Charting a Circular Battery Future in India

Report / November 2025

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Authors and Acknowledgements

Authors

Marshall Abramczyk, RMI
Akshat Aggarwal, RMI
Akshima Ghate, RMI
Marie McNamara, RMI
Sudeshna Mohanty, RMI
Shashvat Singh, India Foundation

Authors listed alphabetically.

Contributing Authors:
Dimpy Suneja, RMI
Pankaj Jhunja (Independent Consultant)

Contacts

indiacomms@rmi.org
shashvat@indiafoundation.in

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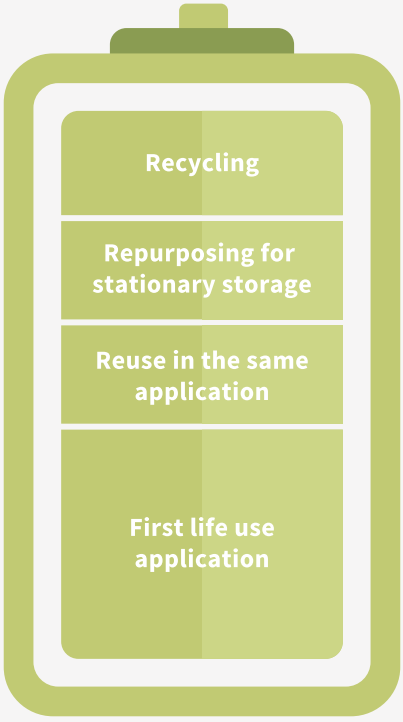
Executive Summary

India is in the early stages of building a robust domestic battery value chain to support its clean energy, mobility, and manufacturing ambitions. As this value chain takes shape, embedding circularity from the outset — through reuse, repurposing, and recycling — will be essential to maximising resource efficiency, reducing import dependence, and securing critical mineral supply. A circular battery economy also enables long-term cost reduction, job creation, and improved environmental performance, while bolstering the resilience and competitiveness of India's future battery ecosystem.

Electric vehicle (EV) growth will drive battery demand. India's EV adoption is accelerating rapidly, with more than 2 million units sold as of 2024.[1] Continued electrification is essential for achieving the country's 2047 energy independence targets, requiring a full transition of sales of new light-duty vehicles, buses, and heavy-duty vehicles to electric by 2043.[2] This shift will drive annual EV battery demand to 1,080 gigawatt-hours by 2050, a 40-fold increase from 2025 projections.[3]

Battery reuse, repurposing, and recycling will enable India to unlock the full life-cycle value of EV batteries. India's battery market is expected to be dominated by lithium iron phosphate chemistries, which have a long functional life, making these chemistries especially well-suited for reuse and repurposing. To maximise value, India must adopt a layered approach to battery circularity, extending battery life through three key stages: (1) reuse: redeploying batteries in their original mobility application; (2) repurposing: adapting them for a second life in alternative applications, such as stationary energy storage; and (3) recycling: recovering valuable materials through chemical or physical processing. These actions can be strategically sequenced to preserve battery functionality for as long as possible, reducing waste and improving life-cycle economics. Exhibit ES1 illustrates a staged circularity hierarchy, where batteries progress from first-life use to reuse, repurposing, and finally recycling. This hierarchy supports environmental and economic objectives, optimising value retention while minimising waste.

Exhibit ES1 The layered life and value of a battery from initial use, reuse, repurposing and recycling



RMI Graphic.

Battery circularity presents a ₹75,500 crore (US$9 billion) opportunity and a chance to shape a self-reliant and efficient battery supply chain.[4] By promoting reuse and repurposing before recycling, India can reduce its dependence on imported minerals, retain more value domestically, and ease pressure on raw material demand even as EV adoption accelerates. By 2050, implementing battery circularity practices could meet over 40% of India's lithium, nickel, and cobalt needs and has the potential to create more than 106,000 direct green jobs.[5] This shift is crucial for securing materials, supporting economic development, and positioning India as a global leader in battery production.

India has a unique opportunity to define its competitive edge in the global battery market through circular economy principles. India's ecosystem resembles early-stage China — fragmented but agile — offering space for rapid innovation and localised solutions. By implementing a strong repurposing and recycling ecosystem, India can chart its own path towards circularity while still leveraging global best practices such as traceability frameworks. Targeted incentives, enabling policies, and public-private partnerships will be crucial in unlocking India's potential for a circular economy. As global battery markets evolve, circularity will become and continue to be a key factor in securing trade, investment, and export opportunities.

An emerging battery circularity ecosystem is already taking shape in India, supported by two key preconditions. First, the Battery Waste Management Rules (BWMR) have established an enabling policy framework by introducing extended producer responsibility for used batteries. These rules apply to all battery chemistries and types placed on the market, across EVs, energy storage systems, consumer electronics, and industrial applications.[i] Second, a dynamic domestic startup ecosystem is emerging in the space of reuse, repurposing, and recycling technologies, with early investments beginning to support their growth. These efforts are laying important groundwork, but stronger policy enforcement and broader market incentives will be critical to scaling circularity nationwide.

Scaling battery circularity in India means addressing a web of interconnected challenges:

- Nascent regulatory framework: The lack of tracking systems, limited incentives to discourage premature battery disposal, and uneven enforcement create confusion and slow progress.
- Financing constraints: High up-front costs and uncertain returns have made circularity unattractive to mainstream investors.
- Fragmented ecosystem: Original equipment manufacturers, fleets, recyclers, and financiers often operate in silos with limited coordination or data sharing, despite the need for integrated action.
- Limited feedstock supply: Weak collection systems and poor traceability reduce the volume of batteries available for reuse, repurposing, and recycling.
- Demand limitations: The absence of a robust domestic midstream (e.g., refining and precursor production) limits offtake for recovered materials, weakening the economic case for recycling.

Tackling these challenges requires targeted progress across five enablers. Policy must focus on maximising value retention — not just compliance. Traceability should unlock accountability and help match feedstock supply with second-life and recycling demand. Finance needs to reach diverse and distributed actors across the chain, including micro, small, and medium enterprises and informal operators. Technology must advance towards modular, circular-ready systems with open battery management system protocols and interoperable diagnostics. And workforce development must build safety-aligned skills while integrating informal actors into formal circular systems.

Strengthened policy guidelines can enable a functional circular economy. The BWMR already provide a strong foundation for safe end-of-life battery handling and can be further strengthened by explicitly prioritising reuse and repurposing alongside recycling. In parallel, enhanced interministerial collaboration can help align definitions, standards, and incentives, ensuring coordinated action across ministries to advance a unified circularity agenda.

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i Except for batteries used in defence and space applications.

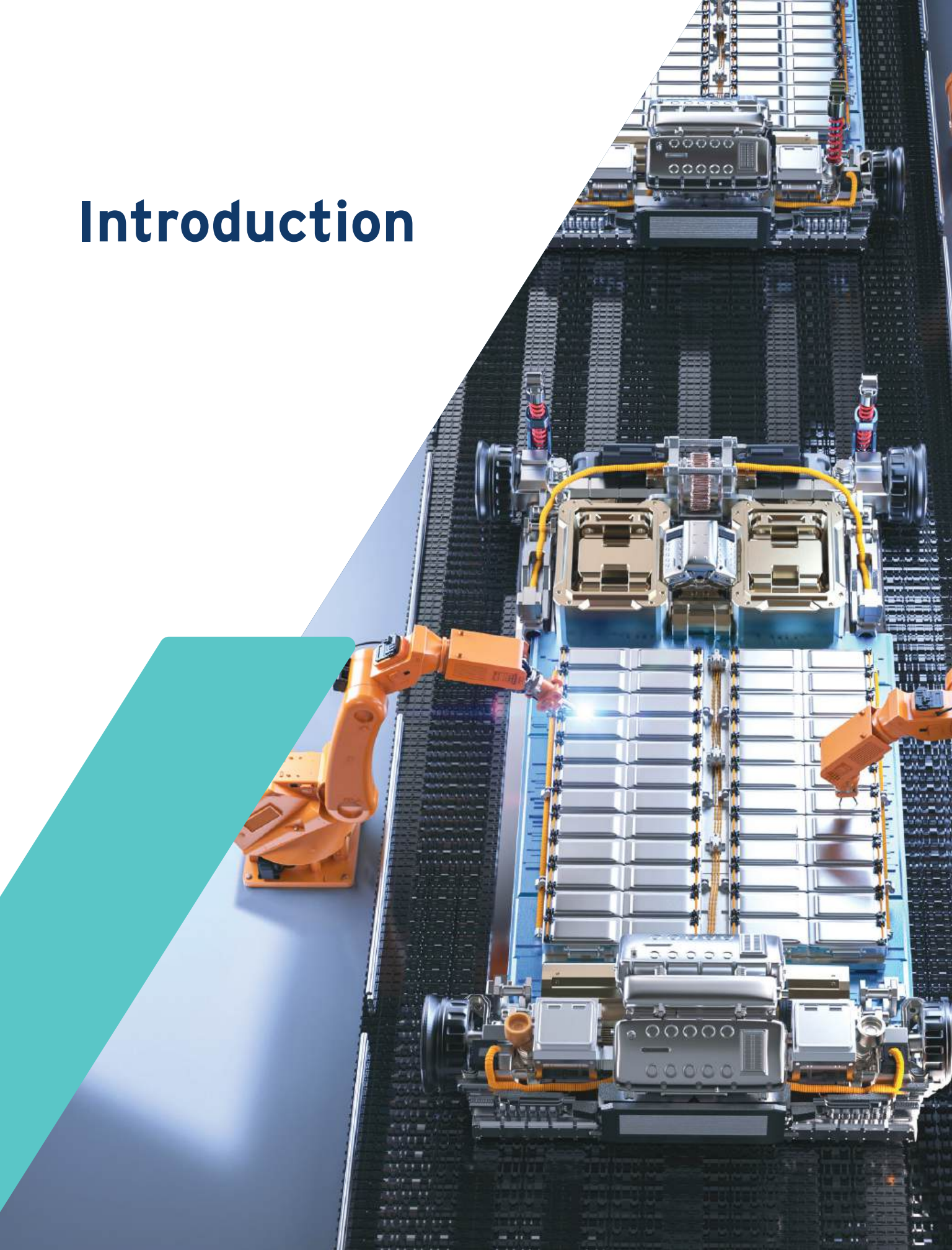
Traceability mechanisms and standard certification frameworks will be key to scaling adoption and building market confidence in second-life applications. Improved traceability is essential to scaling battery circularity; digital platforms should expand to include key diagnostics, such as charging cycle count, depth of discharge, and state of health, linked to each battery. This data should remain accessible throughout the battery's life cycle to inform decisions on reuse, repurposing, or recycling. A complementary certification could also be used to grade batteries using a standard scale tied to safety, performance, and residual value.

Financing must match diverse needs. India will require more than ₹15 lakh crore in investment by 2050 to support circular battery systems.[6] The value chain needs flexible financial instruments — concessional loans, patient equity, guarantees, and results-based finance — tailored to different stages of technological readiness and commercialisation.

Technology and workforce development must advance in parallel to drive innovation and support the development of a circular battery ecosystem. Targeted R&D investment and deliberate cross-sector collaboration are essential to commercializing indigenous solutions and strengthen domestic manufacturing capabilities. Advancements in circular innovation will play a key role in supporting the sustainable growth of the battery value chain. At the same time, coordinated efforts to build technical capacity and upskill workers are essential to meet emerging industry needs. Equally critical is the formal integration of informal-sector workers into the circular value chain to ensure that a transition to a circular battery economy not only improves efficiency but also promotes equity, safety, and long-term livelihood security.

India is at a pivotal point in its battery transition. With battery demand projected to grow more than 40-fold by 2050 and early end-of-life volumes already emerging from commercial EV fleets, the country has a narrow window of opportunity to shape a circular battery economy before fragmented, linear systems become entrenched.[7] Circularity must not be viewed as a downstream cleanup effort. Rather, it is a strategic imperative to secure critical materials, stabilise supply chains, reduce life-cycle emissions, and retain economic value locally. By embedding reuse, repurposing, and recycling into the system from the outset — rather than retrofitting these elements later — India can leapfrog outdated models, sidestep costly inefficiencies, and build a resilient, future-ready battery ecosystem from day one. Doing so will require a resilient and collaborative ecosystem, with stronger coordination across the battery value chain. This will help address supply chain constraints and ensure progress toward India's targets of 100% electrification of new vehicle sales by 2030, energy independence by 2047, and net-zero emissions by 2070.

Introduction



What is battery circularity?

Battery circularity refers to the strategies, technologies, and systems that extend the life of batteries and maximise the recovery and reuse of their materials. Unlike the traditional linear model of extraction, use, and disposal, a circular economy for electric vehicle (EV) batteries maximises the use of materials for as long as possible. In this model, batteries serve their original purpose in EVs during their "first life," then are reused in other EVs or repurposed for less demanding applications like energy storage in their "second life," and finally recycled, where materials are recovered and re-enter the refining stage to support the production of new batteries.[8]

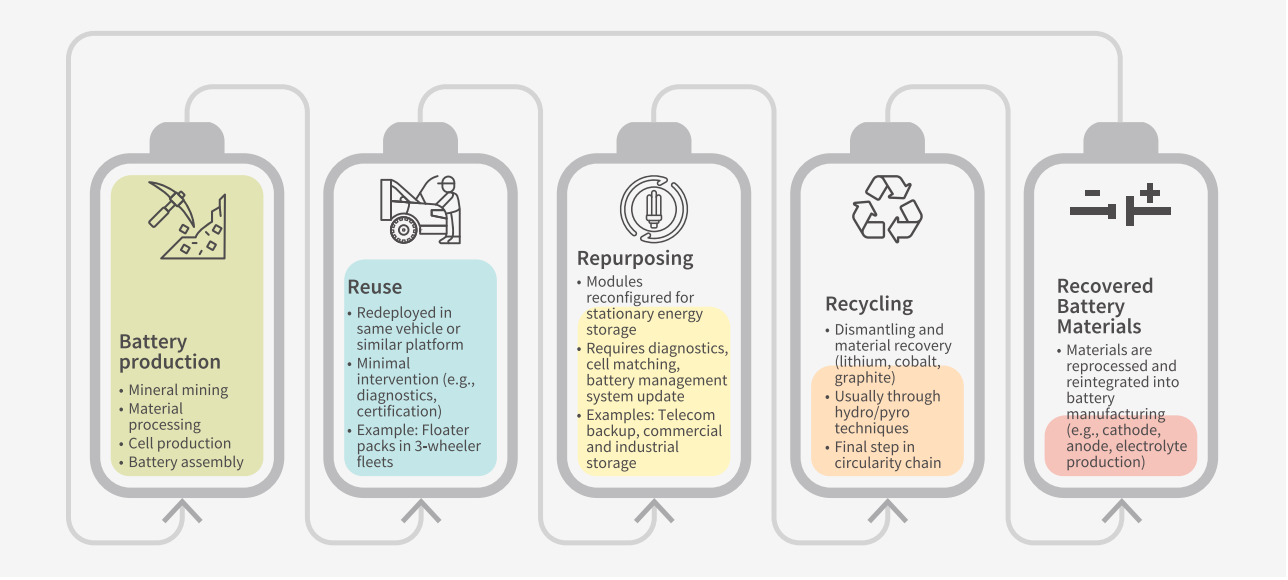
Exhibit 1 Reuse, repurposing, and recycling explained

Second life		**Material recovery**
Reuse	**Repurposing**	**Recycling**
The use of the battery again in its original application - mobility - usually after basic testing or small repairs, without needing to take it apart or change how it's wired. Reusing the battery in a vehicle where its remaining life still meets daily needs.	The use of a battery again in a secondary application, such as stationary energy storage, after disassembly, reconfiguration, or component-level validation. Retooling the battery for an alternative application such as stationary storage.	The recovery of constituent materials, including lithium, cobalt, nickel, aluminium, and graphite, through chemical or physical processing of end-of-use batteries. Recovering minerals to be used in assembly of new batteries.

RMI Graphic.

Battery circularity and creating a robust and secure battery supply chain in India are mutually reinforcing. A well-functioning circular economy can reduce reliance on imported raw materials by recovering critical minerals — such as lithium, cobalt, and nickel — and reintegrating them into domestic manufacturing. This enhances supply chain resilience and buffers against global price variations and geopolitical volatility. At the same time, a robust domestic supply chain, particularly in midstream processing and cell production, is crucial to ensure that recovered materials are reintroduced into new batteries rather than being exported. Together, circularity and supply chain development create a system that supports long-term energy security, value retention, and industrial self-reliance. Exhibit 2 illustrates how reuse, repurposing, and recycling can be applied across the battery life cycle, and how each activity contributes to retaining material value and enabling reintegration into the value chain.

Exhibit 2 Battery circularity loop



RMI Graphic. **Source:** RMI analysis

This report focuses specifically on battery circularity within India's EV sector, including batteries used in two-, three-, and four-wheelers, as well as buses and trucks. Projections indicate that EV batteries will make up the majority of battery waste across all sectors — including stationary applications and consumer electronics — and could account for more than 80% of India's used lithium-ion battery (LiB) volumes by 2035.[9] By focusing on the EV sector, this report offers targeted recommendations tailored to the unique form factors and performance requirements of EV batteries. As the dominant driver of battery demand, the EV sector can serve as a catalyst for India's broader battery circularity system, laying the groundwork for circularity principles that extend beyond EVs and support the entire battery value chain to ensure it is resilient, efficient, and future-proofed.

How circularity is central to India's strategic and economic goals

India's ambitions for energy independence, clean mobility, and industrial self-reliance hinge not only on accelerating battery adoption but also on building a sustainable, resilient system to manage the full life cycle of batteries. Circularity — encompassing reuse, repurposing, and recycling — is foundational to this vision. Developing a thriving secondary-life and material recovery market for batteries in India can strengthen the entire EV sector and directly benefit consumers by building market confidence in battery resale value, reducing residual risk.

The EV sector will catalyse the development of India's battery circularity ecosystem, offering a unique opportunity to design a future-ready system that can accommodate additional waste streams beyond 2035. Circularity enhances domestic value capture, reduces import dependency, and strengthens India's positioning in future-facing global supply chains.

Securing supply chains and advancing mineral security

India's battery demand is projected to reach 1,080 gigawatt-hours (GWh) by 2050 under an ambitious EV adoption scenario.[10, ii] However, the lack of domestic reserves of key minerals needed for battery production could pose a significant constraint.[11] India's mineral sourcing spans multiple countries, including lithium from Australia and Argentina, as well as cobalt from the Democratic Republic of the Congo.[12] Most precursor processing and battery-grade material production are concentrated in countries such as China, South Korea, and Japan, underscoring the need for strategic investments in refining infrastructure to mitigate supply chain vulnerabilities.[13] Cell manufacturing is still at a nascent stage, with a few recent industry investments and early production-linked incentive–supported projects underway. **India remains 100% import-dependent for the refining of key battery minerals such as lithium, cobalt, and nickel, with no commercial-scale domestic capacity currently in place.**[14] Although some domestic capacity exists for battery pack assembly, India remains largely dependent on global supply chains for upstream and midstream processes, including mining, refining, and the production of battery-grade materials like cathode active materials, separators, and electrolytes.

Circular strategies can reduce this dependency by reintroducing recovered minerals into the value chain. RMI modelling suggests that circularity — through secondary life-cycle pathways such as reuse, repurposing, and recycling — can reduce virgin material demand by more than 40% by 2050. This potential for domestic mineral recovery directly supports the objectives of the National Critical Mineral Mission (NCMM), which seeks to enhance resource security through diversified sourcing, import substitution, and value addition in battery metals.

Building industrial self-reliance and domestic value capture

Government schemes such as the Production Linked Incentive (PLI) for advanced chemistry cells (ACCs) and the Prime Minister Electric Drive Revolution in Innovative Vehicle Enhancement Scheme (PM e-DRIVE) are catalysing the growth of India's EV ecosystem. However, without parallel investment in circularity, India risks becoming overly reliant on imported materials and facing persistent value leakage upstream in the battery life cycle.

Integrating circularity into India's battery value chain expands its industrial footprint beyond cell manufacturing. Activities such as black mass refining,[iii] cathode and anode production, mineral recovery, and post-sale services like diagnostics, repair, and resale form a broader ecosystem of value. These functions not only diversify the industrial base but also offer significant potential for domestic reinvestment. The recirculation of materials ensures that the economic value generated during manufacturing is not lost at the end of life (EOL). Instead, it is retained and channelled back into the local economy.

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ii This estimate is based on EV demand modelled on an optimistic scenario that aims to achieve energy independence by 2047, as detailed in the India Battery Outlook section.

iii Black mass refining is the process of extracting valuable metals — such as lithium, cobalt, and nickel — from the powdered residue (black mass) produced by shredding end-of-life lithium-ion batteries.

Unlocking economic value and job creation at scale

RMI estimates that battery circularity represents a ₹75,500 crore (US$9 billion) market opportunity. This figure includes potential profits as well as value generated from recovering critical minerals, land use reductions,[iv] and job creation. Recycling alone could create more than 106,000 direct green jobs, with additional employment opportunities expected from reuse, diagnostics, repurposing, deployment, service networks, and reverse logistics. These roles span informal collection and dismantling in peri-urban areas to technical deployment in rural microgrids or telecom installations. The geographically distributed nature of circular operations aligns with India's broader goals of inclusive and green job creation, especially outside major industrial centres.

Decarbonising the battery life cycle

Over their life cycle, EVs emit 19%–34% less CO_2 than internal combustion engine vehicles. However, a significant portion of EV emissions comes from embodied carbon — emissions generated during the manufacturing and assembly of the vehicle and particularly the battery. According to life-cycle assessments by Lawrence Berkeley National Laboratory and the International Council on Clean Transportation, producing a 40 kilowatt-hour (kWh) LiB under current Indian conditions results in approximately 2.3–2.7 tonnes of CO_2e.[15] Circularity can significantly reduce life-cycle emissions. Although repurposing does not lower a battery's original embodied emissions, it extends the battery's useful life, delivering more energy per unit of carbon. This can reduce per-cycle emissions by 25%–30% compared with retiring the battery and manufacturing a new one. Recycling offers additional emissions benefits by reducing the need for emissions-intensive mining and refining. By substituting a portion of virgin mineral demand, recycling can lower the embodied emissions of new batteries. By 2050, battery recycling in India is projected to prevent more than 2.9 million tonnes of CO_2e emissions, equivalent to taking 700,000 fossil fuel vehicles off Indian roads for a year.[16]

Achieving global market readiness through circularity

As global battery markets mature, circularity is emerging as a competitive differentiator in trade and investment. The European Union (EU) has introduced the Battery Regulation, which will mandate minimum recycled content thresholds starting in 2031 and require full traceability through digital product or battery passports beginning in 2027. China has implemented centralised EOL tracking through its National Monitoring and Management Platform.

iv Although India may not benefit directly from land use reductions due to limited current mining activity, circularity reduces India's dependence on environmentally intensive extraction in other parts of the world.

These standards are setting the bar for international participation in battery markets. For India to establish itself as a hub for battery manufacturing and exports, aligning with emerging global norms is essential. Implementing traceability infrastructure, certifying second-life applications, and standardising recycling outputs will allow Indian manufacturers to meet export requirements and unlock access to premium international markets. Moreover, compliance with global life-cycle requirements helps attract climate-aligned capital and de-risk long-term investments in the battery ecosystem.

Why India's battery circularity trajectory will be unique

India's battery circularity ecosystem is structurally distinct, shaped by rising adoption of two- and three-wheelers — particularly among commercial users — with shorter battery lifespans leading to faster EOL volumes, widespread use of lithium iron phosphate (LFP) chemistries with lower material value, a dominant informal collection sector, and limited domestic manufacturing. Together, these factors mean India will confront large-scale EOL battery management challenges sooner than many countries.

The rise of LFP batteries and its implications for circularity pathways

LFP batteries do not require high-value materials like cobalt and nickel, making traditional recycling economically less attractive compared with other LiB chemistries. Nickel manganese cobalt (NMC) chemistries were initially favoured for EV applications given their higher energy density, which afforded longer EV range for the same battery weight. However, LFP battery energy density has improved significantly in recent years, and given their cost advantage, LFP batteries are now being increasingly preferred by EV manufacturers across the world. At the same time, their inherent advantages — such as longer life, thermal stability, and consistent performance across shallow depth-of-discharge use cases — make them well-suited for second-life applications. Encouraging the reuse and repurposing of LFP batteries in low-power or short-range settings (e.g., personal EVs, intracity logistics, or backup power) can delay premature recycling and improve overall system efficiency.

Informal sector dominance and integration: Today, more than 70% of EOL LiB collection and disassembly is carried out by the informal sector.[17] This dominance stems from an extensive but unregulated network of aggregators and scrap processors, who efficiently collect batteries but often handle them under unsafe conditions, with no environmental safeguards or material traceability. Although formal recycling has emerged in recent years, its access to feedstock is often constrained by this informal-first collection system. Bringing these actors into the formal fold — through models like decentralised clustering, safety training, certification schemes, and eligibility for extended producer responsibility (EPR) credits — is critical.

Traceability and data infrastructure: Unlike the EU, which is rolling out a battery passport system, or China's national traceability platform, India has not instituted a standardised data-sharing mechanism for batteries across their life cycle. As a result, stakeholders in repair, repurposing, and recycling are unable to access critical data such as the state of health (SOH), a measure of how well a battery is performing compared with when it was new, and remaining useful life (RUL). This data gap has multiple knock-on effects: it hinders accurate diagnostics and safe repurposing, makes it difficult to estimate residual battery value for resale or leasing, and impedes underwriters and financiers from assessing risk. In effect, it blocks both economic optimisation and system safety, undermining confidence across the value chain.

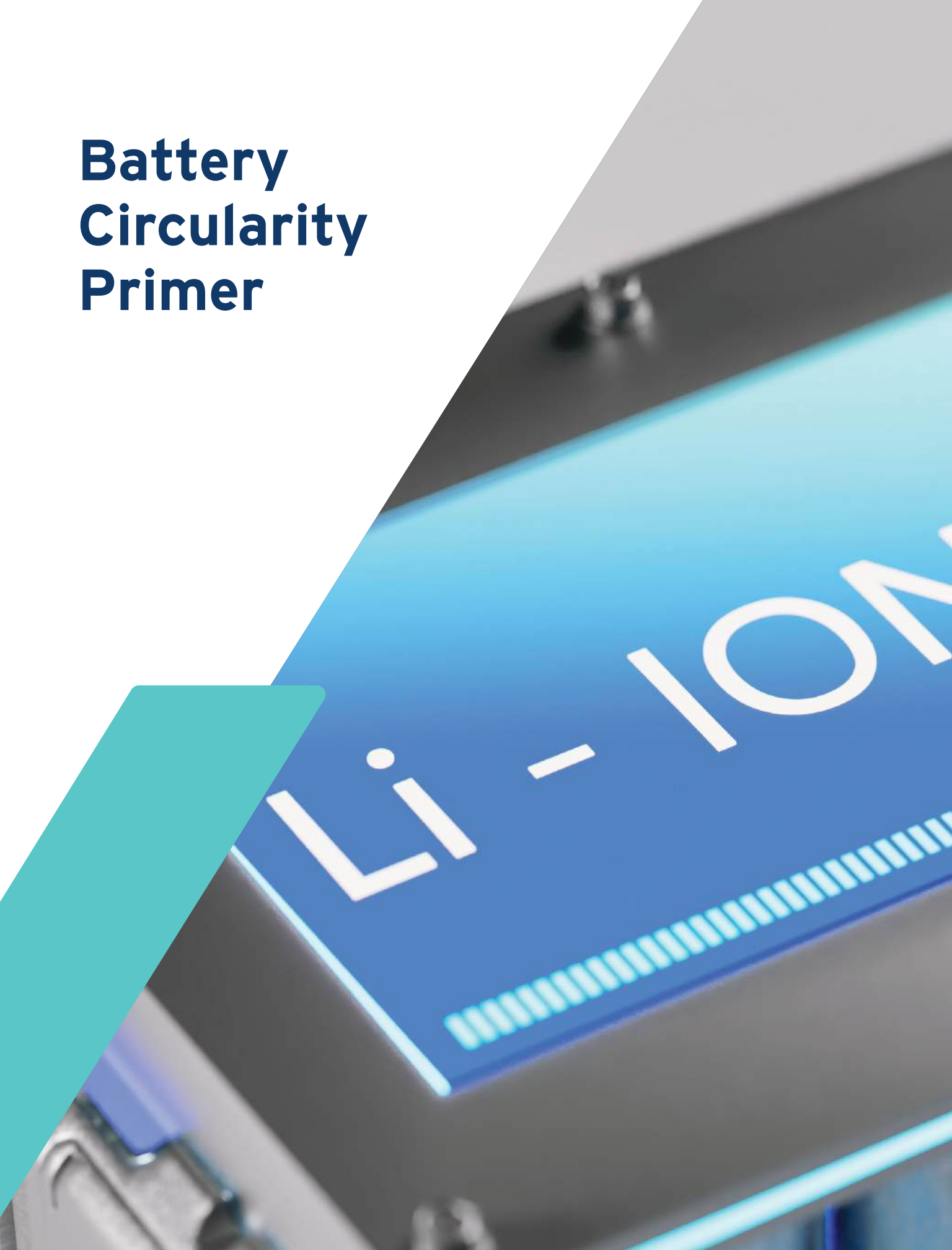
Designing for scale: India's battery future in context with other global actors

As EVs become the dominant demand pull for batteries in India, used EV battery volumes are expected to surge, especially from high-utilisation commercial fleets such as delivery three-wheelers, ride-hailing cabs, and electric buses. These vehicles experience faster battery turnover and will generate the bulk of early EOL volumes. As a result, battery circularity is not an adjacent concern; it is central to the EV and logistics transition today. There is an urgent need to build circular systems before volumes scale beyond manageable thresholds.

In looking at India's battery ecosystem compared with other global actors, India's current circularity ecosystem most closely resembles China's battery sector in the early 2010s rather than the structured, compliance-oriented models of Europe or North America today. Like early-stage China, India faces fragmented oversight, informal-sector dominance, and highly localised battery flows. Yet it also shares China's hallmark agility: rapid experimentation, dynamic startup culture, and industrial ecosystem. Where the two countries diverge is in institutional design. China's ecosystem has evolved through centralised planning, including creation of an officially approved list of certified battery recyclers and mandates requiring EV manufacturers to share real-time battery management system (BMS) data with a national platform, measures that enable traceability and formalisation. India's battery ecosystem can adopt similar traceability measures while also building a competitive edge by leading in battery circularity, particularly through the development of a robust repurposing ecosystem. A budding circularity startup landscape is emerging in India, and by designing effective incentive schemes, enabling policy frameworks, and fostering public–private partnerships, India can cultivate a distinct innovation advantage and position itself as a leader in circular battery solutions.

In this light, the complexity of India's battery value chain is not a constraint; it is a prompt for tailored solutions. Circularity in the Indian context must reflect the realities of informal integration, a battery chemistry mix that will likely be dominated by LFP batteries, and decentralised battery reuse. Instead of replicating regulatory blueprints from elsewhere, India can build a context-specific model, one that draws from global best practices while staying grounded in regional realities.

Battery Circularity Primer



Market analysis and stakeholder insights suggest that the greatest value from used EV batteries can be captured through a staggered approach, starting with *reuse*, followed by *repurposing, and ultimately recycling*.[18] This sequencing maximises economic and material recovery by prioritising strategies that preserve the battery's original form and functionality to the greatest extent possible.

Reuse

Reuse refers to the use of a battery in another mobility application, where the battery typically retains its original pack structure and voltage configuration, with minimal procedures performed beforehand, such as visual inspection, safety testing, and cell or module rebalancing. Reuse is most viable when batteries show signs of ageing but still perform within acceptable limits,[v] allowing continued use without major reconfiguration. It often involves redeploying used batteries in secondhand vehicles, as floater packs during repairs, or reinstalling repaired batteries into a vehicle. This may involve transferring batteries to lower-utilisation vehicles within the same fleet — such as from delivery vans to two-wheelers — or selling them for use in used or retrofitted EVs, where their remaining capacity can still provide reliable performance.

Battery reuse potentially offers a more affordable alternative to purchasing new EV batteries and gives customers more choices. In India, each new battery pack typically costs between ₹1.2 lakh (~US$1,400) and ₹7 lakh (~US$8,150), depending on vehicle type, battery size, and chemistry.[19] Early market data and original equipment manufacturer (OEM) estimates indicate that reused batteries can be 20%–30% cheaper, making them an attractive option for fleet operators and individual buyers looking to reduce up-front costs.[20] With more EV batteries reaching EOL, reuse potential could climb to 10 GWh annually by 2036, resulting in a cumulative reusable market size opportunity of 220 GWh by 2050.

Redeploying used batteries in an alternative vehicle application is still an emerging opportunity. Currently, there are no publicly announced large-scale reuse pilots or commercial models that focus exclusively on this pathway. However, industry stakeholders have begun to explore its viability, particularly for cost-sensitive commercial fleet segments like three-wheelers and light commercial vehicles (LCVs).[21]

How 'reuse' and 'repurposing' coexist as sequential stages in India's circular battery economy

Reuse and repurposing can serve as sequential stages in extending a battery's life cycle and maximising value recovery. A battery's life cycle is typically measured in full charge–discharge cycles. In mobility applications, when the battery reaches an SOH of 80%, it is typically replaced to ensure optimal performance and meet vehicle range needs, although it can still deliver substantial capacity and energy throughput. In series-connected battery packs, overall performance is constrained by the weakest cell—a challenge heightened in climates like India, where thermal gradients can

cause uneven battery ageing. This effect means the weakest cells set the ceiling for the pack's usable SOH, even if the other cells remain healthy; underscoring the need for advancements in cell repair and a more nuanced approach to matching cell quality with the right applications (e.g., using lower-grade cells for less demanding applications like e-scooters). Such strategies could promote reuse and extend battery lifecycles. Additionally, many EV batteries, especially those used in commercial fleets, are retired even before reaching 80% SOH. This is often due to operational priorities such as maintaining range or business constraints related to warranty terms, rather than actual battery degradation. These early retirements create an even longer window for reuse . Three-wheelers and e-buses are especially viable candidates for reuse in lower-demand mobility applications, where uptime, charging time, and range requirements can be more flexible.

Following reuse, repurposing provides a second opportunity to extend battery utility by reconfiguring modules for a secondary purpose. Repurposing is generally pursued when a battery no longer meets the performance or safety standards required for vehicles use but still retains 70%–80% of its SOH, making it suitable for less demanding applications, such as stationary storage.[23] Although energy throughput and charge–discharge efficiency decline with reuse, batteries can still perform effectively in second-life applications such as backup power systems and rural microgrids. By appropriately oversizing battery packs, these systems can still reliably meet power demands with lower SOH batteries. Although not all batteries will undergo both repurposing and recycling, this layered approach maximises their value by extending their functional life before final material recovery.

Repurposing

Repurposing involves disassembling and reconfiguring battery modules from retired EVs — often with repairs — to create new systems for second-life use. Although this process requires time, money, and technical expertise, it extends battery life and adds value before recycling. Market demand exists, but limited retired battery stock is the main constraint. With a typical second life of five years, repurposed batteries are well-suited for off-grid and backup power, though not yet viable for grid-scale storage requiring longer warranties.

Several companies are piloting repurposing initiatives, particularly in high-utilisation fleet segments where battery turnover is rapid and traceability is stronger. Startups like Nunam, Lohum, and BatX Energies are working to redeploy EV batteries in stationary storage applications through combined diagnostics and cell-level testing to ensure the battery is fit for purpose. Lohum, for example, offers both in-house pack disassembly and second-life product development across telecom, commercial backup, and solar-plus-storage markets. In parallel, fleet-focused firms like Turno are enabling structured battery buybacks at the end of first life, with the aim of redeploying batteries into energy storage systems.[24]

Large OEMs such as MG Motor are exploring battery take-back, in-house refurbishment, and stationary second-life pilots.[25] These OEM-led initiatives — while still early — indicate a growing industry recognition that repurposing is not just a sustainability play but also a commercially viable lever to extend product value, retain control over battery assets, and build afterlife service offerings. Together, these pilots signal the emergence of a repurposing ecosystem that is likely to scale alongside India's EV transition.

Recycling

Recycling refers to the mechanical and chemical processes used to extract valuable materials, such as lithium, cobalt, nickel, and graphite, from batteries that are no longer fit for functional deployment. This is the most material- and energy-intensive circularity pathway and the destination for batteries that have degraded beyond safe reuse or repurposing.

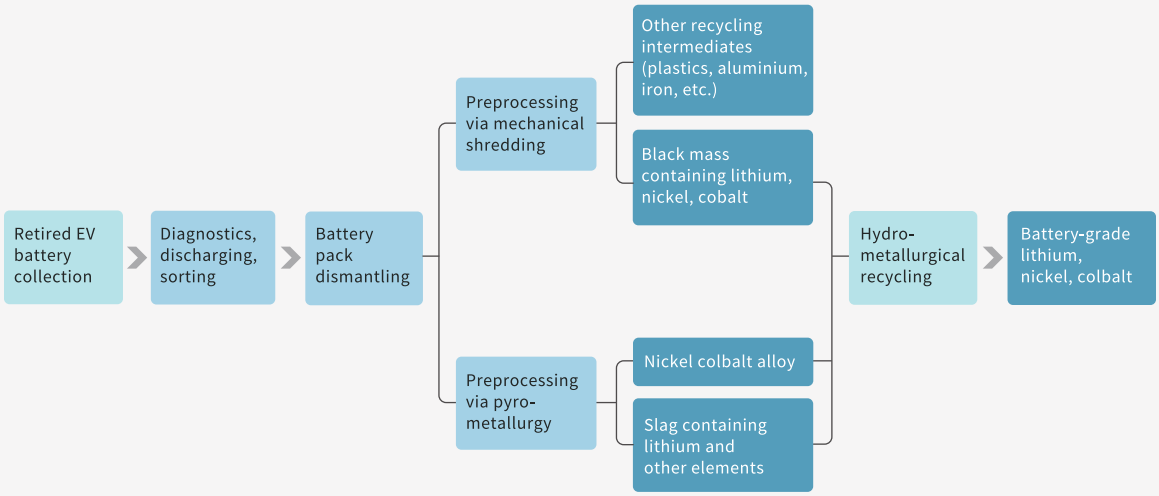
The recycling process typically begins with mechanical shredding, which separates plastics, metals, and electrode materials into distinct waste streams. The most valuable output, known as "black mass," contains a mix of electrochemically active materials that can be processed through pyrometallurgical, hydrometallurgical, or direct recycling techniques, although direct recycling is yet to be commercialised globally. In India, refining black mass remains a challenge due to limited domestic processing capacity, resulting in the export of this raw material and associated value leakage.

v Battery ageing refers to the gradual degradation in performance and capacity that occurs over time due to both calendar ageing (time-based chemical degradation) and cycle ageing (repeated charge–discharge use). This includes reduced state of charge, increased internal resistance, and diminished SOH. Signs of ageing may include reduced range, higher charging times, or abnormal heating patterns. Batteries are often oversized, meaning their full range and discharge cycle are not utilized to meet actual range needs. This underuse means calendar aging is often the primary driver of gradual performance degradation such as reduced state of charge, increased internal resistance, and diminished State of Health (SOH). Common signs of aging include shorter range, longer charging times, and abnormal heating patterns.

How do battery recycling technologies work?

Battery recycling is not a one-size-fits-all process. Depending on the chemistry, infrastructure maturity, and value-recovery goals, different approaches are used to extract materials from EOL batteries.

Exhibit 3 Battery recycling processes and differing technological pathways



RMI Graphic. **Source**: World Economic Forum, https://reports.weforum.org/docs/WEF_Powering_the_Future_2025.pdf

Preprocessing via mechanical processing: Also known as "shredding," this involves mechanically processing battery packs or modules into a fine powder to prepare them for downstream recovery of battery minerals. Shredding the battery enables the subsequent separation of the output into valuable fractions, such as black mass, which contains battery cathode minerals.

- **Strengths:** Proven, scalable, and less sensitive to battery chemistry variations.
- **Limitations:** Mixing of various metals in shredded form reduces recovery efficiency. Postprocessing to separate black mass from the rest of the shredding output and to improve the quality of black mass can require additional preprocessing steps, such as discharging and electrolyte removal from batteries, to ensure safe operations.
- **Relevance to India:** Mechanical shredding does not require prior separation by battery chemistry and is a highly relevant preprocessing solution for handling a diverse inflow of batteries with different chemical compositions and architectures.

Preprocessing via pyrometallurgy: Known as "smelting," this process involves subjecting batteries to extremely high temperatures (typically 1,500°C or more) in industrial furnaces. The result is a metal-rich slag and gas by-products from which high-value metals, such as cobalt, nickel, and copper, can be extracted.

- **Strengths:** Proven, scalable, and less sensitive to battery chemistry variations.
- **Limitations:** Energy-intensive, high carbon footprint, and negligible recovery rates for lithium and aluminium. Often unsuitable for LFP batteries, which dominate India's EV market.
- **Relevance to India:** Given India's growing reliance on LFP-based chemistries—which have low cobalt and nickel content—pyrometallurgy offers limited material recovery value. Moreover, the process's high energy demands and emissions profile run counter to India's decarbonization goals. While some legacy or imported battery streams may benefit from smelting, the method is unlikely to be optimal or widely adopted in India's long-term recycling infrastructure.

Hydrometallurgical recycling: For this, nickel cobalt alloy derived from pyrometallurgical preprocessing or black mass from mechanical preprocessing is subjected to chemical leaching using acids or bases. The dissolved metals are selectively precipitated and recovered as high-grade materials suitable for use in batteries.

- **Strengths:** High recovery efficiency, including lithium and manganese. Allows for selective metal extraction with relatively lower energy input compared to full thermal recovery chains
- **Limitations:** Requires strict chemical handling protocols and generates liquid waste streams that must be carefully managed.
- **Relevance to India:** Well-suited to treat India's growing volume of LFP and NMC batteries, and increasingly seen as the most viable long-term approach for localised refining.

Direct recycling (cathode-to-cathode): This emerging method aims to preserve the battery's cathode structure (e.g., NMC or LFP) and restore it through re-lithiation or rebalancing, avoiding full breakdown into elemental form. The refurbished cathode material can be directly reused in new batteries.

- **Strengths:** Lowest energy use, preserves material value, and minimises waste.
- **Limitations:** Not yet commercialised. Requires consistent pack design and detailed battery data—conditions rarely met today.
- **Relevance to India:** As domestic manufacturing matures and standardised cell-to-pack architectures emerge — particularly for LFP chemistries — India could become a key beneficiary of direct recycling in the medium term. For example, Ace Green Recycling is building a 10,000-tonnes-per-year LFP recycling plant in Mundra, Gujarat by 2026, demonstrating near-commercial scale capability for domestic LFP recovery.

Why it matters: Choosing the right recycling process is essential to maximising material recovery, minimising environmental harm, and aligning with India's battery chemistry mix. As recycling volumes grow, India must invest in hydrometallurgical and direct recycling capacity — not just smelting — if it is to recover lithium, integrate materials into domestic cell manufacturing, and meet circularity targets.[26]

India's battery recycling ecosystem is still in the early stages of development, and a large portion of the manufacturing equipment used for recycling is imported. Current installed domestic capacity is estimated at approximately 50,000 tonnes per year.[27] This capacity is largely concentrated in mechanical shredding facilities, which enable initial material recovery but do not support high-purity refining of critical minerals. As a result, most recovered black mass is exported to international hubs — particularly in China and South Korea.[28]

Exhibit 4 Summary of key stakeholders in India's lithium-ion battery recycling sector

Company	Technology & Process	Current Capacity (in India)	Target Capacity
Attero Recycling	Hydrometallurgical; proprietary black mass refining	15,000 tonnes/year	50,000 tonnes/year
BatX Energies	Low-temperature, low pressure hydrometallurgical; dual mode black mass recovery	3,000 tonnes/year	10,000 tonnes/year
ACE Green Recycling	Zero-emissions hydrometallurgical; modular facilities	1,800 tonnes/year	10,000 tonnes/year (India and Thailand)
Li-cycle	Proprietary mechanical and chemical recycling processes	3,600 tonnes/year	50,000 tonnes/year by 2030
Lohum	Mechanical + Hydrometallurgical; integrated recycling and reuse solutions	~25,000–31,250 tonnes/year1	~125,000150,000 tonnes/year
Metastable Materials	Advanced dry recycling with zero effluents	Pilot stage	1,500 tonnes

Note: List may not be exhaustive
Source: *The Economic Times, YourStory, Recycling Magazine, AutoCar Professional, EQMagPro.*

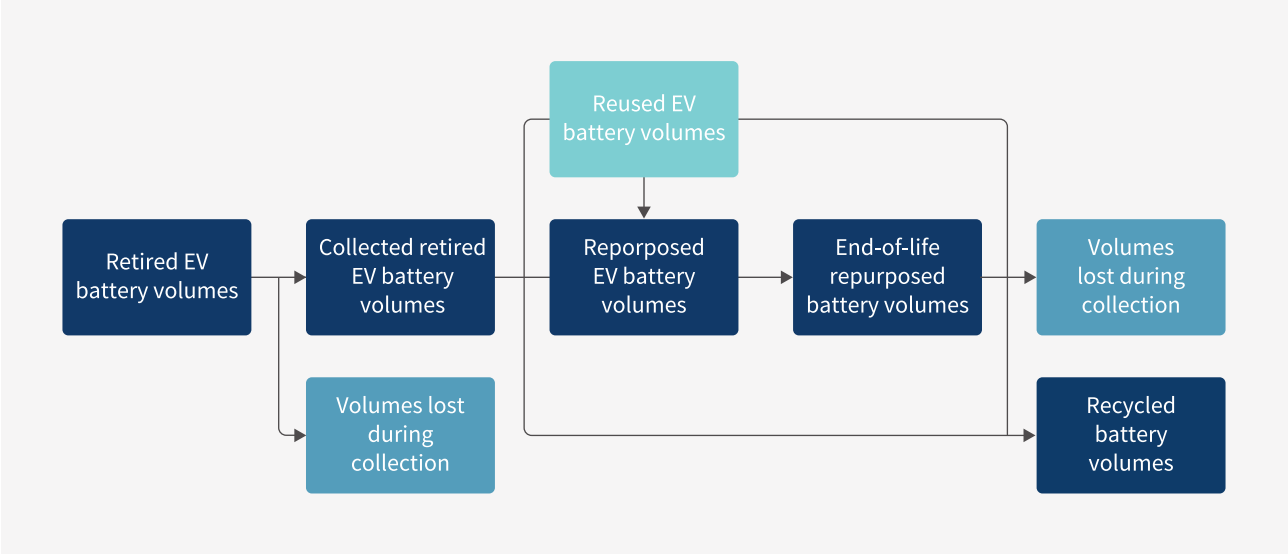
Most of India's formal recyclers currently operate at limited capacity — often below commercially viable thresholds — due to challenges in commercialising, financing constraints, regulatory delays, and inconsistent supply of battery feedstock. One of the main barriers to commercialising prototypes is the high cost of testing. Establishing government-backed or shared testing facilities could help mitigate these costs and accelerate market penetration. Permitting timelines for environmentally compliant plants also remain long, and the absence of coordinated battery collection systems creates volatility in battery feedstock availability.[29]

The ideal flow of circular pathways and balancing real constraints

Battery reuse, repurposing, and recycling are ideally sequential steps in a circular economy, each preserving value while extending a battery's useful life. Maintaining the original form factor as long as possible creates the highest efficiency and value. These activities build on one another, representing stackable layers of circular value recovery.

However, in practice, they often function as discrete decisions based on a battery's health, performance, and remaining capacity. Whether a battery is reused, repurposed, or recycled depends on its SOH, performance characteristics, and remaining energy capacity at the time it is removed from its original application. Although reuse in other mobility applications is the preferred first step, customer acceptance remains untested, and this pathway may not materialise. Furthermore, if a battery is too degraded, it may not be viable for reuse or repurposing. In either case, the battery may go directly to recycling. Exhibit 5 shows the sequence of circularity pathways and how inevitably some volumes will not be collected.

Exhibit 5 Retired battery material flowchart



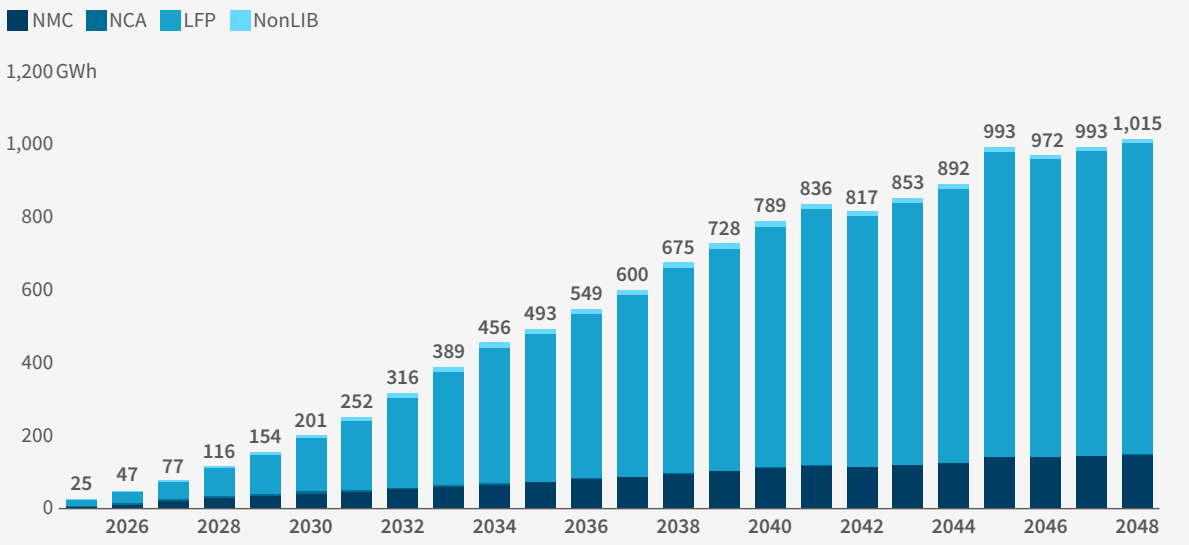
RMI Graphic. **Source:** RMI analysis

India Battery Outlook

EV adoption, which is well under way, will lead to a significant increase in battery demand. A substantial share of battery demand in India is expected to stem from the adoption of EVs, a shift that is already well underway. In 2024, EV sales surpassed 2 million units, accounting for 7.7% of new vehicle sales and reflecting a 25% year-on-year increase.[30] Continued growth in this sector is not only expected but essential to achieving India's national decarbonisation goals. *India at 2047: A Vision for Energy Independence in the Mobility Sector* outlines the pace of EV adoption required across segments to meet India's 2047 energy independence targets. The report outlines the sales targets required to achieve India's vision for energy independence: 100% EV penetration by 2030 for two- and three-wheelers, by 2036 for four-wheelers and light goods vehicles, by 2040 for buses, and by 2043 for medium- and heavy-duty trucks.[31] This trajectory highlights a rapid uptick needed in EV adoption that will translate to increased battery demand.

India's annual battery demand, currently around 25 GWh, is projected to grow more than 40-fold to 1,080 GWh by 2050, driven primarily by EV adoption.[32] The analysis is based on the *India at 2047: A Vision for Energy Independence in the Mobility Sector* energy-independent scenario outlined above, which reflects an ambitious trajectory for EV adoption that will drive battery demand volumes as depicted in **Exhibit 6**.

Exhibit 6 Battery demand forecast by battery chemistry



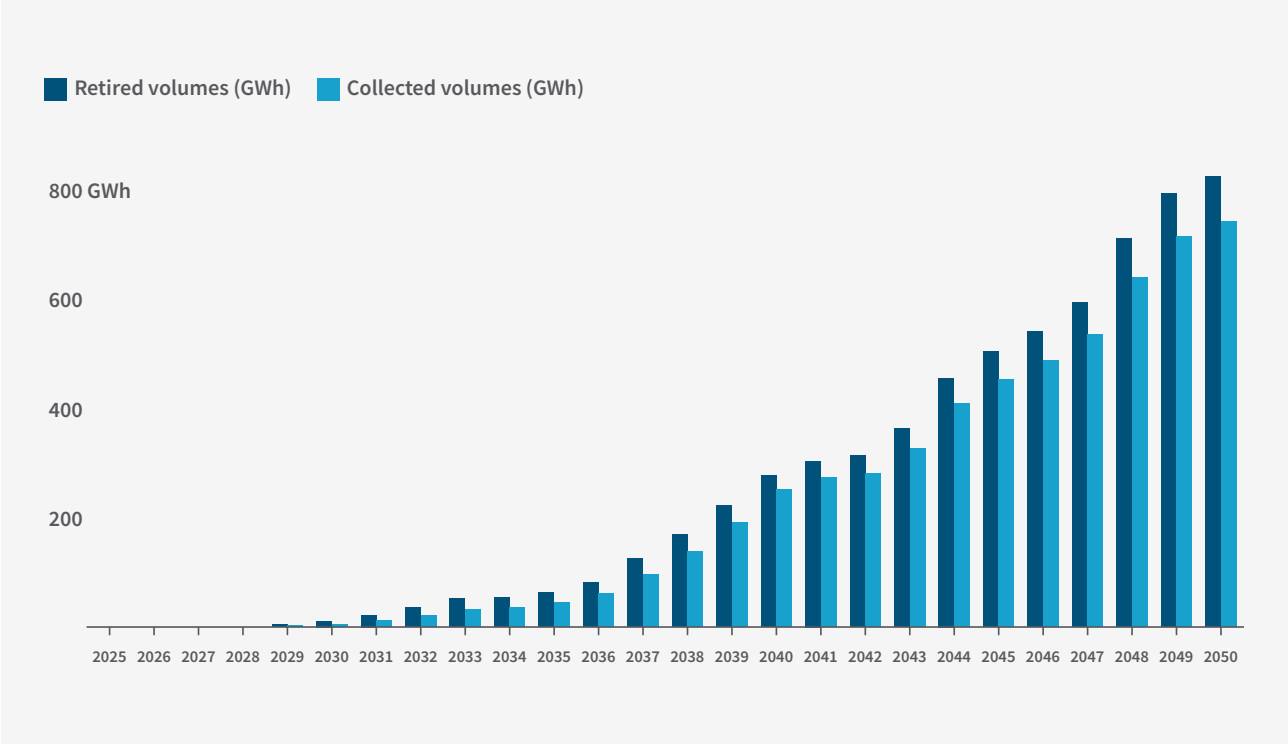
Note: The names of the differing battery chemistries denote the key minerals that make up the battery cathode: nickel manganese cobalt (NMC), lithium iron phosphate (LFP), nickel cobalt aluminium (NCA), non–non-lithium-ion battery (NonLIB). While the overall volume of EOL batteries increases over time, our modelled output shows a few noticeable dips, particularly around 2042 and 2046. These dips result from the way battery lifetime improvements are incorporated into the model. Specifically, to reflect macro-level trends, the model applies stepwise improvements in battery lifespan across certain vehicle segments. This approach introduces sudden drops in projected EOL volumes, reflecting the delayed retirement of batteries that in the future are expected to last longer. Additionally, as mentioned, the projections shown depict an energy-independent scenario where resulting battery demand is expected to reach ~1,000 GWh by 2047. In contrast, under a business-as-usual pathway, battery volumes are projected to reach only 40%–50% of this 2047 expected battery demand.

RMI Graphic. **Source:** RMI analysis, *India at 2047: A Vision for Energy Independence in the Mobility Sector*

As battery demand accelerates, so does the opportunity to recover valuable materials from used EV batteries through repurposing and recycling. Although reuse may emerge as a viable circularity pathway in the future, it is not included in this outlook due to the limited availability of market data and real-world demonstrations. To assess the circularity potential of EV batteries, the analysis models their flow through three key stages: (1) retirement and collection, (2) repurposing, and (3) recycling.

Projected volumes of battery material that can be repurposed and recycled will depend largely on two factors: the average lifespan of EV batteries and the efficiency with which they are collected at the EOL. The analysis estimates the expected lifespan of EV batteries by vehicle segment — drawing on insights from the *India at 2047* report — to project when batteries will retire from their initial EV use.[33] To retain and maximise the value of used EV batteries, strengthening collection systems is critical. Without effective collection, much of the recoverable material and economic value of a used battery could be lost. This analysis assumes an initial collection rate of 50%, increasing to 90% by 2040 across all vehicle segments, to estimate the annual volume of batteries available for repurposing and recycling.[34] The gap between retired and collected volumes reflects material losses resulting from collection challenges, inadequate collection infrastructure, and improper disposal or storage.

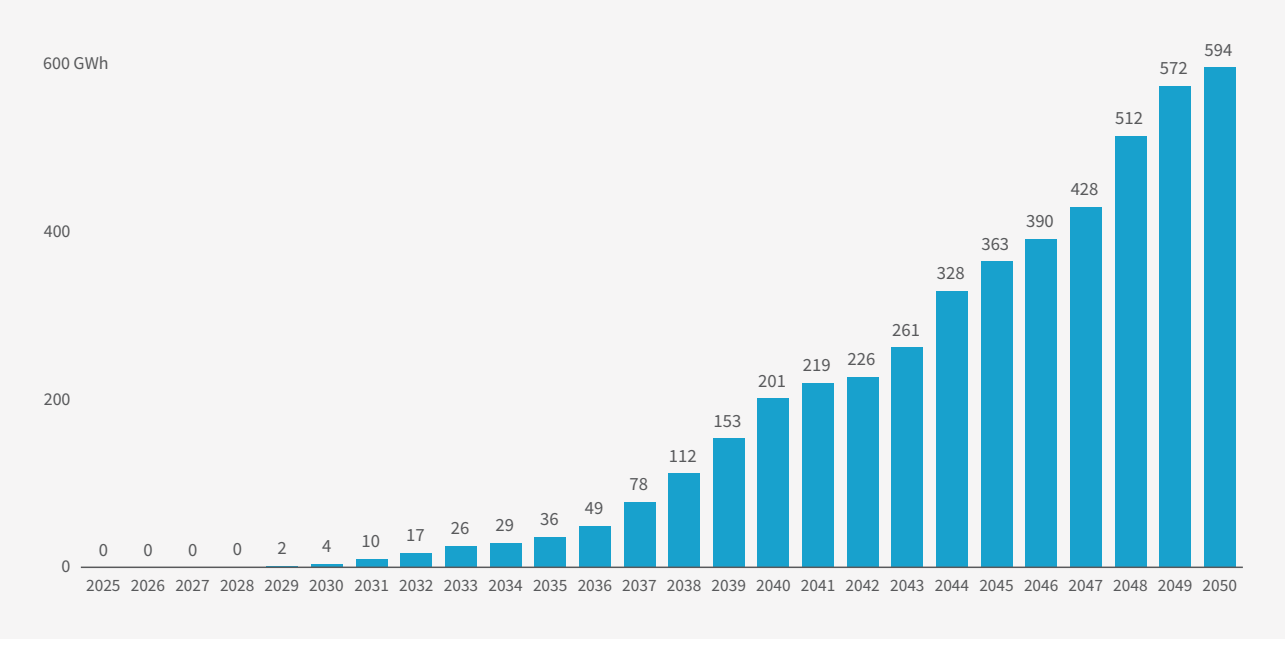
Exhibit 7 Retired EV batteries and the impact of collection loss



RMI Graphic. **Source:** RMI analysis

Batteries available for repurposing are expected to materialise by 2030. This outlook forecasts that EV batteries will first be considered for repurposing before recycling. The analysis projects that 80% of collected batteries will be repurposed, while the remaining 20% — due to damage or excessive degradation — will be sent directly to recycling. Based on these parameters, substantial volumes of used EV batteries will not be available for repurposing until around 2030, when the first wave of EVs sold between 2020 and 2024 begin to retire.[35] Annual volumes are projected to grow from 4 GWh in 2030 to nearly 600 GWh by 2050.[36]

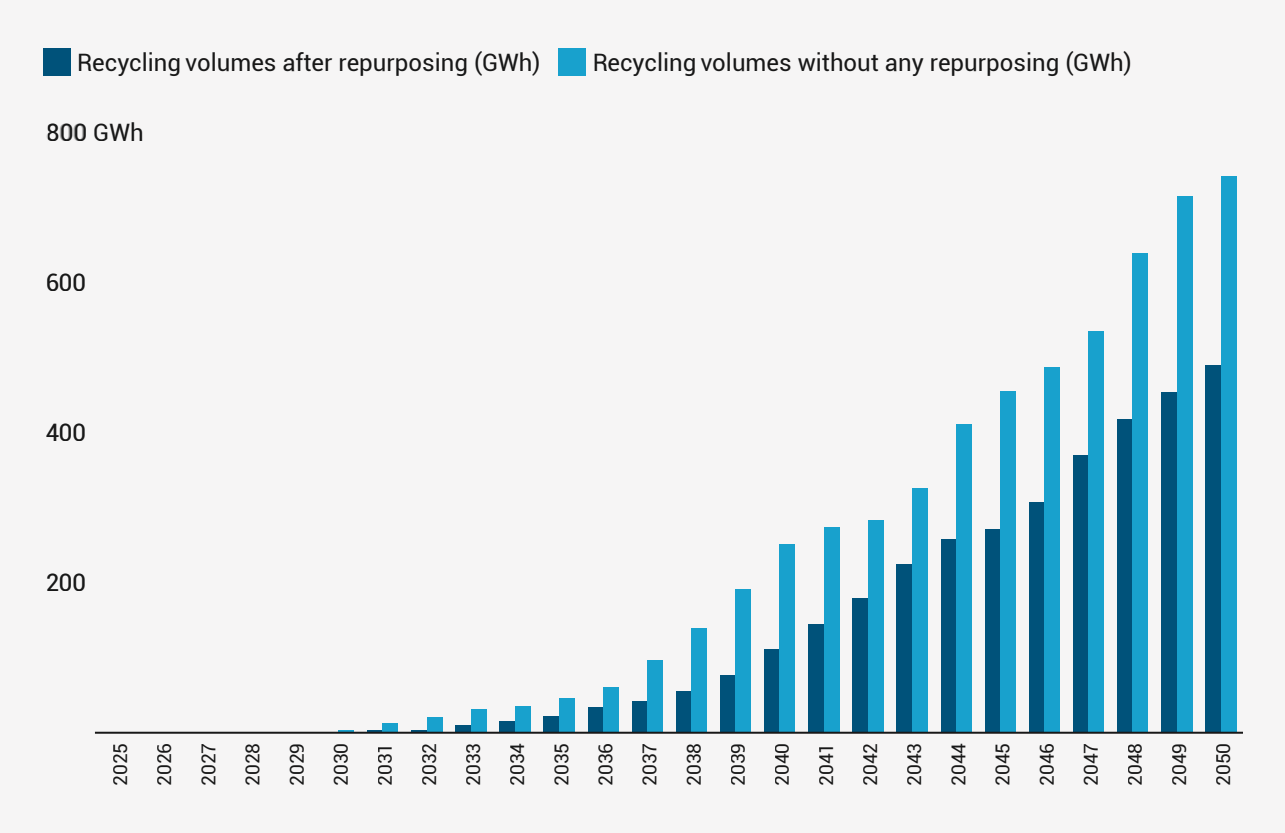
Exhibit 8 Repurposing battery volume summarised as year-over-year inflows



RMI Graphic. **Source:** RMI analysis

Repurposing extends a battery's usable life by three to five years. Repurposing postpones batteries entering recycling feedstocks. This effect is shown in Exhibit 9, which depicts two scenarios: the first is where batteries are recycled immediately after collection, with no repurposing. In the second, which is reflected in this outlook, batteries are repurposed before they need to be collected again and eventually recycled. The model assumes 20% of repurposed batteries are not recovered for recycling due to collection inefficiencies.[37] Thus, repurposing EV batteries sequentially before recycling affects the timing of battery recycling inflows and also the total volume of recycled content over the long term.

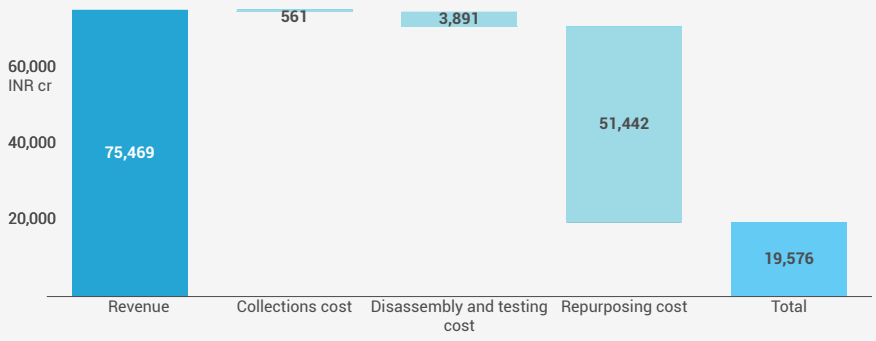
Exhibit 9 Estimated volumes of EV batteries entering the recycling stream



RMI Graphic. **Source:** RMI analysis

Repurposing batteries can generate ₹19,576 crores in economic value annually by 2050. India's battery repurposing market is still in its early stages, with limited available data. This analysis estimates its potential based on expert input, stakeholder interviews, and a step-by-step modelling approach (detailed in **Appendix B**). To estimate economic potential, we projected both the costs and revenue associated with repurposing. Costs were broken down into three main categories: (1) collection; (2) disassembly, testing, and component replacement; and (3) repurposing (reassembly) costs. These costs are expected to decrease over time as the industry gains experience and scales; thus, a 10% cost reduction for every doubling of repurposed battery volume was modelled.[38] Revenue was estimated using BloombergNEF's battery price forecasts.[39] The model then sought to adjust for consumers' willingness to pay for used batteries and the slightly degraded efficiency of used batteries.[40]

Exhibit 10 Annual profitability repurposing in India

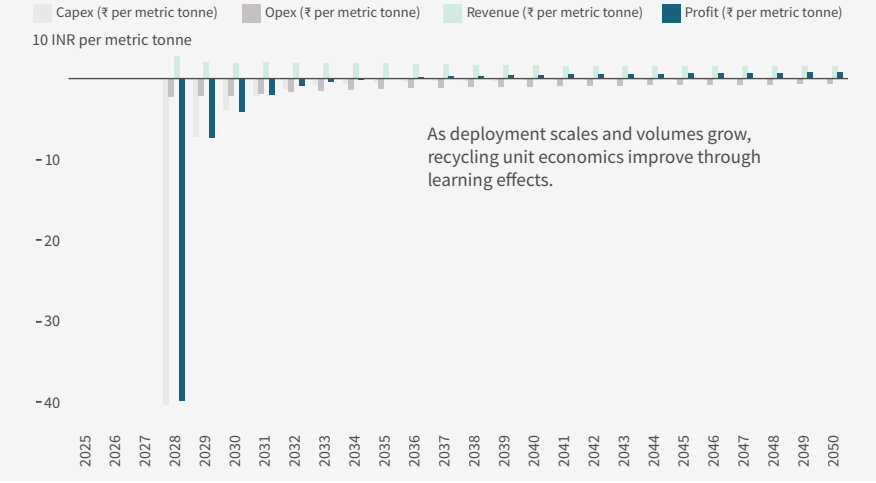


Note: This scenario depicts a 10% log-linear learning rate.
RMI Graphic. **Source:** RMI analysis

The economics of battery recycling hinge on chemistry, scale, and time, factors that may align as volumes increase. The model assesses the economic benefits of recycling by comparing current costs, projected cost reductions, and potential revenue streams. Costs include battery collection, transportation, and facility processing per tonne of feedstock. As the industry scales and gains operational experience, these costs are expected to fall. A 10% cost reduction with each doubling of processed battery volume was modelled to reflect hypothesised learning and efficiency improvements.[41]

Revenue is generated from the sale of recovered materials, including lithium, nickel, and cobalt. At current low volumes, recycling is not yet a profitable endeavour. However, the economics improve significantly at scale, and returns could begin as early as 2033.

Exhibit 11 Recycling profitability per unit volume of recycling



Note: This scenario depicts a 10% log-linear learning rate.
RMI Graphic. **Source:** RMI analysis

Recycling plays a vital role in reducing India's reliance on mineral imports. By 2050, recycling could supply more than 40% of the country's lithium and 48% of the country's nickel and cobalt demand through mineral recovery, directly reducing the need for virgin resource extraction.[42, vi]

Exhibit 12 Mineral demand met by recycling

Lithium

	2025	2030	2035	2040	2045	2050
Lithium demand (metric tonnes)	2,848	23,365	55,379	85,949	106,050	114,167
Lithium recovered (metric tonnes)	0	83	1,861	10,394	25,641	46,962
Lithium demand met by recycling (%)	0	0	3	12	24	41

Nickel

	2025	2030	2035	2040	2045	2050
Nickel demand	5,360	30,017	46,689	70,022	87,766	95,334
Nickel recovered	0	214	3,655	10,919	22,198	45,546
Nickel demand met by recycling	0	1	8	16	25	48

Cobalt

	2025	2030	2035	2040	2045	2050
Cobalt demand	770	4,079	5,998	8,935	11,158	12,109
Cobalt recovered	0	32	519	1,455	2,870	5,856
Cobalt demand met by recycling	0	1	9	16	26	48

RMI Graphic. **Source:** RMI analysis

India has relatively strong reserves of aluminum and iron, it remains highly import-dependent for critical battery metals such as lithium, cobalt, and nickel. Although recent lithium reserves have been identified, these are not yet under commercial extraction. This reinforces the need for recycling strategies that prioritize recovery of scarce, high-value materials, ensuring supply security until domestic production can be scaled.

vi Figures directly correlated to the estimated collection rates described in Appendix C.

vii For example, although battery mineral extraction and cell manufacturing often take place outside of the EU, the EU's Battery Regulation requires accounting for the embedded carbon footprint of batteries sold within the EU market.

Recycling can create more than 106,000 jobs while also reducing emissions and conserving resources.[43] Recycling generates local economic benefits, particularly through job creation and support for regional industries. In contrast, the benefits of reduced resource extraction — such as decreased land disturbance and habitat disruption — are realised in the regions where virgin materials are mined. Although these environmental gains may not directly affect the recycling region — India — they are increasingly relevant to end-use markets, where the embedded environmental footprint of products is regulated.[vii]

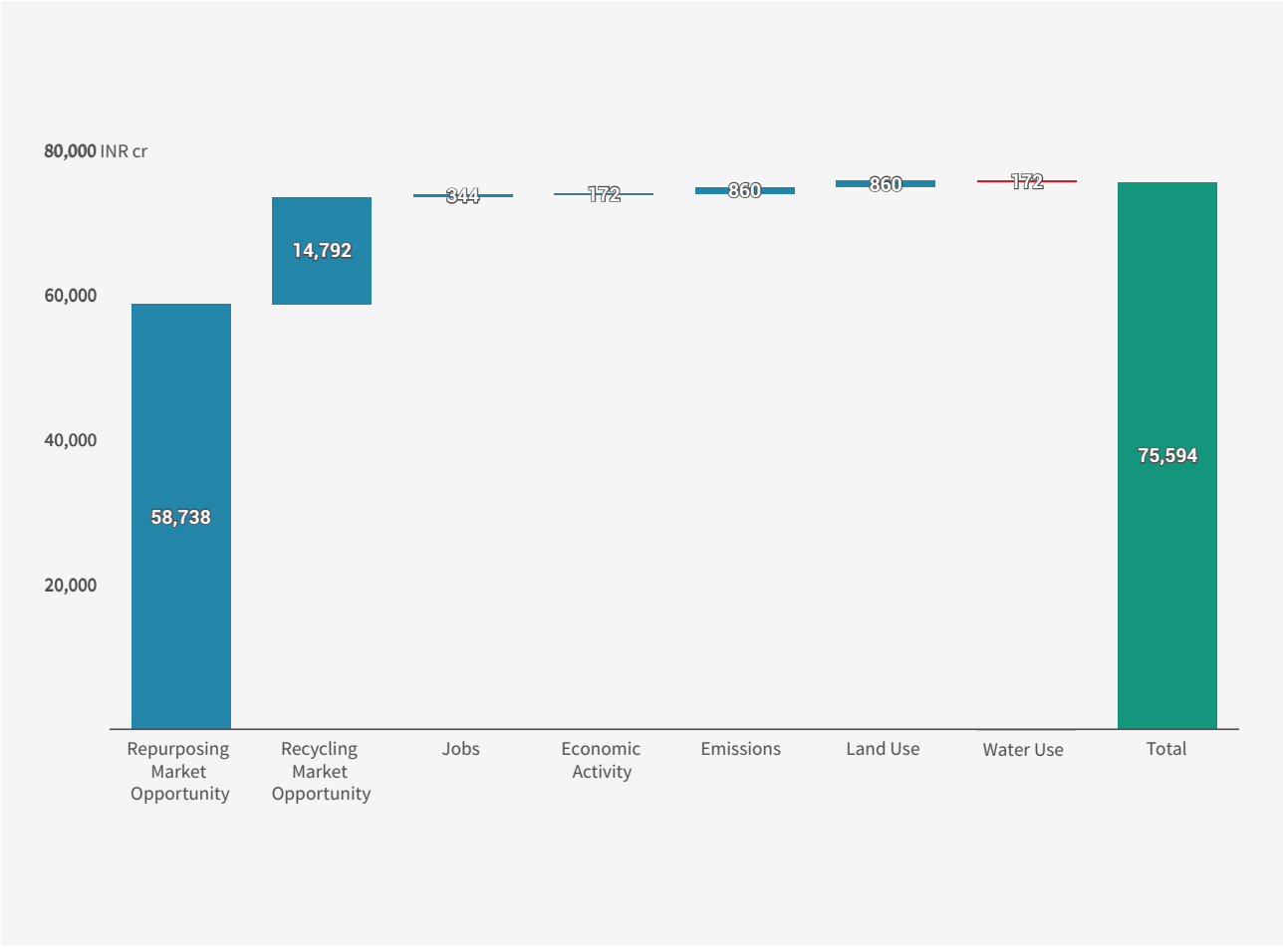
Exhibit 13 Battery recycling by 2050: Impact statistics

Impact	Description
Additional jobs: 106,000 full-time by 2050	Employment is generated through the operation of battery shredding and metallurgical recovery facilities. These direct jobs also stimulate broader economic activity through wage spending and supply chain effects, measured using gross domestic product impact multipliers.
Emissions reduction: 2.9 million tonnes of CO2	Recycling has a lower carbon footprint than mining and processing virgin minerals. Avoided emissions are calculated based on the difference in life-cycle emissions between recycled and mined materials.
Reduction of land use: 16,810 acres	Mining critical minerals, such as lithium, nickel, and cobalt, requires extensive land use, often in ecologically sensitive areas. Recycling, conducted domestically, has a much smaller footprint.
Additional water usage: 2.2 billion gallons	Recycling can consume more water than mining, depending on the water intensity of mining, the refining and recycling technology deployed and the minerals being recovered.

RMI Graphic. **Source:** RMI analysis

The combined value of repurposing, recycling, and related socioeconomic benefits defines the total layered value of battery circularity, representing a market opportunity of ₹75,500 crore by 2050. Exhibit 14 depicts repurposing returns, followed by recycling returns and then the monetised social and environmental benefits. Repurposing creates an additive, not duplicative, value. It does not replace recycling, but rather delays it, allowing batteries to serve a second life before being recovered as materials. This extends the total energy throughput of the original battery investment, lowers the per-kWh embodied emissions, and unlocks economic sectors, such as stationary storage, that can benefit from the battery repurposing market.

Exhibit 14 Net present value of repurposing and recycling forecasted returns (2025–50), social and environmental value



Note: Economic activity refers to spending associated with wages. The economic opportunity of repurposing is quantified, but job creation, economic activity, emissions cuts, and land use savings are only shown from recycling, given the limited data available on repurposing and challenges in discerning additionality.

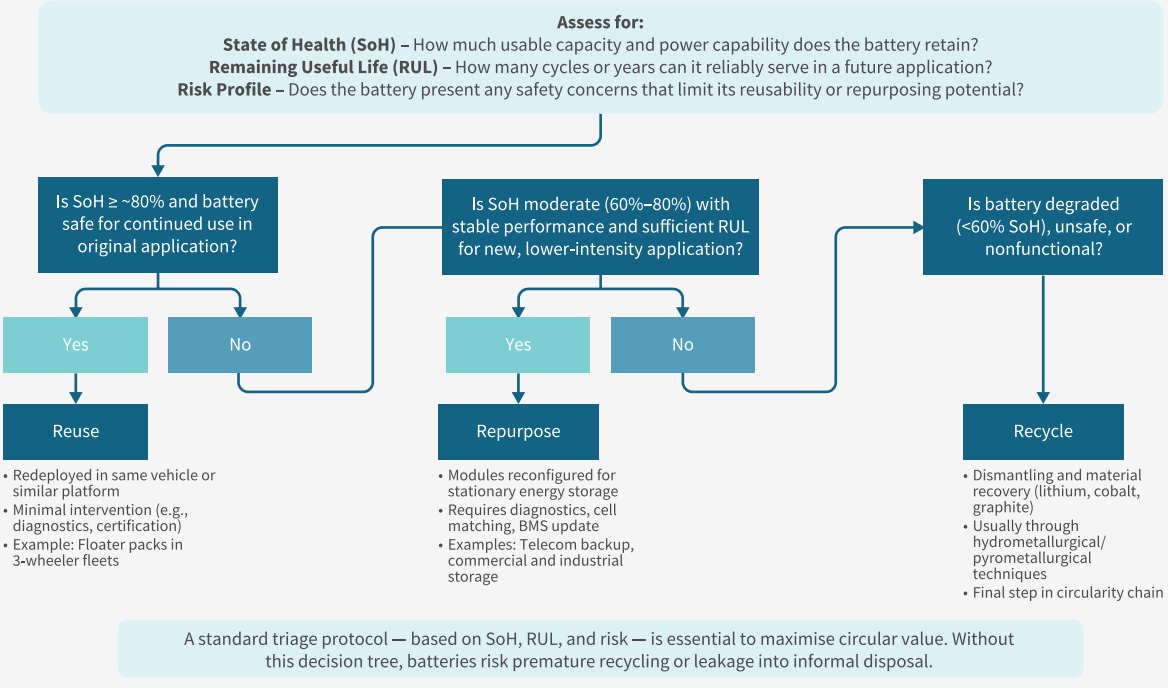
RMI Graphic. **Source:** RMI analysis

Enabling Battery Circularity

Decision framework

Designing a viable circular battery ecosystem is not about maximising one lever — reuse, repurposing, or recycling — but about intelligently routing batteries to their optimal use. This involves creating a decision-making framework that can be tailored to various use cases by combining tools such as diagnostics, common standards, data, and supporting infrastructure to guide the optimal retention of battery value and minimise inefficiencies and unnecessary battery discarding. In some cases, repurposed batteries can even have a third life, particularly when individual cells with residual capacity are harvested and used in ultra-low-demand applications such as solar-powered streetlights, hand tools, or emergency torches. Although such opportunities are highly use-case-specific and opportunistic, they can still offer greater economic and environmental value than immediate recycling, especially for chemistries like LFP that have limited material recovery value.

Exhibit 15 Battery End-of-Life Triage Framework: Reuse, Repurpose, or Recycle



RMI Graphic. **Source:** RMI analysis

Together, these elements create a decision-making framework that directs each battery to the most appropriate circularity pathway — reuse, repurposing, or recycling — based on its condition, safety, and market potential.

Enabling architecture

Achieving battery circularity in India requires confronting a complex set of interlinked challenges. Nascent regulatory frameworks (such as emergent tracking mechanisms), limited incentives to discourage premature battery disposal, and uneven enforcement can stall momentum. Profitability in repurposing and recycling remains constrained this decade, which makes financing even more challenging, pending greater economies of scale. A more resilient and circular supply chain will also depend on strengthening the domestic midstream and introducing targeted incentives to promote the local use of recycled content. Without these measures, recovered battery materials may be exported, diminishing their value to domestic manufacturing and mineral security. Today, the battery ecosystem is fragmented, with OEMs, fleets, recyclers, and financiers operating primarily in isolation. Although these hurdles, detailed further in Appendix A, are real, so too is the opportunity for circularity to create monetisable value, enhance battery value chain resilience, and unlock new pathways for sustainable industry growth. With the right policy, market, and institutional support, India can lead in shaping a robust circular battery economy.

Realising battery circularity at scale in India requires a coordinated transformation across policy, traceability, financing, technology development, and workforce development. Policy must shift from compliance to value retention. Traceability must be established, not just for compliance, but to retain value and ensure accountability across the system. Financing must evolve to serve diverse, distributed actors and technologies at differing levels of commercialisation. Technology must be modular, traceable, and circular by design. The workforce must be equipped with tools and training to facilitate this transition. Together, these shifts can build a circular battery economy that enhances mineral security, strengthens domestic manufacturing, and delivers inclusive economic benefits. The following subsections outline how each enabler supports one or more circularity pathways — reuse, repurposing, and recycling — and where targeted action can deliver the most significant impact.

Policy

Policy is crucial to scaling battery circularity, shaping the incentives, standards, and coordination necessary to retain value throughout the battery life cycle. There is a foundational policy framework in place via the NCMM to support battery circularity, and the Indian government has expressed clear interest in advancing sectoral growth. However, the primary challenge lies in coordination across agencies and stakeholders. Although supportive policies, such as the Battery Waste Management Rules (BWMR), exist, there are gaps in policy that effectively supports the ecosystem on a systemic level, and there is at times uneven enforcement of existing policies, limiting their overall effectiveness. This section outlines the current policy landscape, highlighting emerging efforts, opportunities to address gaps, and additional recommendations to strengthen India's circular battery economy policy regimen.

BWMR introduced EPR and digital tracking for EOL batteries, marking a shift towards formalised accountability for managing batteries. Under these rules, an entity that manufactures, sells, or imports batteries is defined as a producer and is responsible for ensuring safe disposal of

EOL batteries by collecting, refurbishing, or recycling a percentage of the total battery volume delivered to the Indian market in a given year,[viii] with targets set at 70% by 2024–25, 80% by 2025–26, and 90% from 2026–27 onwards,[ix] as per Schedule II of the BWMR.[44] These obligations are fulfilled through authorised recyclers and refurbishers and verified via EPR certificates. To support this effort, the Central Pollution Control Board (CPCB) launched an EPR portal in 2023 to register producers, recyclers, and refurbishers. The portal tracks battery volumes self-reported by producers and records the quantities of refurbished or recycled batteries from registered entities, measured in dry weight.[45]

Announced in the 2024–25 Union Budget, NCMM is a seven-year initiative running through FY 2030–31, aimed at mobilising ₹16,300 crore to support battery mineral exploration, processing, recycling, and value chain development. Of that, ₹1,500 crore is dedicated to incentivising recycling (i.e., setting up recycling facilities and supporting infrastructure) with a targeted scale of recycling capacity to process 400 kilotonnes by 2030.[46]

Additional policies or frameworks that affect battery circularity are as follows:

- PLI scheme: India's PLI scheme for ACC batteries incentivises 50 GWh of domestic cell manufacturing capacity. [47]
- State EV policies: Several Indian states (e.g., Tamil Nadu, Maharashtra, Karnataka) have EV policies that mention battery recycling infrastructure, and a few are beginning to explore reuse or second-life storage pilots.[48]
- Vehicle scrappage policy: Establishes protocols for EOL vehicle handling,[49] which can serve as a gateway for recovering used batteries and redirecting them into second-life or recycling pathways.
- Battery Aadhaar: Tata Elxsi — working with NITI Aayog and United Nations Environment Programme — has launched the Battery Aadhaar initiative. This blockchain-based traceability system records ownership history to build transparency across the battery life cycle.[50]

Refining existing policy schemes

India has laid the groundwork with a solid policy ecosystem. Targeted updates can embed circularity more deeply, support adaptive implementation, and enable decisions grounded in real-world performance and system feedback. Policy measures include:

- Minimum recycled content in public incentive and procurement schemes: Integrating minimum recycled content requirements into industrial schemes like the PLI for ACCs and public procurement frameworks would establish firmer demand for recycling. This would

viii Refurbishment is a specific term defined in the rule as repairing, reconditioning, and repurposing for second life.

ix These targets are calculated based on the total quantity (by weight) of batteries placed in the market in a given year. Producers are required to ensure that the corresponding percentage of these batteries is collected and processed through authorised recycling or refurbishment channels.

increase demand for secondary materials in battery manufacturing and energy storage projects. However, time-bound targets must be carefully designed to ensure they align with the availability of the domestic recycled mineral supply. Without this, such targets could lead to unintended consequences, such as increased reliance on exports or unsustainable practices. The Ministry of Heavy Industries (MHI) could undertake such an initiative.

- Regulatory adjustments to BWMR: The following recommendations can be considered to strengthen the existing framework:
  - The rules should have a value-additive approach by prioritising reuse and repurposing before recycling.
  - The regulatory framework should introduce the concept of shared or transferable producer responsibility. Under this model, verified second-life operators — such as reuse or repurposing firms — would inherit EPR obligations once a battery is reused or repurposed. This would extend accountability beyond the first use cycle, incentivise second-life business models, and support compliant, trackable circular flows.[51]
  - EOL should not only be defined, as it currently is, in a time-bound manner in the BWMR rules rather than being based on SOH, real-time diagnostics, and verified safety indicators. Revisions would enable batteries to remain in service longer when safe and viable, thereby supporting reuse and repurposing opportunities.
  - Certification and empanelment under EPR must be expanded beyond recyclers to include qualified repurposers to enable a more circular approach. Currently, very few, if any, second-life battery refurbishers are formally registered as eligible entities to receive used batteries and claim EPR credits. As a result, OEMs have little incentive to sell or transfer EOL batteries to repurposers because only recyclers are recognised under the existing framework. This effectively excludes refurbishers from participating in the EPR ecosystem.
  - Vehicle OEMs should have an incentive to meet EPR obligations directly by leveraging their existing dealership and service centre networks to collect batteries, given their direct customer relationships and potential interface as a collection hub. These revisions should be considered by the Ministry of Environment, Forest and Climate Change (MoEFCC). The CPCB, as the implementing agency, could be tasked with operationalising these changes through updated guidelines and compliance mechanisms.
  - Obligations for end-users — including OEMs, fleet operators, and individual consumers — to dispose of used battery packs through registered, authorised entities should be strengthened. Enhancing and enforcing traceable disposal pathways can help ensure responsible material recovery and improve environmental compliance.

Establishing standards to promote battery circularity

Clear and uniform standards would provide market clarity, support coordinated industry development, support interoperability, and uphold safety and environmental safeguards, ultimately boosting confidence in battery reuse, repurposing, and recycling. Recommendations to consider include:

- Embed circularity in battery design standards: Most batteries sold today are not designed for safe disassembly, diagnostics, or second-life use, limiting the viability of repair, reuse, and recycling. India should embed design for circularity (DfC) into manufacturing and

import standards through the Bureau of Indian Standards (BIS), including requirements like repairability, modular architecture, clear labelling, reprogrammable BMS, and access to diagnostic data. Linking these standards to PLI eligibility, resale classification, and import approvals will ensure circularity is built into battery design from the start.

- Establish certification standards for second-life batteries: India should draw on international frameworks such as UL 1974, known as the standard for evaluation for repurposing batteries. This US engineering standard details processes for testing and evaluating used batteries to determine their suitability for secondary use.[52] This should include standards for SOH thresholds, electrical reconfiguration, and thermal management. Currently, neither the BIS nor the BWMR provide such guidance. In the absence of enforceable norms and diagnostic infrastructure, repurposing carries elevated risks, including uneven module performance and potential safety hazards, such as thermal runaway. The Automotive Research Association of India (ARAI) could undertake such efforts in collaboration with BIS.
- Establish a national certification framework on battery diagnostics and grading: Certification informed by industry inputs should provide a standardised diagnostic and grading system for used batteries. This certification, issued by an authorised body such as BIS, could assess batteries based on verified SOH and safety indicators using a standard grading scale (e.g., A, B, C). These grades can then be linked to warranty tiers and resale price bands, offering clarity and consistency in the second-life battery market to support and expand reuse and repurposing opportunities.
- Introduce a right to repair and repurpose: To enable safe and scalable second-life use, OEMs should have a standard disclosure framework on cell-level degradation data and allow secure reprogramming of BMS via standardised software interfaces. This will reduce information asymmetry, empower refurbishers, and support a competitive market for reuse and repurposing. The Ministry of Consumer Affairs could potentially establish this right through regulation to help unlock higher-value circularity pathways while ensuring safety and traceability.

Retaining value through domestic black mass processing and trade rules

Phasing in disincentives on black mass exports will help retain critical materials within the country. One way to do that is:

- Regulate black mass export: Black mass exports should be controlled, and over time incremental thresholds should be put in place in alignment with the buildout of domestic refining capacity. For this to work effectively, it needs to be paired with public investment and policy incentives for domestic midstream development, such as refining, precursor production, or cathode integration. This could potentially be undertaken by the MoEFCC and the Ministry of Commerce and Industry.

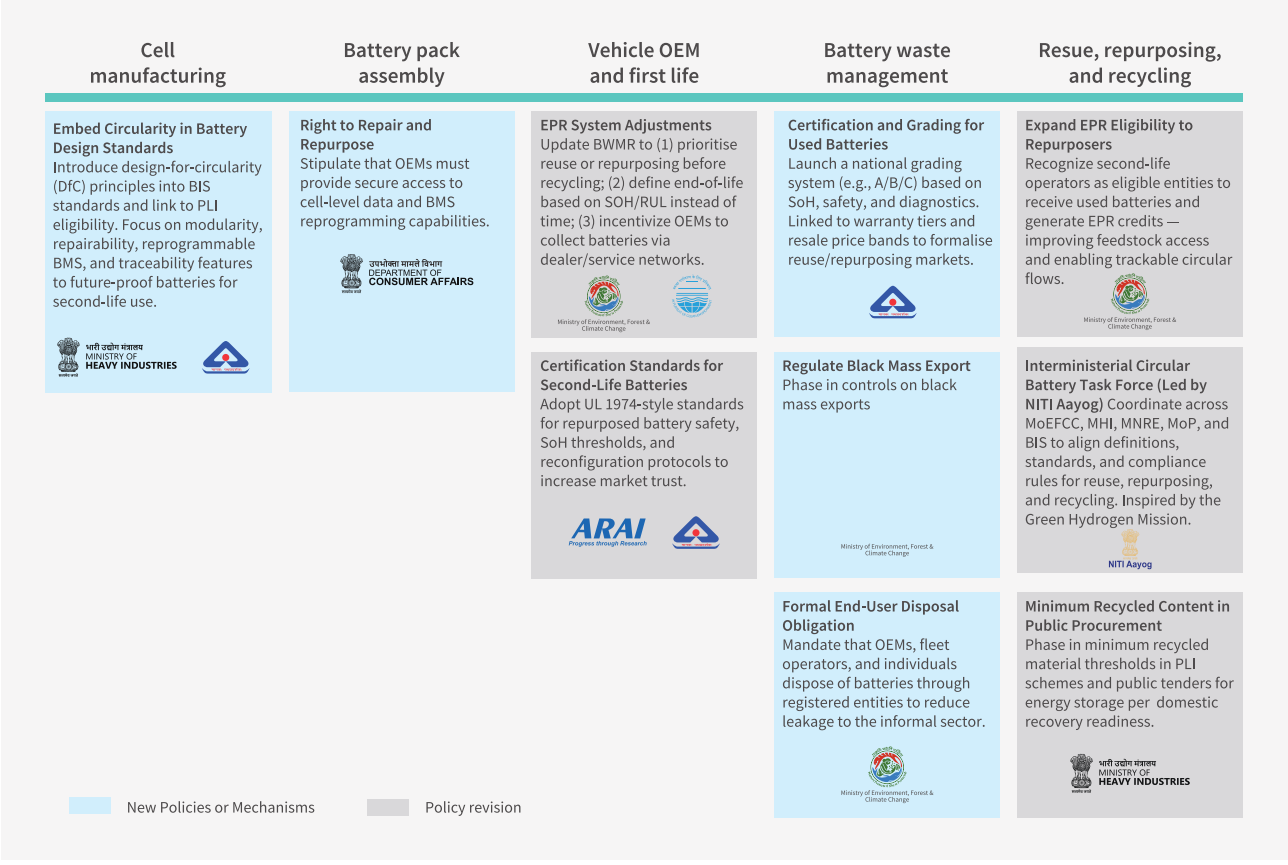
Cross-agency coordination

Battery circularity spans multiple ministries; however, current regulations, subsidies, and tenders often lack aligned definitions and performance thresholds for batteries. One way around that is:

- Interministerial circular battery task force: An interministerial circular battery taskforce led by NITI Aayog and comprising MoEFCC, MHI, Ministry of New and Renewable Energy, Ministry of Power, and BIS could be established to advise on policy coherence, publishing joint guidelines on reuse, repurposing, and recycling, and harmonising data standards across compliance and incentive programmes. Such efforts could lay the groundwork for a unified national circularity strategy and support circularity project implementation.

Exhibit 16 outlines key policy interventions across the battery life cycle, from cell manufacturing to EOL management. The headers represent value chain stages and interventions are colour-coded: blue for new policies or institutions and grey for revisions to existing frameworks. Logos indicate the lead government agency, and brief titles summarise each recommendation. Together, these actions form a coordinated policy architecture to scale battery circularity in India.

Exhibit 16 Summary of key policy recommendations



RMI Graphic. **Source:** RMI analysis

Traceability

Traceability refers to the ability to track a battery and its materials across the entire life cycle, from mineral extraction to manufacturing, usage, and EOL management. In the context of battery circularity, traceability plays two essential roles. First, it ensures accountability by tracking how battery materials are sourced, used, and ultimately managed at the end of their life. Second, it helps close information asymmetries by providing stakeholders — such as OEMs, recyclers, and second-life providers — with reliable data to determine whether a battery should be reused, repurposed, or recycled.

From a policy perspective, traceability is a critical enabler of effective regulation. Without a reliable method to track battery ownership and responsibility, enforcing EOL management rules becomes challenging. Traceability supports compliance while also creating the transparency needed to build market confidence, particularly for reuse and repurposing. A leading example of traceability supporting policy implementation is the EU's introduction of digital product passports (DPPs) under its 2024 Battery Regulation. Starting in 2027, every battery placed on the EU market must include a DPP, accessible via QR code on the battery pack. These DPPs will collect and store life-cycle data to facilitate circularity, alongside a focus on mineral origin and embodied emissions.[53]

Robust traceability enhances decision-making across the battery value chain, from determining if a battery should be reused, repurposed, or recycled, to verifying safety for resale or warranty eligibility. It enables producers to meet compliance requirements, empowers refurbishers to assess value, and allows regulators to enforce standards. Ultimately, traceability ensures that circularity is not just a technical possibility, but a trusted and scalable market reality.

Battery Aadhaar builds on the global battery passport framework but is designed to address India-specific challenges, such as integrating the informal sector and managing variable data access. Launched in May 2025, the platform provides each battery with a secure digital identity, enabling end-to-end life-cycle traceability, from raw material sourcing to reuse, recycling, and final disposal. Developed by Tata Elxsi and a consortium of partners, Battery Aadhaar aims to enhance regulatory compliance, safety, and environmental stewardship by capturing and sharing key data, including manufacturing origin, usage history, and material composition.[54] Although it shows strong promise, detailed insights on its real-world implementation are still forthcoming.

Recommendations to strengthen the Battery Aadhaar framework include

- Provide degradation metrics: The framework should capture key battery health indicators — such as cycle count, depth-of-discharge history, and SOH — to enable better reuse and repurposing decisions.
- Integrate with BMS: Full integration with BMS is critical to ensure real-time, continuous data capture throughout the battery's life cycle.
- Enable public access through a digital portal: Data collected should be made accessible via a verifiable third party to ensure some degree of accountability, either embedded within the

CPCB compliance system or linked to a national traceability portal to support transparency, reporting, and stakeholder coordination.

India's emerging battery intelligence ecosystem is being catalysed by a new wave of startups developing diagnostics and traceability platforms. These companies aim to provide services that support better decision-making for second-life batteries, enhance operational safety, and establish the necessary infrastructure for circularity at scale.

Exhibit 17 Landscape of startups and their funding

Company	Focus Area	Recent Milestone
Nunam	Specialises in second-life battery systems for energy access. Uses machine learning based grading and SOH estimation to assess the potential of retired EV batteries for reuse and repurposing.	Funded by the Audi Environmental Foundation, piloting second-life battery energy storage systems for rural electrification in India.
The Energy Company (TEC)	Offers a full-stack artificial intelligence(AI)-driven battery platform ("Flexi") that monitors SoH, thermal behaviour, and performance across use cycles.	Raised $2M Pre-Series A in 2024 from Siana Capital to expand battery analytics and traceability across India.
BatteryOK/ EV Doctor	Has developed a portable AI based diagnostic device ("EV Doctor") that assesses battery health, safety, and capacity in under 15 minutes.	Deployed at independent EV service centres; featured in national media as a low-cost tool for resale diagnostics.
Battery Smart	Operates a nationwide batteryswapping network for erickshaws and two-wheelers. Tracks battery health using in house data and telemetry to optimise lifecycle and enable reuse.	Raised $50 million+ in Series B in 2023–24, part of which is focused on analytics and battery life extension.

RMI Graphic. **Source:** Audi company website (Nunam), https://www.audi-umweltstiftung.de/en/home-of-greenovation/greenovation-projects/nunam/; YourStory (The Energy Company), https://yourstory.com/2025/02/energy-company-bags-2m-pre-seriesa-funding; Better India (BatteryOK), https://thebetterindia.com/424375/ev-doctor-ai-battery-testing-shubham-mishra-ajay-vashisht-batteryok-technologies-battery-safety/; Economic Times (Battery Smart), https://economictimes.indiatimes.com/tech/funding/battery-smart-raises-33-million-in-funding-from-tiger-global-blume-ventures-others/articleshow/101534542.cms

Recommendations for strengthening India's battery intelligence ecosystem

Despite its strong potential, India's battery intelligence ecosystem lacks a centralised framework for documenting and standardising outcomes. Without regulatory requirements, participation and robust traceability remain fragmented. Traceability becomes valuable — and market-enabling — only when industry actors follow a common, standardised approach to tracking a battery's life cycle.

Currently, multiple voluntary initiatives led by different technology actors result in a piecemeal system that does not address the full scope of needs. To avoid this fragmentation, India should pursue public–private partnerships to develop and scale unified standards. For example, in the EU, the implementation of battery passports has been driven by regional regulations, prompting

public–private consortia, such as the Global Battery Alliance and Battery Pass, to collaboratively define compliance metrics and data reporting standards. These efforts encompass contributions from industry, nonprofit organisations, and government stakeholders. India should build on these global conversations and adapt lessons to its local context. Establishing alignment with international best practices while accounting for domestic needs — such as integrating the informal sector — will be key.

Additionally, India lacks a consistent method for measuring the impact of diagnostic tools and traceability systems on battery reuse rates, safety, and lifespan. Addressing this evidence gap will require a platform or protocol to systematically capture, evaluate, and report the impacts across various use cases. This infrastructure is crucial for demonstrating how traceability supports circularity and unlocks economic value.

Financing

Advancing battery circularity in India requires targeted financial interventions, but this is not a straightforward process. Capital needs across the circularity chain are often perceived as high risk, with activities spread across a fragmented network of small and specialised players. These characteristics limit the ability of traditional lenders and institutional investors to engage at scale. Moving from isolated pilot initiatives to a nationally integrated circular economy will demand not just more capital but also a fundamentally different approach to how that capital is structured, deployed, and de-risked.

So far, India's battery circularity sector has attracted approximately ₹1300 crores (US$150 million) in formal investment, with more than 70% concentrated in battery recycling startups.[55] These companies are typically backed by patented technologies, scalable infrastructure, or international partnerships, characteristics that make them more appealing to venture and institutional investors. Moreover, recycling provides measurable returns through the recovery of high-value materials, such as lithium and cobalt, making it a more financially attractive segment within the ecosystem.

Other segments of the circularity chain — particularly battery reuse and repurposing — have received significantly less capital. These business models often lack proven scale, predictable revenues, or investor familiarity. For instance, less than 1% of collection-focused startups have secured any formal equity investment, and only 20%–40% of refurbishers have attracted external funding.[x] This disparity reflects not only investor risk perception but also structural barriers to capital access that disproportionately affect small and often informal actors.[56]

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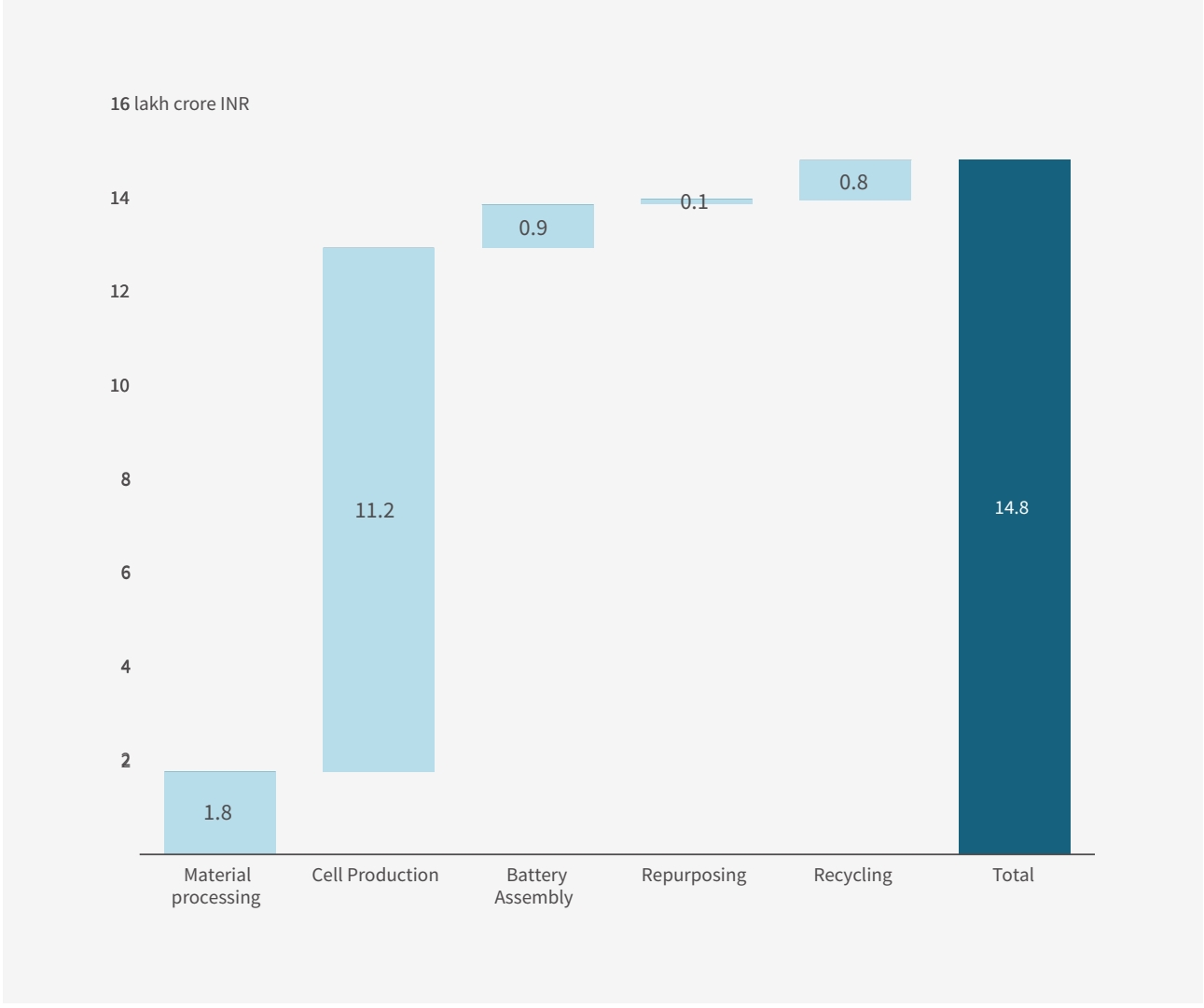
x In this report, we use the term "refurbisher" to refer to actors engaged in repurposing batteries (i.e., disassembling, testing, and reconfiguring end-of-first-life battery modules or cells for second-life applications such as stationary energy storage). While the BWMR uses "refurbisher" to describe such entities, the term is often used interchangeably with "repurposer" in industry discussions.

Meeting India's growing battery demand will require substantial investment over the coming decades. By 2030, RMI estimates that ₹2.68 lakh crore (approximately US$31 billion) will be needed to scale production and infrastructure. Looking farther ahead, this requirement is projected to rise sharply, reaching ₹14.69 lakh crore (approximately US$175 billion) by 2050 to support the expected battery demand, from material processing to recycling. Exhibit 18 depicts the battery supply chain investment needs across the value chain and Exhibit 19 depicts the incremental investment need and potential sources of capital.

Exhibit 18 Battery supply chain investment needs through 2050



Note: These figures represent the capital expenditure investments required to achieve the desired 2050 capacity. Material processing, cell production, and battery assembly are sized to meet India's battery demand by 2050. Repurposing and recycling investments are sized according to the capacity mentioned in the India Battery Outlook section. Capital intensity estimates are based on Tesla estimates (Master Plan Part 3, Tesla, April 2023, https://www.tesla.com/ns_videos/Tesla-Master-Plan-Part-3.pdf).

RMI Graphic. **Source:** RMI analysis

Exhibit 19 Battey supply chain investment deep dive (INR lakh Crore)

Segment	Capital need	Possible Sources of capital and means to implement	2030	2040	2050
Material processing	• Project equity covers high up-front costs and early risks as the technology scales in India. • To attract private investment, blended finance can combine public and commercial funds to reduce risk.	• A concessional equity platform to attract private investment is highly applicable for underserved or nascent activities. • Offtake agreements provide revenue certainty, making projects more attractive to investors by stabilising cash flow.	₹0.42	₹1.30	₹1.76
Cell production	• Cell production needs subsidies or low-interest loans due to high costs and long paybacks. • Patient capital and tools like viability gap funding can bridge early revenue gaps.	• Sovereign green bonds can fund projects directly or through fiscal incentives. • Public-private partnerships help share investment and operational risks.	₹2.08	₹8.18	₹11.16
Battery Assembly	• Battery assembly needs project equity for setup, machinery, and R&D. • Commercial debt helps scale operations to meet rising EV demand.	• Extending PLI schemes and fiscal support can accelerate battery manufacturing and attract more private investment.	₹0.17	₹0.68	₹0.93
Battery Repurposing	• Patient equity is needed for business model development. • Concessional finance helps fund infrastructure. Public procurement reduces demand risk.	• ESG and impact investors, Development Financial Institutions, and Special Purpose Vehicles (SPVs) can aggregate capital to drive impact. • Credit guarantees and concessional loans enable infrastructure deployment.	₹0.001	₹0.01	₹0.11
Battery Recycling	• High facility capex and regulatory uncertainty call for concessional finance and VGF to ensure bankability.	• Green bonds, SPVs, and development financial institutions are critical in the early stages. • Recycled content mandates help build demand-side certainty for recovered materials.	₹0.00	₹0.19	₹0.84

Notes:

* Metal refining processes include leaching, solution purification, and the production of chemicals products for battery metals.

† This process involves three key steps: electrode manufacturing, cell assembly, and finishing. Electrode manufacturing and finishing processes are standardised mainly across chemistries, while cell assembly varies depending on the cell geometry (e.g., cylindrical, prismatic, pouch), which affects equipment design and production methods.

‡ Battery cells are electrically connected and grouped into modules, which are then integrated into battery packs.

Additionally, the listed capital needs and potential sources are not exhaustive; rather, they represent viable initial pathways worth exploring. The appropriate financing approach will depend on the borrower's funding needs, technology readiness, and the revenue model of the specific battery value chain activity being pursued. Investment figures are derived from RMI analysis detailed in Appendix D.

Analysis projections indicate very low volumes of retired batteries available for recycling in 2030, which results in very low investment needs (₹0.00172 lakh crore) compared to those corresponding to 2040 or 2050.

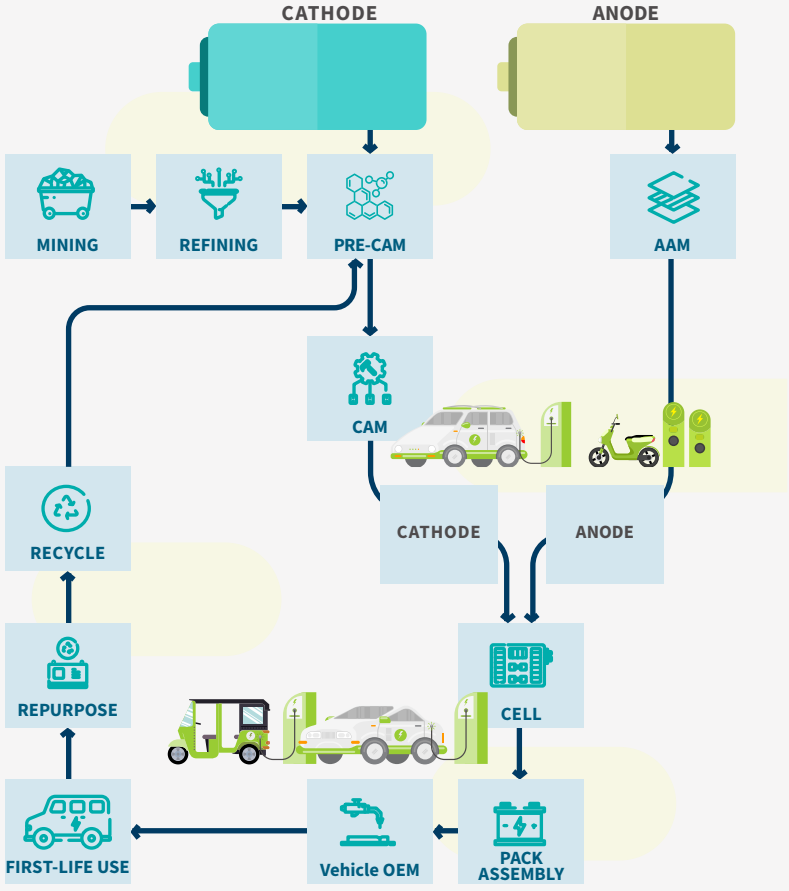
RMI Graphic. **Source:** RMI analysis

This analysis reveals that the most substantial need for funding lies in the midstream segment, specifically cell manufacturing. At the same time, investment in repurposing and recycling is nearly 10 times lower. Given the lower capital needs, investing in repurposing and recycling can offer a more feasible entry point for investors. Directing funds here can strengthen the battery value chain, reduce import dependence, and build local technical capacity, capabilities that can in turn de-risk and attract larger investments across upstream and midstream activities.

Why supporting midstream growth in India is critical

Midstream manufacturing — encompassing cathode and precursor production, cell assembly, module design, and repurposing — serves as the critical link between upstream raw materials, recycling, and downstream end uses. A robust domestic midstream can foster stable demand for recycled materials, such as lithium, graphite, and cathode precursors, thereby supporting the circular economy.

Exhibit 20 Linking circularity to midstream



Note: CAM = cathode active material; AAM = anode active material.
RMI Graphic. Source: RMI, https://rmi.org/wp-content/uploads/dlm_uploads/2024/11/evolving_ecosystems.pdf

India's battery value chain lacks midstream cathode and anode material production, and thereby a viable domestic offtake market for recycled battery materials, limiting the economic case for recycling. Without strong domestic midstream capacity, recovered materials from used EV batteries are often exported, weakening incentives for local collection and recycling and limiting the growth of a circular battery economy in India.

Establishing midstream manufacturing in India would help reverse this trend by anchoring domestic demand for recovered materials, creating a more stable and profitable market for recyclers. It would also enable the formation of joint ventures that de-risk investment in recycling infrastructure through reliable offtake agreements. Over time, this could drive market demand for advanced recycling technologies and enhance India's position in the global battery value chain. This underscores the need for targeted technological development and investment to enable midstream capabilities.

A detailed look at financing circularity

While the previous section explored investment needs across the entire battery value chain due to its deeply interconnected nature, this section zooms in on financing mechanisms tailored explicitly to support circular business practices. These include reuse, repurposing, recycling, and enabling activities such as collection. Many circularity players are small or fragmented, with capital needs shaped by differences in business models, risk profiles, and technological maturity. As a result, a uniform financing approach will not suffice. India must adopt a layered financing strategy, deploying tailored mechanisms such as concessional debt, equity, or credit guarantees to unlock investment across the ecosystem. Establishing accredited national testing centres would also reduce investor uncertainty by providing trusted data on RUL and battery health, enabling clearer residual value assessments and better underwriting for reuse, repurposing, and recycling ventures. Exhibit 21 illustrates how such fit-for-purpose financial tools can be mobilised to support secondary life-cycle pathways for EV batteries and catalyse the growth of a circular battery economy.

Exhibit 21 Financing instruments by stage of the circular battery value chain

Value Chain Stage	Financial Mechanism
Collection and Aggregation	**Results-based financing (RBF):** RBF can be used to incentivise safe collection and verified handover of batteries from informal actors, with payouts linked to measurable outcomes. Informal actors often lack access to credit, but guaranteed RBF payouts tied to performance can attract pre-financing, build trust, and enhance compliance.
	Credit guarantees: Informal actors are high-risk for lenders, but guarantees reduce default risk for lenders extending working capital loans to small aggregators, making loans more viable and attractive.
Reuse	**Equity (Patient Capital):** Early-stage models need flexible capital; equity supports growth without repayment pressure. Startups require equity to build SOH grading technology, traceability layers, and resale operations.
	RBF: Provides payouts for verified deployment of second-life batteries in specific sectors (e.g., electric mobility) to encourage market development where unit economics are still uncertain.
	SPVs*: SPVs reduce financial risk and provide a structured way to pilot reuse markets.
Repurposing	**Credit guarantees:** Asset light or small players often lack access to credit; guarantees can help them secure small loans
	Concessional finance: Long-term loans at below-market rates can enable actors to finance equipment that can be used to scale.
	Sustainability Linked Loans (SLLs): Loans tied to ESG metrics, such as GHG reduction or energy access work to aligns financial terms with social and environmental performance.
	SPVs: An SPV can provide OEMs and/or end-consumers with the means to raise funds and aggregate used batteries for deployment in backup power, telecom infrastructure, or microgrids. Recycling & Black Mass Processing
Recycling & Black Mass Processing	**Fiscal government incentives:** Waiving or reducing the goods and services tax on batteries for second-life use to that of similar metal ores (i.e. 5%) can reduce costs and improve the economics of reuse and repurposing.
	Green bonds: Institutional capital at a lower cost for long-duration infrastructure projects.
	Concessional finance: Reduces interest rate burden for large plants.
	Viability Gap Funding (VGF): Public co-funding to bridge the initial revenue and cost gap that often presents in infrastructure investments.
	SPVs: Joint ownership models can be created for clustering, recycling, and dismantling hubs.
	R&D financing: Grants, concessional R&D loans, or blended public–private funds can be deployed to de-risk innovation in advanced recycling technologies, particularly to address challenges such as electrolyte reactivity, purification, and high-purity harvesting. Without targeted support, many of these solutions will remain commercially unviable despite their environmental benefits.

* SPVs are a legally separate company created for a specific objective, often to hold assets, manage risk, or isolate liabilities from the parent organisations.

RMI Graphic. Source: RMI analysis

Technology development

Advancing battery circularity in India requires targeted technology development across the battery life cycle, from design to second-life applications and EOL material recovery. Developing domestic upstream and midstream capabilities will reduce India's reliance on imports, while promoting environmentally friendly technologies can lower energy use and minimise health risks. Academia–industry collaboration, particularly with startups and MSMEs, will be essential to translate R&D into scalable solutions that meet India's upstream, midstream, and downstream needs. The opportunities for technological advancement detailed below can unlock scale, improve safety, and maximise value retention.

Circular design: Prioritisation and standardisation of modularity and ease of disassembly can extend product life and streamline EOL processing. The following recommendations for R&D can support circular design, ease of repair, and disassembly to promote circularity:

- Cell and pack design: OEMs should explore standardised, modular formats that support easy disassembly and component replacement. Innovations in cell geometry (e.g., prismatic, pouch) can enable greater interchangeability and design flexibility.

- DfC: Indigenous manufacturing should support designs that minimise the use of adhesives and welded joints to enable safer, faster EOL processing, facilitating disassembly, repair, refurbishment, and less risky handling.

- Modularity: As India seeks to strengthen its upstream and midstream manufacturing, greater attention and R&D support should be directed towards modularity. Modularity refers to designing battery components and manufacturing systems in scalable, interchangeable units. This approach enables facilities to expand or upgrade incrementally without overhauling entire systems — reducing capital intensity and improving adaptability. Applied across the battery value chain, modularity allows refining, processing, and other midstream operations to scale with market demand, strengthening the investment case. At the cell or pack level, it also enables easier replacement of degraded components, improving longevity and efficiency.

- Testing centres: India will need a network of nationally distributed testing centres to support startups and researchers in material synthesis and validation. These centres should also serve as standard-setting institutions for remaining useful life (RUL) testing, helping determine whether batteries are suited for secondary use or should move directly to recycling.

Second-life applications: Enabling battery repair and refurbishment is central to advancing circularity. A key enabler is the design of BMSs with open architectures that support reconfiguration and third-party access. The following recommendations outline how data management and system interfaces can support second-life battery applications:

- BMS reconfiguration and data access: Government bodies with R&D mandates and funding should work with private actors to support the development of battery packs with

reprogrammable or open-architecture BMS alongside standardised protocols that enable secure, third-party access and reconfiguration. These improvements would reduce technical and cost barriers to second-life deployment, streamline integration, and enhance traceability and value recovery across the circular battery ecosystem.

- Diagnostics and testing: There is a need to establish specialised labs and develop advanced machinery capable of testing batteries and cells across a range of chemistries and cell configurations to assess SOH, RUL, and thermal performance accurately.

- Data capture and processing: Public and private actors should work in partnership to develop interfaces to store and process critical data that allows battery health analysis not only at the pack level but also at the module and cell string levels for robust analysis of the health of units as well as targeted intervention during repair, refurbishment, and repurposing.

EOL material recovery: India's recycling infrastructure is still in its early stages and lags global standards. The following recommendation can be undertaken to improve recycling efficiency and maximise value capture:

- Direct recycling: There is a need for public and private actors to invest in R&D for mechanical and direct recycling methods that recover aluminium, copper, and graphite efficiently, offering low-energy alternatives to pyrometallurgy.

- Cleaner recycling processes: Research into aqueous processing and high-purity harvesting techniques can reduce toxicity, lower costs, and improve industrial-scale safety. There is scope to improve the efficiency and safety of hydrometallurgical and pyrometallurgical methods.

BMS as a diagnostic tool a look at how advancements lie at the intersection of policy, traceability, and technology development

Advancements in BMS technology, especially in how operational data is recorded and shared, are essential to enabling second-life battery applications. A BMS continuously monitors key parameters such as voltage, temperature, current, and cell balancing to ensure safe and efficient performance throughout a battery's life. This data plays a critical role in diagnostics, life-cycle assessment, and determining whether a battery can be reused, repurposed, or recycled. However, to realise these benefits, improvements are needed in both BMS functionality and data accessibility. This text box outlines the core capabilities that must be enhanced to support traceability and how data needs to be accessible for refurbishers and recyclers to make informed decisions on how a battery has aged and performs to effectively reuse, repursue, or recycle batteries.

To support second-life decisions, the BMS must deliver four core functions. First, it must accurately estimate SOH, capturing usable capacity and degradation to assess whether a battery is suitable for reuse. Second, it should monitor thermal events and

safety conditions, flagging anomalies that might affect safe handling or redeployment. Third, it must log usage history — including charge–discharge cycles, depth of use, and stress events — to validate battery condition, support resale, and enable warranties. Last, the BMS must interface effectively with external systems — such as chargers, diagnostics tools, and other battery systems — particularly in repurposed applications where integration is essential.

Today, however, most BMS data remains inaccessible. OEMs often restrict access through proprietary software and closed firmware. No common standards or regulatory requirements exist for sharing diagnostics. As a result, refurbishers and recyclers usually rely on diagnostics to assess the performance and determine an optimal secondary use for a battery. Battery diagnostics often require lab facilities or complex machinery, and assessments require a specialised workflow. Existing processes also frequently require dismantling batteries to perform diagnostics, as batteries are not designed for easy disassembly, making this process time-consuming and labour-intensive. Therefore, in many cases, usable batteries are discarded simply because their operational history cannot be verified.

Emerging business models, such as BMS-as-a-service, aim to bridge this gap by creating systems where usage data is logged, securely stored, and shared across ownership cycles. However, in the absence of regulation, such solutions remain fragmented and inconsistently adopted. Scaling circularity in India will require minimum data-sharing standards and secure, encrypted platforms to ensure key BMS data is accessible to authorised refurbishers and recyclers. Delivering this capability lies at the intersection of policy design, traceability frameworks, and technology development, highlighting the need for coordinated action across all three domains.

Workforce development

A circular battery economy cannot succeed without a skilled and adaptable workforce. As technologies and business models evolve, there is a pressing need to equip workers with the knowledge and capabilities required across the battery value chain. The recommendations below speak to how workforce development and skilling can and should be an integral part of this transition:

Reskilling and just transition: As EV adoption and circular supply chains expand, India has a unique opportunity to shape the future workforce proactively. This transition will create new demand for skilled labour across battery manufacturing, repurposing, and recycling. By investing in reskilling programmes for workers from adjacent sectors — such as automotive, extractive industries, and the informal economy — India can build a more inclusive and future-ready manufacturing base. There is a need to fund structured reskilling programmes for workers transitioning from extractive industries and the informal sector, with certification tied to job placement in licensed roles such as diagnostics, repair, or refurbishment. These programmes should prioritise long-term capacity building and integration into formal employment channels

- Launch public-private partnerships to deliver short-format, practical workshops (e.g., one to two days) tailored to urban repair and salvage workers who already work with vehicle or electronics components. These trainings build on their existing technical experience and provide targeted upskilling for safe battery handling, with pathways towards integration into licensed recycling or refurbishment centres.

Integration of battery circularity and workforce development into state EV policies: Several Indian states already include skill development in their EV policies, presenting an opportunity to incorporate battery circularity and workforce development aims and frameworks into these efforts.

- Develop state-level skill enhancement centres focused on training in battery engineering, the mechanics of battery repurposing, and diagnostics.
- Provide incentives to startups and micro, small and medium enterprises (MSMEs) that offer apprenticeships in circular battery applications under innovation or skilling missions.

Safety and handling standards: As battery packs age or are repurposed, they may become electrically unstable or pose a hazard. Training workers in proper handling, transportation, storage, disassembly, and safety protocols is crucial to protecting both workers and surrounding communities.

- Enforce safety protocols for all facilities handling used batteries by aligning licensing standards with mandatory training and certification requirements for personnel. This ensures that safety compliance is grounded in both regulation and workforce capacity.

Technology, data, and diagnostics skills: Technicians and engineers must be equipped to use digital tools that track battery health, manage second-life performance, and facilitate circularity through traceability and diagnostics.

- Create short-term certification courses on BMS, data analytics, and traceability platforms.
- Encourage industry partnerships to supply diagnostic tools and real-world datasets to training centres.

Centralised and multibrand refurbishment hubs: High-quality refurbishment requires skilled labour and standardised processes, often only feasible at scale. Centralised facilities can support the product lines of multiple OEMs, offering a strategic opportunity to scale repurposing and provide long-term employment opportunities.

- Facilitate the establishment of regional battery refurbishment centres serving multiple brands, with public co-investment in workforce development.
- Provide training grants and staffing subsidies for these centres to scale skilled labour for testing, reconditioning, and warranty management.
- Use data from these centres to inform curriculum and adjust certification programmes based on real-world performance trends.

Integrated education pathways: The early integration of battery circularity concepts into vocational education can help build awareness and foster long-term workforce pipelines. Students exposed to emerging technologies and sustainability principles early are more likely to pursue careers in EV- and battery-related sectors.

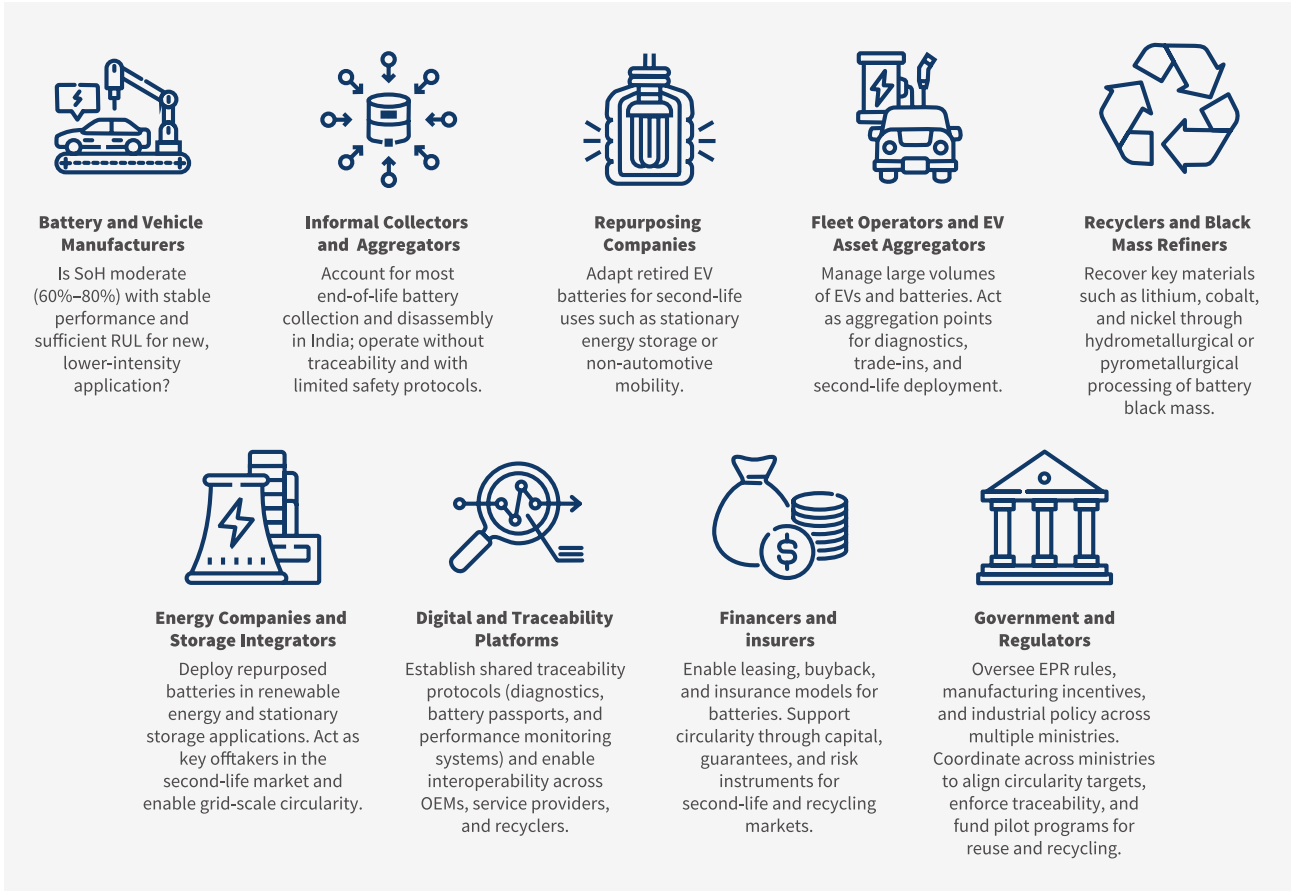
- Develop "battery basics" outreach modules for secondary and trade schools, including site visits to recycling and refurbishment centres.
- Create regional scholarships or training voucher programmes for students entering EV or battery-specific vocational programmes.
- Host industry-led hackathons and innovation challenges on safe disassembly and modular reuse of EV batteries.
- Provide faculty development grants to update engineering syllabi with content on battery EOL considerations.

Workforce development success will depend on coordinated efforts among governments, industry, and educational institutions to provide targeted training, reskilling, and pathways for both new entrants and transitioning workers. Investing in people, alongside technology and infrastructure, is critical to building a resilient, sustainable, and equitable circular battery economy.

Stakeholders: Who Needs To Be Involved and Why It Matters

Battery circularity is not just a technological challenge; it is a system-level effort shaped by the choices of multiple, interdependent actors. The recovery and reintegration of battery value depend on coordination across stakeholders who have historically operated in silos, including battery designers, diagnostics providers, vehicle financiers, fleet operators, and EOL processors. Industry bodies such as the Society of Indian Automobile Manufacturers and allied associations play a pivotal role in convening these stakeholders, setting standards, and fostering collaboration to accelerate circularity. This section outlines the current and emerging roles of these key stakeholder groups in India's battery circularity ecosystem and explains why their active participation is essential, not only for advancing circularity but also for supporting the long-term success of India's clean mobility and energy transition.

Exhibit 22 Key stakeholders and their roles in the circularity ecosystem



RMI Graphic. Source: RMI analysis

Battery and vehicle manufacturers

OEMs — for batteries and vehicles — play a foundational role in shaping circularity outcomes. Decisions regarding the design and placement of the battery within the vehicle determine how easily a battery can be disassembled, tested, or reconfigured. As circularity matures, OEMs are expected to play a more active role in enabling product longevity by sharing performance data, designing for disassembly, and participating in battery take-back systems. Their role will also evolve to include the integration of recycled material into new cell production, creating true closed-loop feedback between EOL recovery and new manufacturing.

Informal collectors and aggregators

India's battery recovery ecosystem remains heavily reliant on informal actors — kabadiwalas, scrap traders, and small aggregators — who operate outside formal compliance systems. These collectors often serve as the first point of contact for EOL batteries, especially in the two- and three-wheeler segments. Drawing on their experience in the lead-acid market, they have developed extensive, efficient collection networks that offer doorstep services and quick cash payments, often outcompeting formal channels.

However, this system lacks safety standards, environmental safeguards, and traceability. Batteries are dismantled without protective gear, stored in unsafe conditions, and often sold to unlicensed handlers. Despite these risks, their role in aggregating volume is critical. Formalising this sector — through incentives, technology integration, and partnerships — could unlock large volumes of battery feedstock while improving livelihoods and ensuring safer, compliant operations.

Second-life battery companies and refurbishers

A growing number of companies are developing second-life battery applications by disassembling retired batteries, testing their components, and repurposing them for uses such as home storage, telecom backup, and rural energy. Firms such as Lohum, Nunam, and Log9 show that with proper diagnostics and traceability, second-life batteries can reliably serve nonautomotive markets. However, challenges like high disassembly costs, weak safety standards, and low market awareness persist. Scaling this segment will require certified resale channels, warranty systems, and platforms to aggregate demand and reduce investment risk.

Fleet operators and EV asset aggregators

Fleet operators — particularly in commercial two- and three-wheeler and e-rickshaw segments — are emerging as central actors in the battery circularity ecosystem. These firms manage high volumes of vehicles and batteries under predictable usage conditions, making them ideal partners for structured battery take-back, diagnostics, and reuse pilots. Yet today, most fleets dispose of degraded batteries through informal channels due to a lack of structured trade-in systems or resale markets.

In addition to OEM-led collection channels, companies operating fleet-as-a-service models — such as Turno — have begun to explore battery aggregation and trade-in partnerships. Their role will be especially important in establishing the physical and logistical flows needed to support large-scale second-life deployment. Fleet operators also have a unique ability to capture high-quality usage data through telematics and battery analytics. This is data that can be used to support residual value estimation and warranty underwriting. In future solutions, they are likely to serve as key intermediaries between first-life and second-life ecosystems.

Recyclers and black mass refiners

Recyclers such as Attero, Gravita, and BatX Energies are scaling black mass recovery using chemistry-specific technologies like hydrometallurgy. Their ability to supply battery-grade inputs hinges not only on infrastructure expansion, but also on reliable, traceable feedstock and alignment with midstream users. Their coordination role — bridging informal aggregators and formal manufacturers — is vital to building a closed-loop system that captures environmental and economic value.

Digital and traceability platforms

Innovation in diagnostics, traceability, and decision-support tools is essential to de-risking second-life battery flows. Battery intelligence startups (e.g., The Energy Company, BatteryOK) are developing diagnostics, traceability, and grading platforms. These solutions are not just technical tools: they are foundational to building a transparent, investable circularity ecosystem.

Energy companies and storage integrators

These companies operate grid-scale renewable energy infrastructure, microgrids, and backup systems, where repurposed EV batteries can be integrated as cost-effective energy storage solutions. By providing long-term demand for refurbished batteries, these actors help stabilise second-life markets and improve utilisation of retired mobility batteries. Their participation also links circularity to India's broader energy transition goals by enabling clean, reliable, and affordable power solutions that draw on domestic battery resources.

Financial institutions and insurers

Financial actors, including banks, leasing firms, and insurers, are largely absent from India's circular battery ecosystem. Most second-life transactions are self-funded or grant-supported, and warranties are rare. Yet as battery costs fall and second-life volumes rise, the viability of circularity will hinge on the availability of financial products that spread risk, unlock working capital, and protect against underperformance.

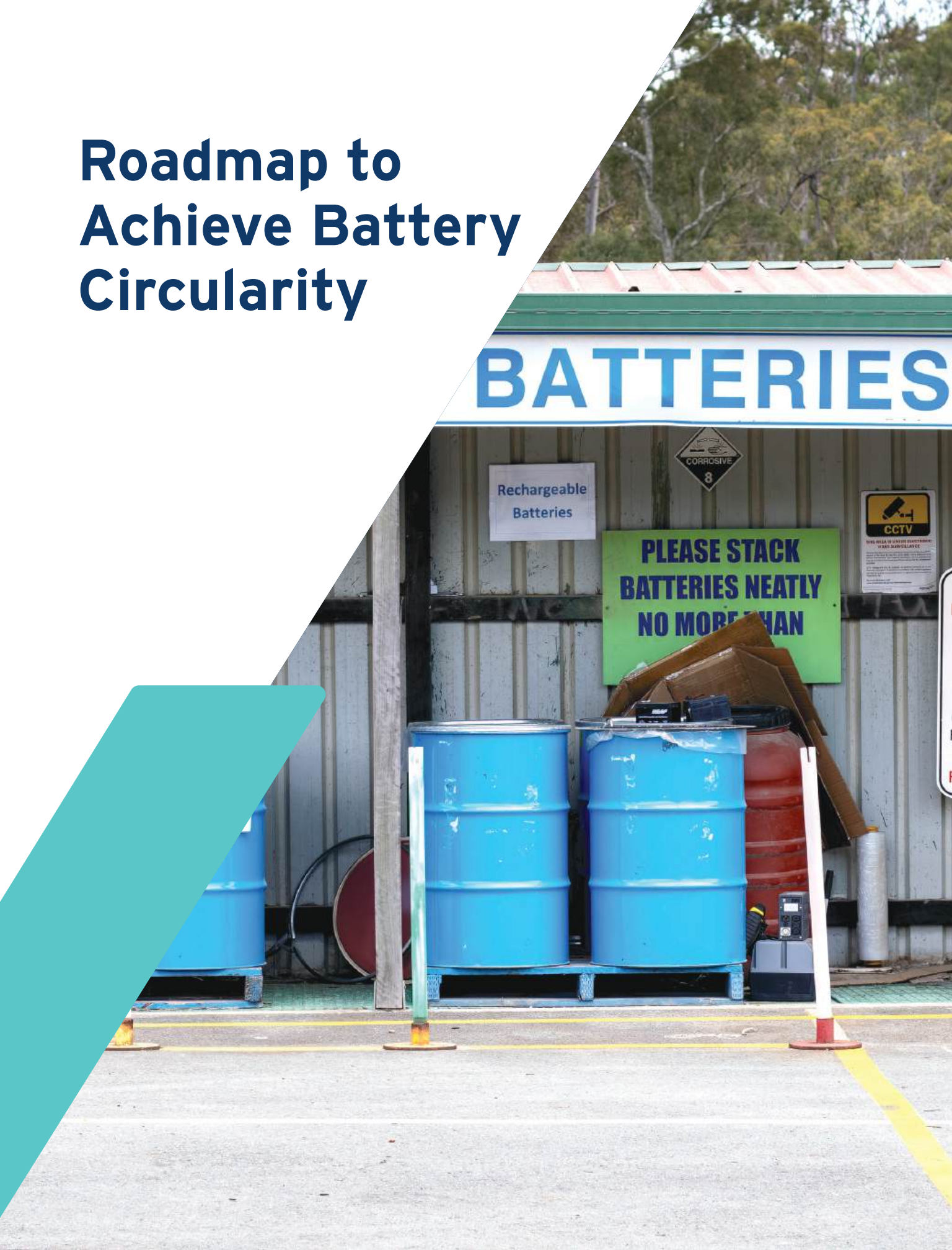
Insurers could play a role in offering SOH-linked performance guarantees. Banks could support capital expenditures for repurposing or recycling infrastructure. Financiers could enable leasing or buyback models that include EOL recovery clauses. For these services to emerge, however,

clear data standards and market norms around residual value and performance are essential, underscoring the need for collaboration with technology providers and regulators.

Government agencies and regulators

The government can advance battery circularity by shaping policy, investing in infrastructure, and fostering partnerships. Agencies such as MoEFCC, MHI, Ministry of Mines, and NITI Aayog are already shaping circularity frameworks through the BWMR, the PLI for ACCs, and the NCMM. Greater coordination and stronger enforcement present key opportunities to further strengthen existing enabling policies. Moving forward, public institutions can support implementation through shared traceability platforms, pilot funding for SOH diagnostic testing, and refurbishment facilities. Government procurement programmes can also help scale circularity by creating guaranteed demand for certified second-life systems, especially in public fleets and rural energy initiatives. Lastly, to navigate complexities in international partnerships for emerging technologies, the government can play a key role in facilitating or supporting the formation of international collaboratives and partnerships.

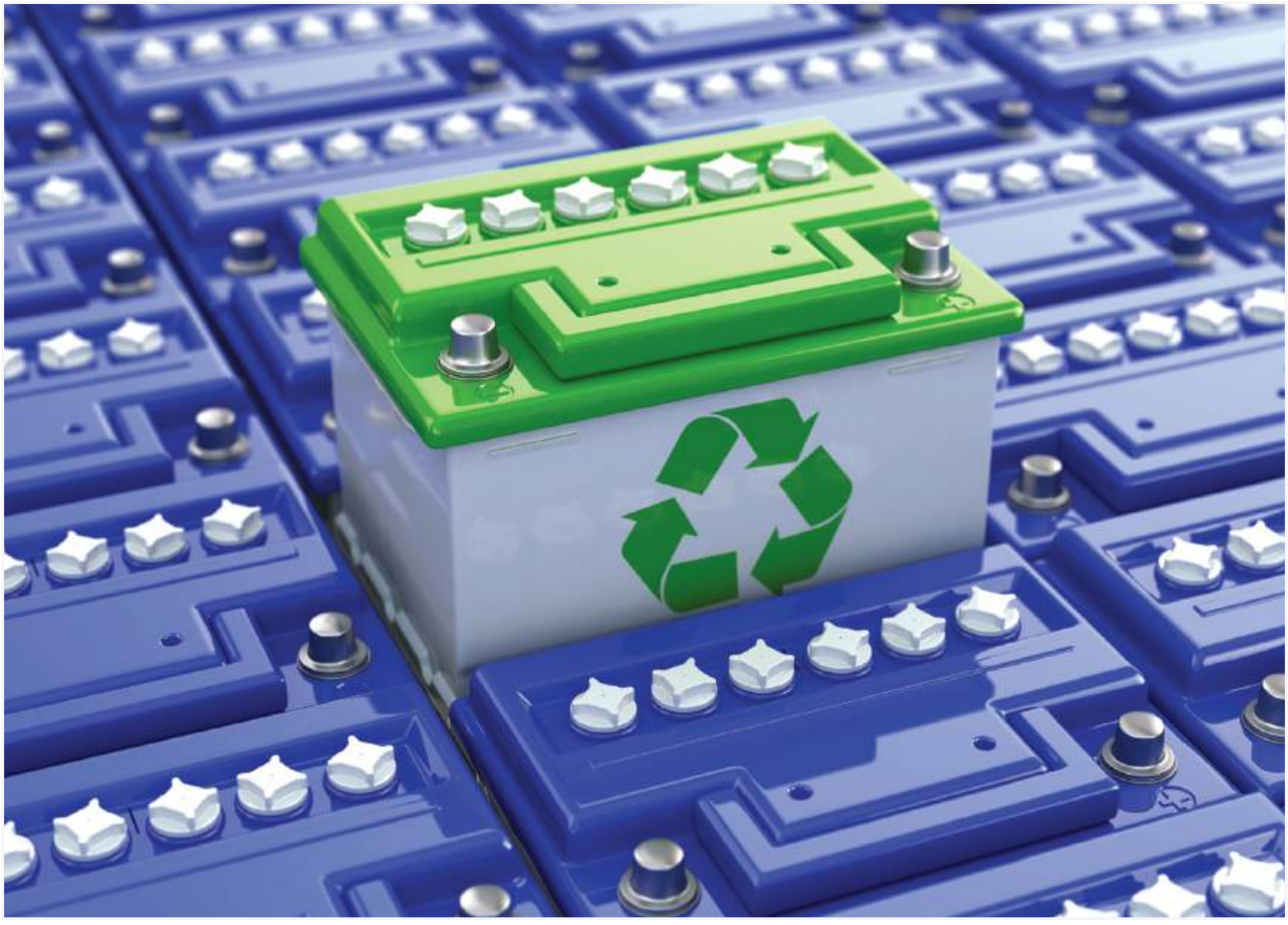
Roadmap to Achieve Battery Circularity



A strong and resilient battery ecosystem will be a cornerstone of India's clean energy transition, supporting renewable energy integration, electric mobility, and energy-storage deployment in line with India's goal of achieving energy independence by 2047 and reaching net-zero emissions by 2070.

India stands at a pivotal juncture, with rapidly growing demand for electric vehicle batteries — and a unique opportunity to embed circularity from the outset to maximise value, minimise environmental impact, and strengthen supply chain resilience. However, this is not a simple task — the battery value chain is complex, involving diverse actors and fragmented systems. This concluding section outlines a practical pathway forward — translating ambition into action through measurable targets and focused interventions. It presents a shared vision for how India can operationalise battery circularity at scale, grounded in what is feasible, necessary, and timely.

By defining what success looks like in 2026, 2030, and 2047, India can build a circular battery economy that not only reduces waste but also strengthens domestic manufacturing, creates green jobs, and enhances mineral security. Achieving this vision will require more than ambition; it will necessitate strategic alignment, institutional coordination, and a sustained commitment to long-term systems change.



By 2026: Laying the groundwork

India's priority must be to create an enabling environment with supportive policies, grounded in data and backed by investment in research, development, and pilot-scale demonstrations that validate emerging technologies, such as advanced diagnostics, direct recycling, and reuse applications. This effort should also include creating accredited testing centres to establish standards for battery health and remaining useful life.

Exhibit 23 Recommended actions to complete by 2026

Laying the groundwork
Traceability: Establish an interindustry body to guide and advise on the development of a SOH grading and diagnostics framework.
Policy: Empanel a national task force on battery traceability to define and draft minimum traceability requirements and seek industry recommendations to help amend the Battery Waste Management Rules to further strengthen and explicitly prioritise reuse and repurposing alongside recycling.
Finance: Establish foundational financial mechanisms — such as credit guarantees, concessional capital, and results-based incentives — to support early-stage circularity actors and fund reuse, repurposing, and recycling pilot projects.
Technology development: Strengthen academia–industry partnerships and create national testing centres to accelerate R&D, validate battery health, and advance second-life and recycling solutions across the battery value chain.
Workforce development: Engage informal sector actors to identify reskilling needs, implement safety trainings, offer basic diagnostics courses.
Strengthen the battery supply chain: Build and incentivise the creation of reverse logistics networks to support the safe collection of retired EV batteries.
Ecosystem coordination: Launch a public-private platform to drive coordination, innovation, and the implementation of scalable battery circularity projects. Develop circularity pilots and testing centres to validate emerging solutions such as direct recycling, innovative black mass processing, diagnostics, battery passports, and reuse applications, creating a pipeline for commercial deployment.
Knowledge exchange: Strengthen ties with international leaders and cohorts on battery circularity to promote a two-way knowledge exchange.

RMI Graphic.

By 2030: Scaling circularity across the ecosystem

Before 2030, India should aim to establish a functioning, self-sustaining circular battery economy capable of reusing, repurposing, and recycling over 200 GWh of batteries and reaching a recycling capacity of 1.2 million tonnes. Exhibit 24 outlines the key actions to achieve this pursuit.

Exhibit 24 Recommended actions to complete by 2030

Scaling Circularity Across the Ecosystem
Traceability: Operationalise a national battery traceability system (e.g., Battery Aadhaar) to log SoH, usage, and ownership.
Policy: a) Notify a national battery traceability standard that stipulates the disclosure of key battery parameters — such as SOH usage history, and ownership — throughout the battery's life-cycle. b) Develop design guidelines that promote circularity — such as modular architecture, standardised labelling, and disassembly-friendly construction — to ensure batteries are built for reuse, repurposing, and recycling.
Finance: Scale circularity financing through blended capital platforms, sovereign green bonds, and public procurement anchors to enable commercial investment in midstream manufacturing, second-life deployment, and large-scale recycling infrastructure.
Technology development: Embed design-for-circularity principles and modular midstream solutions that can scale with demand. Make recylcing methods more efficient through dedicated R&D to enable high-purity material recovery, foster electrode self-healing, and address challenges related to electrolyte reactivity.
Strengthen the battery supply chain: Strengthen domestic capacity in mineral reprocessing and mid-stream capacity — including cathode, anode, precursor, and cell production — to support the domestic offtake of recycled material.
Workforce development: Build a nationwide skilled workforce for battery circularity by integrating circular economy content into education systems, scaling national safety and certification programs, and formalising reskilling pathways through state-supported training centres, industry partnerships, and centralised refurbishment hubs.
Ecosystem coordination: Advance public-private partnerships that support scaled development of battery circularity.
Knowledge exchange: Strengthen international collaboration and standard alignment to reflect the global and interconnected nature of the battery value chain

RMI Graphic.

By 2047: Full Integration

By India's centenary, battery circularity should be deeply embedded in the manufacturing landscape, generating jobs and strengthening supply chains. The targets detailed in Exhibit 25 can support the nation's vision for energy independence.

Exhibit 25 2047 targets and outcomes

Material self-reliance: 95% of critical minerals are recovered at scale and fed back into cell manufacturing to supply over 40% of India's critical mineral needs

Environmental resilience: Battery recycling avoids the high emissions of mineral extraction — resulting in a cumulative emissions reduction of 2.9 million tonnes of CO_2 through 2050

Economic inclusivity: A thriving network of service providers; micro, small, and medium enterprises; and informal actors are integrated into formal circularity value chains

Export readiness: Compliance with global content and life-cycle standards unlock premium export markets and attract greater investment into India's battery value chain

RMI Graphic. **Source:** RMI Analysis

India has an opportunity to shape a circular battery economy that is not only environmentally sound but also economically strategic. By aligning policy, traceability, financing, technology development, and workforce development around clear, actionable priorities, the country can move beyond pilots and toward a national system that extends battery life, supports domestic industry, and strengthens long-term energy security. Overcoming existing supply chain constraints and unlocking India's full battery-circularity potential requires a comprehensive, collaborative approach, with enhanced coordination across the battery value chain. With the right push, India could become a global leader in this space thanks to the favourable battery chemistries in use, strengths in digital technology, competitive labour costs, expanding infrastructure, and strong government support for EV adoption. The roadmap presented above, along with the solution pathways detailed throughout this report, seek to serve as a practical guide for implementing battery circularity in India.

Appendices

Appendix A: Challenges

Exhibit A1 Key challenges in setting up a circular battery supply chain

Challenges	Description
Technology & Design:	Constraints regarding the technical readiness of batteries for circularity • Batteries are often not designed for reuse and repurposing (e.g., they are difficult to disassemble due to sealed packs and welded connections). • The lack of standardisation in cell and module design limits the ability to scale reuse and repurposing. • A lack of technological commercialisation domestically in recycling and a need for premium research institutions to play a more proactive role in relevant research.
Supply chain gaps	Gaps in India's upstream and midstream supply chain • India remains heavily dependent on imports of cathode and anode materials. • The country lacks domestic midstream infrastructure (e.g., refining, precursor processing), limiting its ability to re-integrate materials into new battery component production.
Collection & Logistics	Collection leakage and inefficiencies • Used battery collections are predominantly informal, making it difficult to ensure consistent, safe, or reliable handling, valuation, and sorting of used batteries. • Weak reverse logistics and storage infrastructure lead to bottlenecks in transport.
Work force	The need for skill development and workforce formalisation • Process improvements are needed to effectively integrate informal actors into workforce training into the formal system. There is a need to train technicians for safe disassembly and reassembly.
Traceability	Information gaps limit effective reuse, repurposing, and recycling. • Limited visibility into a battery's condition, performance, and usage history — compounded by most OEMs not sharing key life-cycle data like charge-discharge cycles or temperature history — makes it difficult for market actors to assess battery health and determine the most suitable circularity pathway. There is no standardised method for tracking battery degradation over time, leading to inconsistencies in evaluation.

Challenges	Description
Policy	Current policies in India lack standardisation, legal clarity, and the enforcement needed to enable safe, reliable, and financially viable reuse, repurposing, and recycling. • Fragmentation between regulatory bodies impedes the development of holistic policies to support circularity. • The lack of standardisation for certifying safety, remaining life SoH, and residual value limits market development. • Unclear designation on who is liable for the use and safety of reused or repurposed battery fails creates additional risk. • The Battery Waste Management Rules, 2022, implement Extended Producer Responsibility (EPR), making producers accountable for end-of-life battery waste; further, the framework offers limited recognition of reuse and repurposing, and inconsistent enforcement hinders its effectiveness in supporting a circular ecosystem.
Economic viability	The financial viability of circular battery practices remains constrained in the near term, and market demand for such solutions is still unclear. • The absence of a formal secondary market and weak demand signals for reused and repurposed batteries undermine their retained residual value and limit commercial viability. • The absence of reliable methods to assess a battery's state of health (SOH) and remaining useful life (RUL) makes it challenging to determine residual value. This uncertainty poses a significant risk to stakeholders, often leading them to undervalue used batteries, which ultimately increases the total cost of ownership through higher EMIs, insurance premiums, and related expenses. • The growing dominance of lithium iron phosphate (LFP) chemistries — known for lower concentrations of high-value materials — reduces the economic incentive for recycling, constraining profitability. • Market nascent limits investor confidence and restricts access to financing for circular battery businesses.

Source: RMI Analysis

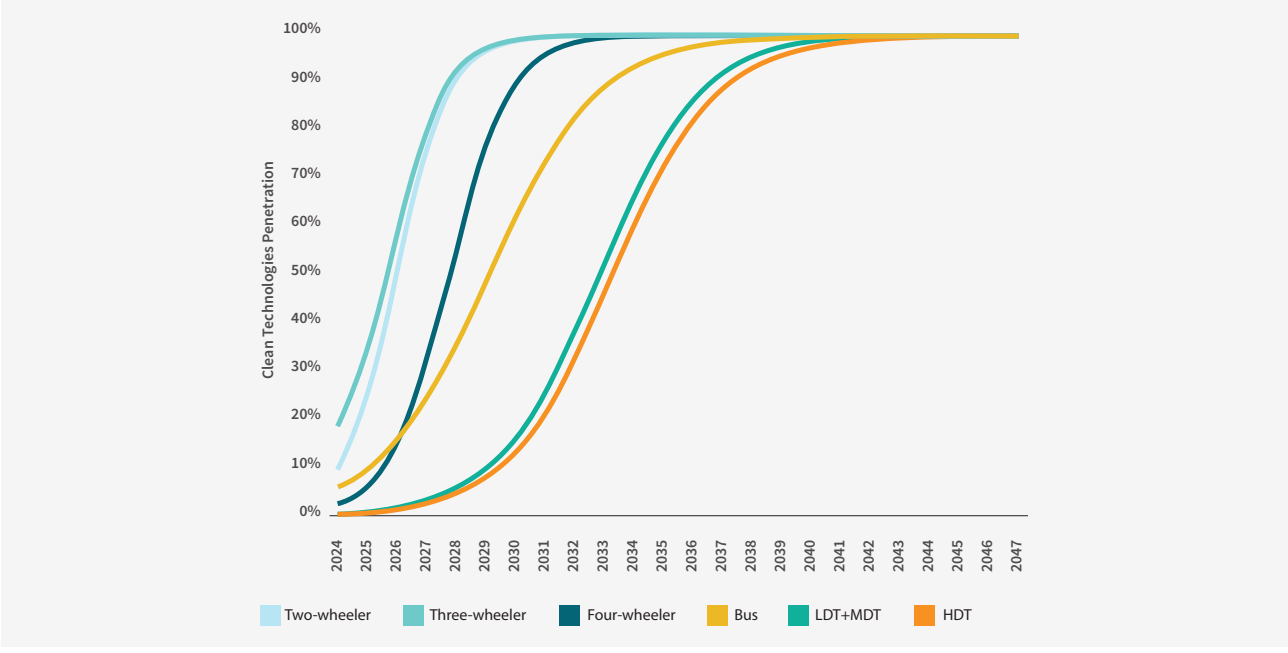
Appendix B: Modelling the impact of battery repurposing in India

This appendix presents the step-by-step methodology used to estimate the economic and material impact of second-life battery repurposing in India. The goal is to assess usable battery volumes, infrastructure needs, revenue potential, and underlying costs from 2025 to 2050. The model is calibrated using expert inputs, cost benchmarks, and conservative estimates to reflect the nascent state of the Indian repurposing market.

Step 1: Estimate EOL battery volumes

Total EOL battery volumes are derived from India's EV adoption forecast by segment — two-wheelers, three-wheelers, four-wheelers, LCVs, buses, and trucks — and segment-specific retirement profiles. EV penetration rates were derived from *India at 2047: A Vision for Energy Independence in the Mobility Sector,* which depicts an energy independence scenario for the mobility sector aimed at achieving energy independence by 2047.[57]

Exhibit B1 Clean fuel vehicle sales penetration levels in India by vehicle segment and scenario, 2024–47



Note: The energy-independent scenario is based on achieving no crude oil and gas imports beyond 2047. The scenario envisions aggressive EV penetration through ambitious strategies to transition most of the vehicle stock away from crude oil and gas by 2047. This analysis uses the EI scenario's ambitious clean fuel targets as benchmarks to estimate future battery volumes and guide proactive circularity planning.

RMI Graphic. Source: RMI, India at 2047

Retirement ages are three years (three-wheelers), five to six years (LCVs, including four-wheelers in fleet applications), and seven to eight years (buses and trucks). Battery volume is measured in GWh and linked to segment-specific average energy densities sourced from BloombergNEF.

Step 2: Calculate repurpose volumes

A share of EOL batteries is assumed viable for repurposing, factoring in:

- **Collection rate:** 50% in 2025, improving to 90% by 2040, then held constant.
- **Repurposing eligibility:** 80% of collected batteries assumed viable (based on SOH, physical condition, and format compatibility).

Step 3: Adjust for oversizing in second-life applications

Stationary storage applications often require battery oversizing to ensure performance from degraded cells:

- **Oversizing factor:** 111.67x (i.e., 1.67 GWh of repurposed battery capacity is required for every 1 GWh of usable energy delivered). This adjustment accounts for degradation without double-counting losses in SOH.

Step 4: Model lifetime extension and recycling deferral

- **Operational life:** Repurposed batteries are assumed to deliver a conservatively estimated three additional years in stationary storage. Actual life depends on diagnostics and application profile, but it is typically aligned with the secondary warranty period that refurbishers can confidently support.
- **Second collection rate:** 80% of repurposed batteries are assumed to reenter the formal system for recycling after their second life.

Step 5: Apply battery price benchmarks

Battery prices are sourced from BloombergNEF projections (2015–35) and extrapolated using a 10% learning rate until 2050:[58]

- **2035 price:** US$66.29/kWh
- **2050 price (extrapolated):** US$27.67/kWh

Prices are adjusted using a degradation-based discount (initially 30% in 2025, reducing to 10% by 2040) to reflect buyer perception of second-life systems.

Step 6: Estimate per-unit and aggregate revenue

Revenue is estimated as:

- **Per-unit revenue** = price × (1 – discount factor)
- **Total revenue** = usable repurposed GWh (after oversizing) × per-unit revenue

Annual and cumulative revenues are calculated through 2050. From 2025 to 2040, price-based revenue declines are expected to reflect ongoing price reductions and SOH-linked discounts. After 2040, a price floor of US$27.67/kWh is held constant.

Step 7: Estimate repurposing costs

Three cost heads are modelled:

1. **Collection Costs:**
   - Benchmarked at ₹3,500/tonne (2025), declining to ₹2,000/tonne (2040)
   - Volumes converted using energy densities (kWh/kg)
2. **Process costs (disassembly + diagnostics):** These are costs involved in safely dismantling battery packs and assessing their condition (e.g., SOH, capacity) to determine suitability for second-life use. Includes labour, safety measures, and testing infrastructure.
   - Benchmarked at ₹180/kWh (2025), declining to ₹90/kWh (2040)
   - Benchmarked at ₹180/kWh (2025), declining to ₹90/kWh (2040)
   - Decline modelled using cumulative revenue volumes and a 10% learning rate
3. **Repurposing (reassembly) costs:** This covers the bill of materials and refurbishment components required to reconfigure batteries for second-life use. It includes new or upgraded hardware such as BMSs, inverters, converters, cooling systems, housing, and replacement cells to address degraded modules.
   - Benchmarked at US$28/kWh (2025), declining with the same learning rate
   - Costs can be reduced if batteries are designed up front for second-life compatibility, without penalising first-use applications.

Margins are calculated as a residual between revenue and total cost components.

Exhibit B2 Repurposing cost components and key assumptions for forecasting

Cost Component	Decline Type	Notes
Collection cost (₹/MT)	Linear decline	Goes from ₹3,500/MT (2025) to ₹2,000/MT (2040), reflecting improved logistics and aggregation efficiency. Not tied to volume.
Process cost (₹/kWh)	Learning rate (10%)	Includes diagnostics, testing, and integration. Decline modelled using a volume-based learning curve starting at ₹180/kWh.
BoM/integration cost	Learning rate (10%)	Starts at US$28/kWh. Reduced over time based on the same learning curve.
Margins	Fixed target (25%–50%)	Grows with maturity, not calculated via learning.

RMI Graphic. Source: Interviews with stakeholders, 2024–25; Tobiah Steckel et al., https://doi.org/10.1016/j.apenergy.2021.117309

Exhibit B3 Key assumptions for modelling repurposing volumes, costs and revenue

Component	Value / Approach	Source / Rationale
Oversizing factor	1.67x	SOH-based energy degradation
Second-life duration	Three years	Conservative estimate based on Commercial and Industrial use case warranty expectations
Second-life collection rate	80% post-second-life	Reflects distributed storage traceability limitations
Battery degradation curve	Linear to ~60% SOH by year 3; then declining to 15% by year 8	Based on stakeholder insights, warranty norms, and industry degradation patterns
Battery price (2025)	Starts at $117.52/kWh in 2025, reaches $53.39/kWh in 2040	BloombergNEF
Battery price (2041)	Interpolated using an exponential decay curve with a 10% learning rate (e.g., $27.67/kWh by 2050)	Derived from BloombergNEF data
Discount on repurposed value	30% in 2025, reducing to 10% by 2040	Based on stakeholder insights
Repurposing revenue formula	Battery price x (% SOH x discount factor)	RMI analysis and stakeholder validation
Per-unit process cost	₹180/kWh in 2025, reducing to ₹90/kWh by 2040 using a 10% learning rate	Based on stakeholder insights
Collection cost	₹1500–₹3500/ton (₹30 ₹35/kWh) depending on the year	Based on stakeholder insights and industry benchmarks
Currency conversion	US$1 = ₹86	Static assumption for INR conversion
Discount rate used when deriving Net Present Value profits in 20250	10%	RMI analysis

RMI Graphic. Source: RMI analysis; BloombergNEF, https://about.bnef.com/electric-vehicle-outlook/; stakeholder interviews, 2025; ABC Transport, https://abctransport.co.in/blog/truck-transportation-charges-in-india-calculate-per-km-cost/

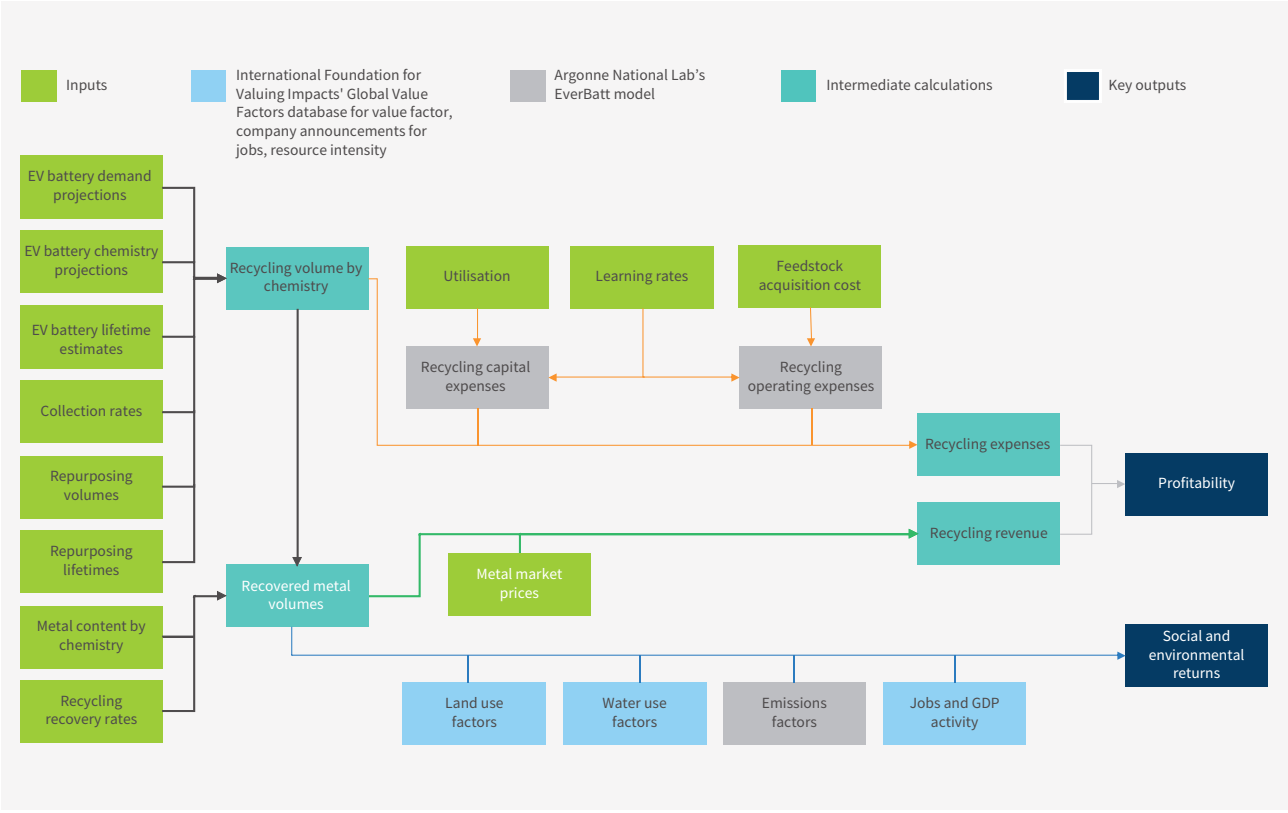
Note on BoM cost estimate (US$28/kWh)

This estimate derived from a US value chain study that applied levelised cost of storage methodology to second-life LiBs.[59] Although the paper did not draw on India-specific data and so is not a direct reflection of local repurposing or reassembly costs, supply chains, or repurposing practices, it remains one of the most detailed public benchmarks available. We use it here as a proxy to inform our analysis, and we will update these estimates as more representative data from the Indian market becomes available. It has been cross-validated with Indian second-life battery experts; although indicative, it falls within the plausible cost range for India and may be refined as more local data emerges.

Appendix C: Modelling the impact of battery recycling in India

This appendix outlines the step-by-step methodology, assumptions, and data sources used to model the technical and economic potential of LiB recycling in India through 2050. The goal is to quantify (1) the material recovery value based on recovered volumes of lithium, cobalt, graphite, and other critical minerals, and (2) the systemic impact of scaling formal recycling infrastructure, measured in terms of profitability, green jobs and their gross domestic product (GDP) impact, avoided resource use, and life-cycle greenhouse gas emissions avoided relative to virgin material extraction.

Exhibit C1 Value creation through a circular battery value chain



RMI Graphic. Source: RMI analysis

Step 1: Estimate recycling battery volumes

Battery EOL volumes are derived using segment-wise battery demand forecasts, chemistry, and retirement ages. The demand trajectories used in this analysis are based on RMI's *India at 2047: A Vision for Energy Independence in the Mobility Sector* report, detailed in Appendix B.[60] Battery chemistry projections are referenced from the BloombergNEF *Electric Vehicle Outlook 2024*, based on the global scenario.[61] The steps below seek to detail how the volume of batteries available for recycling were derived.

- All EOL batteries are captured for formal repurposing and recycling. Collection rates begin at 50% in 2025 and increase to 90% by 2040.
- Assumptions on collection rates in 2025 are based on known data points around battery collection rates from EU waste statistics.[62]
- Simplifying assumptions were made on India's BWMR collection targets to inform collection rates through 2040.[63] The targets stated in BWMR vary by segment and compliance cycles for tailored implementation. However, such granularity in modelling demands significant resources without significantly improving the directional insights sought.
- Repurposing volumes, as described in Appendix B, are diverted for repurposing use duration before being re-collected for recycling.

Step 2: Determine recovered metal volumes

Each collected battery for recycling is mapped to a specific chemistry (LFP, NMC, nickel cobalt aluminium) based on segment and year-wise adoption trends. Each chemistry has a distinct composition of key recoverable materials (e.g., lithium, cobalt, nickel). Material content per kWh is based on cell-level mass fractions derived from Argonne National Lab's EverBatt model. Further material-specific recovery rates, viable with hydrometallurgical recycling practices, are applied to determine the volumes of recovered metal. Improved recovery volumes are applied for future years, based on best-in-class recovery rates.[64] For formal recyclers using hydrometallurgical processes, recovery efficiencies are modelled as:

- All EOL batteries are captured for formal repurposing and recycling. Collection rates begin at 50% in 2025 and increase to 90% by 2040.
- Nickel: 95% between 2025 and 2030, increasing to 98% by 2040
- Cobalt: 95% between 2025 and 2030, increasing to 98% by 2040
- Lithium: 80% between 2025 and 2030, increasing to 95% by 2040

Step 3: Estimate recycling revenue from recovered material volumes

Recovered material volumes are multiplied by average global commodity prices to estimate annual and cumulative revenue potential. Prices referenced are the average from Q1 2024 to Q4 2022: cobalt: US$33/kg; lithium carbonate: US$15/kg; nickel sulfate: US$21/kg.[65]

Step 4: Estimate recycling costs

Capital and operational expenditures for recycling facilities are estimated from the Argonne National Lab's EverBatt model, which assumes mechanical shredding and hydrometallurgical recovery processes.[66] The EverBatt model can reduce capital expenses through economies of scale. Exhibit C2 shows the cost estimate across categories, estimated from the EverBatt model.

Exhibit C2 Recycling costs, fixed and variable

Bucket	Category	Low (US$/tonne)	High (US$/tonne)
Fixed costs	Facility	83	18,094
	Collection and transport	219	777
	Maintenance	5	1,863
	Labour	2	23,956
	Other fixed costs	23	2,265
Variable costs	Disassembly	470	470
	Preprocessing	200	200
	Utilities	40	40
	Materials	1,650	1,650
	Other variable costs	50	50
Feedstock acquisition costs	Feedstock acquisition costs	90	161

Note: Fixed and variable cost buckets are defined by the EverBatt model. For this analysis, fixed costs are aggregated as capital expenses, and variable costs and feedstock are aggregated as operational expenses. Feedstock acquisition costs are assumed as 5% of the residual value of metals contained in batteries and therefore vary with the battery chemistry.

Additionally, a 10% learning rate is applied to assess how cost reductions occur over time.

RMI Graphic. Source: Argonne National Lab, https://www.anl.gov/amd/everbatt; RMI analysis

Step 5: Profitability modelling

The cost and revenue inputs are then used to estimate profit per tonne.

Step 6: Social and environmental return estimates

The social value of recycling is based on the salaries paid for recycling jobs and the economic impact of these jobs. The number of jobs in recycling is derived from investment announcements from various companies, with a salary assumed to be approximately ₹212,500/y, and an associated economic activity (GDP multiplier) of 0.5. The environmental value is based on resource intensity (land, water, emissions) of mining lithium, nickel, and cobalt versus recycling various chemistries. Resource use is tracked through various company announcements, and the economic value associated with avoided resource use is calculated using global value factors from the International Foundation for Valuing Impacts.[67]

Appendix D: Battery reuse volumes and deployment potential in India

This appendix outlines the methodology and assumptions used to estimate the potential market of battery reuse in India between 2025 and 2050. In this context, reuse refers to the continued application of an end-of-first-life battery in the same or equivalent use case, typically enabled by early battery retirement from commercial fleets and redeployment into lower-mileage operations within the same segment. While not all batteries will follow this pathway, reuse is increasingly viewed as a technically feasible and underexplored opportunity in India's battery circularity ecosystem. The modelling presented here quantifies the cumulative and annual GWh volume of batteries that may be eligible for reuse, primarily from fleet-operated three-wheelers, LCVs, and buses.

Exhibit D1 Key modelling assumptions on battery reuse volumes

Component	Assumption/Value	Notes
Battery retirement age	Three to eight years, segment-specific	Shorter for commercial segments (e.g., three-wheelers at approximately three to four years)
Collection rate	100% for fleet segments	Reflects aggregator ownership and service-based business models
Reuse eligibility factor	50% of the collected batteries	Based on SOH ≥65%, structural safety, and reliability
Applicability filter	Three-wheelers, LCVs, buses only	The reuse potential is limited to structured commercial applications
Reuse factor	0.5	Reflects partial life extension, no oversizing needed
Reuse lifetime extension	Two to four years post-retirement	Reflects reduced intensity use post-fleet exit
Market capture rate	100% of eligible volumes	Optimistic assumption, future ecosystem dependent
Oversizing factor	1.0	Reuse occurs within the same form factor and power profile

RMI Graphic. Source: industry stakeholder conversations; Akshima Ghate et al., https://rmi.org/ insight/india-at-2047-mobility/

Key results

- **Total cumulative reuse potential (2025–50): ~220 GWh**
- **Average annual reuse volume (2030–45): ~10 GWh/year**
- **Inflexion point:** Reuse potential scales significantly post-2035, coinciding with the retirement of India's first large EV fleet cohorts.

Appendix E: Investment requirements across the battery circularity value chain

This appendix outlines the methodology, assumptions, and data sources used to estimate cumulative capital investment needs through 2030, 2040, and 2050.

Step 1: Define the scope of the value chain

The capital modelling includes the supply chain segments in Exhibit E1.

Exhibit E1 Scope of the battery circularity value chain

Segment	Description
Material processing	Leaching, purification, and conversion of mined metals into battery-grade chemicals
Nickel refining	Processing of nickel into battery-grade form
Cobalt refining	Solvent extraction and upgrading of cobalt intermediates
Lithium refining	Conversion of lithium into $LiOH.H_2O$; modelled with 6.048 lithium carbonate equivalent-to-$LiOH.H_2O$ conversion factor
Cathode manufacturing	Active cathode material production; demand scaled using 2.39 kg/kWh LFP cathode density
Anode manufacturing	Active anode material production; demand scaled using 1.56 kg/kWh LFP anode density
Cell production	Electrode coating, stacking/winding, electrolyte filling, and formation testing
Battery assembly	Module and pack assembly, including thermal and BMS integration
Battery recycling	EOL material recovery via shredding and hydrometallurgy
Battery repurposing	Diagnostics, testing, and system integration for second-life applications

RMI Graphic.

Step 2: Estimate battery demand volumes

Battery demand was modelled across EV (two-wheelers, three-wheelers, four-wheelers, LCVs, trucks, buses) and stationary storage segments using RMI's internal GWh demand forecasts. Investment needs were sized to meet the capacity required to serve this demand, with refiners and active material producers scaled using mass-based conversion from GWh (using chemistry-specific kg/kWh assumptions).

Step 3: Apply capital intensity estimates

Capital intensity estimates were taken directly from Tesla's Master Plan Part 3 and internal industry interviews. For India, values were converted using an INR/US$ exchange rate of ₹86.

Exhibit E2 Capital intensity of value chain components

Segment	Capital Intensity (Unit)
Nickel refining	US$20 million/kt per year
Cobalt refining	US$30 million/kt per year
Lithium refining (LiOH)	US$30 million/kt per year
Graphite refining	US$17 million/kt per year
Manganese refining	US$14 million/kt per year
Cathode manufacturing	US$15 million/kt per year
Anode manufacturing	US$3 million/kt per year
Cell production	US$80 million/GWh per year
Battery assembly	US$10 million/GWh per year
Recycling	US$15 million/GWh per year
Repurposing	₹5–₹7.5 crore/GWh per year

Note: kt = kilotonnes.

RMI Graphic. Source: Tesla, https://www.tesla.com/ns_videos/Tesla-Master-Plan-Part-3.pdf; RMI analysis

Step 4: Calculate investment needs

Cumulative investment needed was derived across each segment based on the projected GWh and raw material demand volumes detailed in Appendix B.

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