct recycling can preserve cathode structures, reduce waste, and reduce the need for pristine raw materials. Toyota's collaboration with Argonne focuses on direct recycling for lithium-ion batteries, including nickel, manganese, and cobalt cathode chemistries. This illustrates how OEMs and laboratories are treating recycling as a materials supply and manufacturing issue rather than only an end-of-life waste-management issue. Structurally, this means some recovered material can re-enter the value chain at refining, precursor, or active material stages. This could meaningfully reduce supply chain exposure to virgin extraction for materials, but still depends on collection volumes, chemistry mix, processing yields, and qualified recycled-material output.[6]

Solid-State Battery Development

Solid-state battery development is influential for the value chain because it changes the importance of electrolyte, separator, lithium-metal anode, cathode material, and manufacturing process capabilities, even though broad commercial deployment in EVs is still in development. In the past few years, Toyota and Idemitsu have agreed to work on mass production technology for solid electrolytes and supply chain formation for all-solid-state batteries. Separately, Volkswagen's PowerCo and QuantumScape have also entered an agreement to industrialize solid-state lithium-metal battery technology. In addition, Nissan states that it aims to launch an EV with in-house all-solid-state batteries by fiscal year 2028. These efforts suggest a future structure in which specialized solid-electrolyte materials, new cell designs, and manufacturing expertise could become more strategically important.

[6] Amjad Ali et al., "Sustainable Recycling of End-of-Life Electric Vehicle Batteries: EV Battery Recycling Frameworks in China and the USA," *Recycling* 10, no. 2 (2025): 68.