



Closing the Loop

A Roadmap for Building
Circular Battery Value
Chains in India



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CLOSING THE LOOP

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Closing the Loop: A Roadmap for Building Circular Battery Value Chains in India

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ABOUT THE CRRET WHITE PAPER SERIES

The CRRET White Paper Series is the flagship publication series of the Centre for Resource Efficiency, Recyclability and Circularity in Energy Transitions (CRRET) at the Indian Institute of Technology Madras. The series provides a trusted platform for disseminating evidence-based research, technical insight, and policy perspectives that support the transition towards a circular and resource-efficient economy.

A white paper occupies a distinctive place between academic scholarship and public decision-making. Journal articles speak chiefly to specialists, while policy briefs must compress complex questions into a few pages. A white paper does what neither form can do alone: it assembles the full body of evidence on a question of public importance, examines that evidence with academic rigour, and presents the findings in a form that policymakers, industry leaders, and financiers can act upon. The most influential white papers become shared reference points for entire sectors. They define terms, consolidate scattered data, name structural problems candidly, and set out pathways that are practical, sequenced, and implementable.

Each paper in the series is developed through rigorous research, drawing on interdisciplinary methods and on collaboration with academia, industry, government, and international partners. Findings are grounded in primary evidence wherever possible, triangulated against the published literature, and translated into actionable recommendations intended to inform policy, guide industry practice, and advance innovation.

The series addresses emerging challenges and opportunities at the intersection of resource efficiency, material circularity, recycling technologies, and sustainable energy transitions. Its themes include critical minerals and materials, battery circularity, e-waste and solar photovoltaic waste management, plastics recycling, life cycle assessment, industrial symbiosis, resource recovery, sustainable manufacturing, and circular economy strategies for clean energy systems.

The present volume, *Closing the Loop: A Roadmap for Building Circular Battery Value Chains in India*, inaugurates the series. Built on direct consultations across India's battery value chain, it exemplifies the approach to which the series is committed: patient evidence, plain analysis, and recommendations that can be carried into practice. Through this and the volumes that

follow, CRRET aims to foster knowledge exchange, promote evidence-informed decision-making, and contribute to resilient, low-carbon, and circular energy transition pathways that support sustainable economic development.

Series Vision

To become a leading knowledge platform that advances research, policy, and practice in resource efficiency, recyclability, and circularity, enabling sustainable energy transitions in India and beyond.

Series Tagline

Evidence-based insights on circular economy, resource efficiency, recycling technologies, and sustainable energy transitions.

PREFACE

India's transition towards electric mobility represents one of the most significant industrial and sustainability transformations of our time. As electric vehicle adoption accelerates and domestic battery manufacturing expands, ensuring that batteries remain within a circular economy will be critical for strengthening resource security, reducing environmental impacts, and enhancing the resilience of future supply chains. While considerable attention has been devoted to battery technologies and manufacturing, achieving circularity ultimately depends on coordinated action across the entire battery value chain—from producers and manufacturers to recyclers, policymakers, and consumers.

Recognizing this need, this white paper has been developed by the HSBC India - supported Centre for Circularity at the Indian Institute of Technology Madras. Rather than relying solely on secondary evidence, the study sought to understand the realities, opportunities, and challenges experienced by key stakeholders actively shaping India's emerging battery ecosystem. Through extensive stakeholder consultations complemented by a review of academic literature, policy documents, and industry reports, the study brings together diverse perspectives to provide an evidence-based assessment of India's battery circularity landscape.

The objective of this white paper is not to prescribe a single pathway for battery circularity, but to stimulate informed dialogue and support evidence-based decision-making. The recommendations presented in this report are intended to contribute to ongoing discussions on policy design, industry practices, and institutional coordination required to build a resilient and circular battery value chain in India. As technologies, markets, and regulations continue to evolve, many of these recommendations will require continuous refinement through collaboration among government, industry, academia, and civil society.

I would like to express my sincere gratitude to HSBC India for supporting the Centre for Circularity and for recognizing the importance of advancing knowledge on battery circularity in India. I also extend my heartfelt appreciation to all the organizations and stakeholders who generously shared their time, experiences, and insights during the course of this study. Their openness and willingness to engage made this work possible.

It is my hope that this white paper serves as a useful resource for policymakers, industry leaders, researchers, and practitioners working towards a more sustainable, resource-efficient, and circular battery ecosystem. More importantly, I hope it encourages continued collaboration

across the battery value chain, recognizing that the transition to circularity is a shared responsibility that can only be achieved through collective action.

A handwritten signature in blue ink, appearing to read 'Krishna' with a stylized flourish at the end.

Dr. Krishna Malakar

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EXECUTIVE SUMMARY

India's battery revolution is accelerating. Electric vehicle adoption is surging, energy storage deployment is expanding, and battery manufacturing capacity is being built. Yet beneath this momentum lies a fundamental contradiction: India is building a battery economy without a corresponding circular economy to manage the resulting waste, secure critical minerals, and build domestic industrial capacity. Without a vigorous circular framework, the country risks not only perpetuating its dependence on imported minerals but also missing a revolutionary economic opportunity: one that could create green jobs, reduce carbon emissions, and position India as a global leader in sustainable battery value chains. This white paper, based on stakeholder consultations¹ with four original equipment manufacturers, two producers, and four recyclers across India's battery value chain, identifies five critical system gaps and proposes a sequenced roadmap to address them. The findings reveal that India's battery circularity challenge is not simply a recycling challenge; it is a value-chain coordination challenge requiring alignment among industry, regulators, financiers, and technology providers.

Five Key Findings

1. India faces a growing battery circularity challenge. With Electric Vehicle (EV) sales approaching 10 million units annually by 2030 and battery demand surging from 10 GWh in 2024 to an estimated 220 GWh by 2030, India is generating battery waste at an unprecedented scale. Since the notification of the Battery Waste Management Rules (BWMR) 2022, approximately 58.26 lakh tonnes of battery waste have been recycled, yet the current collection and recycling infrastructure is insufficient to meet future demand. Battery circularity represents a ₹75,500-crore market opportunity, but only if the foundational facilitators are in place.

2. Circularity readiness is uneven across stakeholders. Stakeholder consultations reveal substantial variation in preparedness for battery circularity across OEMs, battery producers, and recyclers. While some organizations have established advanced circular design frameworks, blockchain-enabled traceability systems, active take-back mechanisms, and high-purity material recovery capabilities, others remain at much earlier stages of circularity, including limited awareness of Extended Producer Responsibility (EPR) obligations and basic recycling operations. These disparities extend beyond technological capability and reflect broader governance and institutional gaps, with sustainability reporting and corporate strategies often overlooking end-of-life battery management. Closing these readiness gaps will require coordinated regulatory action and greater alignment across the battery value chain.

3. The LFP paradox threatens long-term sustainability. India's preferred battery chemistry, viz., Lithium Iron Phosphate (LFP), provides compelling advantages in cost, safety, and longevity. Yet stakeholder consultations revealed unanimous agreement across OEMs, battery producers, and recyclers that LFP recycling is not economically viable under current conditions. LFP contains only 1-2% lithium and primarily iron and phosphorus: materials with low recoverable value. As the market shifts decisively toward LFP, with projections suggesting it will account for over 60% of battery demand by 2047, India is creating a future waste liability rather than a circular resource. Without policy intervention: differentiated EPR fees, viability gap funding, or technology breakthroughs, LFP batteries will accumulate as unrecycled waste.

4. Informal-sector collection remains indispensable. Stakeholder consultations indicate that recyclers obtain 60-90% of their feedstock from the informal sector, underscoring its central role in collecting end-of-life batteries, particularly from two- and three-wheelers and consumer electronics. The informal sector is not a "leak" to be eliminated; it is the backbone of collection. At the same time, stakeholder consultations suggest that claims of zero leakage remain difficult to verify in the absence of robust post-sale traceability. The path forward is not elimination but formalization through aggregation centers, licensing, and a reduction in Goods and Services Tax (GST): not coercion, but incentives that make formal channels more attractive than informal ones.

5. Governance and market failures outweigh technology constraints. Advanced recyclers already achieve world-class recovery rates, with some recovering 97-99% of lithium, cobalt, and nickel, and achieving battery-grade purity exceeding 99.5%. The binding constraints are not technological; they are policy and market failures: EPR targets that are unrealistic and chemistry-agnostic; GST at 18% that disincentivizes formalization; no recycled-content mandates to create demand for recyclers' outputs; traceability initiatives that remain fragmented and unimplemented; and financing barriers that leave even promising recyclers struggling to access capital. Technology is ready; governance must keep pace.

Five Priority Actions

1. Reform EPR targets. Shift from arbitrary collection percentages to performance-based, chemistry-specific targets aligned with actual battery lifespan (10-15 years). Differentiate EPR fees by chemistry to reflect actual recycling costs, with LFP batteries requiring higher fees or viability gap funding. Create a centralized credit clearing house with floor and ceiling prices to stabilize the market. *Lead agencies: Ministry of Environment, Forest and Climate Change (MoEFCC), and Central Pollution Control Board (CPCB).*

2. Launch Battery Aadhaar. Mandate a phased national battery traceability registry with unique 21-character Battery Pack Aadhaar Numbers (BPAN) for every battery, starting with imported cells and high-value EV packs. Build on the three-layer identification architecture: physical alphanumeric marking, QR code (QR) code with static data, and a secure central server with dynamic lifecycle data. Ensure compatibility with global battery passport frameworks, including the EU Batteries Regulation. *Lead agencies: MoEFCC, CPCB, NITI Aayog.*

3. Reduce GST on recycled battery materials. Cut GST on recycled battery scrap from 18% to 5%. This is the single most unanimous demand across all recyclers: a rare consensus. GST reduction would narrow the price gap between formal and informal channels, making formal recycling economically competitive and driving formalization. *Lead agencies: GST Council and Ministry of Finance.*

4. Mandate recycled content. Implement and enforce minimum recycled-content requirements for new batteries (e.g., 10% by 2030, 20% by 2035), aligned with the FY 2027-28 mandate already announced. Complement with robust verification and certification mechanisms to prevent fraudulent claims. Differentiate targets by chemistry to reflect varying recycling economics. *Lead agencies: MoEFCC and CPCB.*

5. Build domestic refining and cell manufacturing capacity. Without domestic cell manufacturing, closed-loop circularity is impossible. Scale up the Production Linked Incentive for Advanced Chemistry Cell (PLI-ACC) scheme (₹18,100 crore for 50 GWh) and the Critical Mineral Recycling Incentive Scheme (₹1,500 crore) to catalyze investment in refining capacity. Support the transition from R2 (black mass producers) to R4 (end-to-end refiners). Invest in testing infrastructure and common-facility centers for separation science and materials characterization. *Lead agencies: Ministry of Mines, Ministry of Heavy Industries, and Ministry of Science and Technology.*

The Roadmap

Short Term (2026-2028): Foundational Enablers

The initial phase establishes the regulatory and institutional foundations for circularity. GST reform from 18% to 5% on recycled scrap creates economic incentives for formalization by narrowing the price gap between formal and informal channels. Battery Aadhaar pilots introduce lifecycle traceability, enabling EPR verification and state-of-health assessment for second-life applications. Government-facilitated aggregation centers integrate informal collectors into formal value chains, providing infrastructure, training, and market linkages. Revised EPR targets shift from

arbitrary collection percentages to performance-based, chemistry-specific obligations aligned with actual battery lifespan. These four actions are mutually reinforcing: GST reform enables formalization, traceability enables verification, aggregation centres enable integration, and EPR revisions align incentives.

Medium Term (2028-2032): Scaling the Circular Battery Ecosystem

Building on the foundations, this phase develops the infrastructure needed to close material loops. Recycled-content mandates create demand-side pull, requiring producers to incorporate minimum percentages of recycled materials and forcing the link between design intent and material procurement. Domestic refining capacity converts black mass into battery-grade salts, reducing dependence on exports and capturing domestic value. Testing infrastructure ensures quality assurance for recycled materials, building confidence among manufacturers. Nationwide expansion of the collection network scales formal collection to meet increasingly demanding BWMR targets. These actions address the key constraints that currently prevent the development of closed-loop material flows.

Long Term (2032-2040): Facilitating Closed-Loop Integration

The final phase achieves full circularity through integration of the entire value chain. Closed-loop battery manufacturing ensures that recycled materials flow directly back into domestic cell production, eliminating the current open-loop dynamic. Domestic precursor industries develop production of cathode and anode active materials, completing the value chain from recycling to cell manufacturing. Circular battery markets, including mature EPR certificate trading, second-life battery markets, and carbon credits, create diversified revenue streams that make circularity economically self-sustaining. By 2040, India's battery circularity journey should transform from a collection-and-export model to a truly closed-loop system in which materials flow continuously from recycling back into domestic manufacturing.

Mutual Reinforcement

Each phase builds on the previous (see Fig. A): short-term foundations enable medium-term infrastructure, which enables long-term integration. The roadmap is not a sequence of independent actions but a coordinated strategy where each element reinforces the others. Success requires sustained political will, institutional coordination, and stakeholder alignment across government, industry, and financiers.

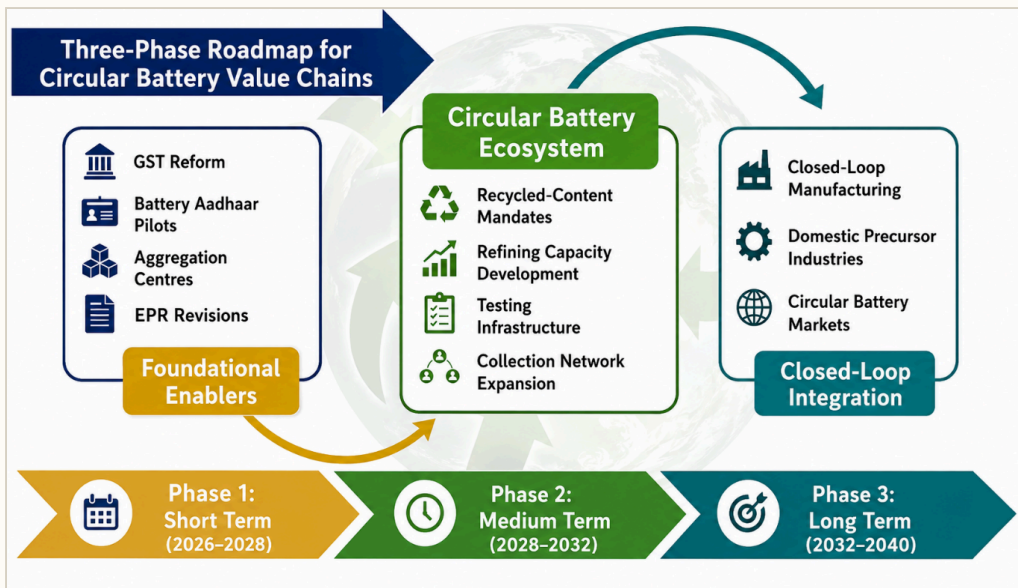


Fig. A. Implementation roadmap for India's battery circularity transition: Each phase builds on the previous one: short-term foundations enable medium-term investments, which in turn enable long-term integration. The roadmap reflects stakeholder consensus on priority actions and is designed to be practical, sequenced, and implementable

The Opportunity

India stands at a decisive moment. The country's battery revolution is gathering pace, and the choices made today will determine whether it delivers on its promise of sustainability, resource security, and economic opportunity or creates a mounting waste liability and perpetuates import dependence. The technology exists. The policy foundations are being laid. The stakeholder consensus is emerging. What remains is the political will and institutional capacity to coordinate action across the value chain. By building a circular battery economy, India can secure its critical mineral supply, create green jobs, reduce carbon emissions, and position itself as a global leader in battery circularity. The time to act is now.

NOTES

1. This white paper is based on semi-structured stakeholder consultations conducted as part of the HSBC India -supported project on battery circularity and sustainable energy transitions at IIT Madras. Details of the methodological framework adopted to conduct this research are provided in Annexure 1. To maintain confidentiality and protect commercially sensitive information, the identities of the original stakeholder organizations have been replaced with coded identifiers: Original Equipment Manufacturers (OEM1, OEM2, OEM3, OEM4), Producers (PROD1, PROD2), and Recyclers (REC1, REC2, REC3, REC4). ↩

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CHAPTER

1

The Strategic Importance of Battery Circularity

1.1. India's battery transition

India's electric mobility revolution is gathering pace across all vehicle segments. The country's lithium-ion battery (LiB) demand for electric vehicles (EVs) stood at approximately 10 GWh in 2024, with projections suggesting this could surge to between 422 and 698 GWh by 2040 (Gode et al., 2021). Annual LiB demand is projected to reach 220 GWh by 2030, requiring corresponding investments in manufacturing capacity, raw material sourcing, and end-of-life (EoL) management infrastructure (Bhattacharya et al., 2025). The Battery Waste Management Rules (BWMR) 2022 and their subsequent amendments represent the primary regulatory framework governing this transition, establishing extended producer responsibility obligations and recovery targets for battery waste. Beyond EVs, battery energy storage systems are emerging as a critical facilitator of India's renewable energy ambitions. Grid-scale storage, commercial and industrial applications, telecom backup, and utility-scale battery energy storage systems are all driving demand for battery deployment. According to the Central Electricity Authority, India will require 41.65 GW (208.25 GWh) of Battery Energy Storage System (BESS) capacity by 2029-30 to manage a grid where variable renewable energy penetration is expected to reach 40% of total generation. Other estimates suggest requirements could reach 47 GW by 2031-32, underscoring the scale of the opportunity for battery circularity (ESMAP, 2020; Hemavathi, 2025). Stationary batteries, with their longer lifespans of 15-20 years, present unique circularity challenges: they will remain in service for extended periods before reaching EoL, creating a delayed but significant waste stream that current policy frameworks may not adequately address (Sarkar et al., 2026). The intersection of EV growth and energy storage deployment amplifies both the opportunity and the risk: India can either build a circular battery ecosystem that secures domestic material supplies or allow spent batteries to become an environmental liability (Alagarsamy et al., 2025).

India's battery transition is fundamentally constrained by its dependence on imported critical minerals. The country relies heavily on imports for lithium, cobalt, and nickel: the key components of lithium-ion batteries. During fiscal year 2024, India's imports of critical minerals surged dramatically: by 921% for lithium, 137% for nickel, and 85% for cobalt (Goel et al., 2024). This dependence is compounded by global supply chain concentration. China refines approximately 74% of global lithium, 35% of nickel, and 80% of cobalt, while controlling 98% of Lithium Iron Phosphate (LFP) cathode active material production (Goel et al., 2024). For India, this represents not merely an economic challenge but a strategic vulnerability: the country's energy transition ambitions rest on materials sourced from supply chains over which it has limited influence (Kaur et al., 2023; Hemavathi, 2025). Spent EV batteries represent a domestic source of critical minerals that can reduce import dependence if effectively recovered (Kumar et al., 2025; Lahan et al., 2026).

1.2. Why Circularity Matters

Circularity provides India a practical pathway to reduce its dependence on imported critical minerals (see Fig. 1). Recycling LiB can recover valuable materials and significantly reduce the country's reliance on imports (Lahan et al., 2026). Efficient recycling of LiB provides a solution: recovering up to 80% of lithium from EoL batteries could substantially reduce India's dependence on imports and help establish a resilient, circular battery supply chain (Panda et al., 2023). The Government of India has recognized this imperative through the ₹1,500 crore Incentive Scheme for critical mineral recycling, approved in September 2025. The scheme aims to develop domestic recycling capacity for LiBs, e-waste, and industrial scrap, thereby reducing import dependence and supporting clean energy and advanced manufacturing sectors. A functioning circular loop for minerals requires collection infrastructure, processing capacity, and, "most critically", demand for recycled materials through domestic manufacturing (Zhang et al., 2026; Adegboye et al., 2024).

The waste management challenge posed by EoL batteries is both immediate and growing. Since the notification of the BWMR 2022, approximately 58.26 lakh tonnes of battery waste have been recycled under the Extended Producer Responsibility (EPR) mechanism. However, as battery deployment accelerates, the volume of EoL batteries will grow rapidly (Bhattacharya et al., 2025). If EoL batteries are treated simply as waste, India creates new environmental burdens and misses a chance to recover value. Circular economy pathways can reduce dependence on landfills by over 70% while enabling the recovery of valuable materials (Islam & Iyer-Raniga, 2022). The informal sector plays a dominant role in battery collection and dismantling, managing nearly 90% of India's battery waste. Weak enforcement of the BWMR 2022, limited collect-

ion networks, and the dominance of informal recyclers impede circularity (Rizos & Urban, 2024; Gahlaut & Dwivedi, 2024). Strengthening policy enforcement and building institutional capacity at the state level are critical priorities (Varshney et al., 2020; Joshi et al., 2021).

Circularity is not merely an environmental imperative; it is a strategic facilitator of India's energy transition. A domestic circular battery economy insulates the country from supply shocks, reduces lifecycle carbon emissions, and supports the Atmanirbhar Bharat (self-reliant India) vision (Verma et al., 2026; Upasani, 2026). Recycling LiB paves India with a practical pathway to recover critical materials, cut carbon emissions, and reduce dependence on imported minerals (Kumar et al., 2025). Recycling at scale can reduce battery production carbon emissions by up to 90% (Dunn et al., 2021). The international policy landscape is also evolving. The European Union (EU)'s Batteries Regulation, with its mandatory recycled-content requirements and battery passport provisions, will affect Indian battery exports and supply chains (de Waal, 2025; Su et al., 2025). India must build domestic circularity capabilities not only to serve its own market but also to remain competitive in global battery and EV value chains (Dwivedi & Akula, 2025; Hasan, 2026).

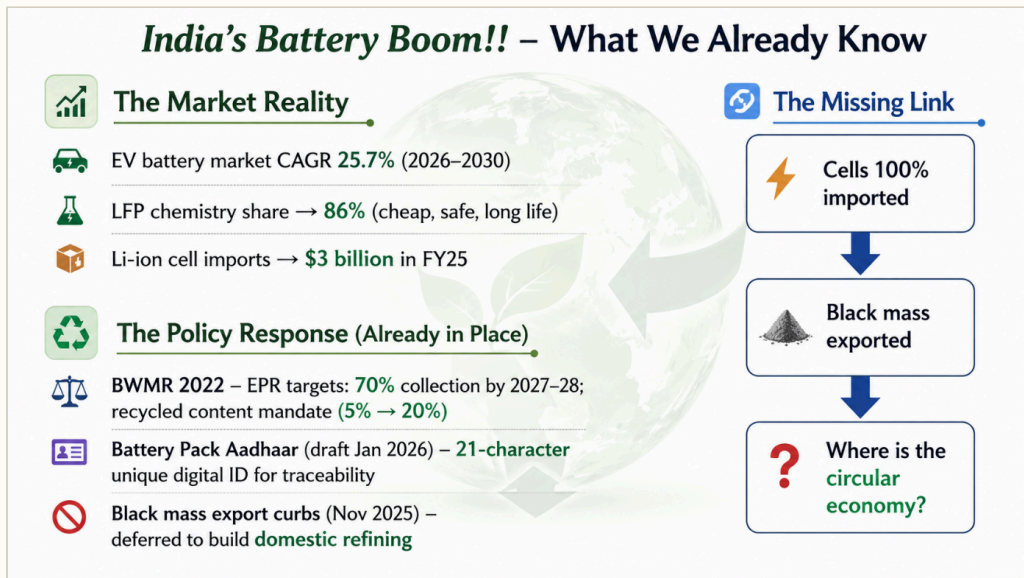


Fig. 1. India's battery landscape: market growth, policy response, and the missing link

1.3. Circularity as an Economic Opportunity

Battery circularity represents a substantial economic opportunity for India. Recent estimates suggest that battery circularity in India represents a ₹75,500 crore (US\$9 billion) market opportunity (Goel et al., 2024). This value creation spans multiple segments: collection and dismantling; material recovery and refining; second-life applications; and manufacturing battery-grade materials from recycled feedstocks. A formalized recycling and reuse industry could meet nearly 40% of the country's demand for key minerals (Kaur et al., 2023). The Government of India has taken steps to catalyze this opportunity through the Critical Mineral Recycling Incentive Scheme, which has approved 58 companies to develop domestic recycling capacity (Hemavathi, 2025). Private investment is following suit, with firms announcing significant investments in critical minerals refining facilities.

The circular battery economy has significant employment potential. Battery recycling is projected to create more than 106,000 direct green jobs, with other estimates suggesting between 27,000 and 41,000 new jobs by 2030 (Kaur et al., 2023). These jobs span the value chain: collection and aggregation, dismantling and sorting, material recovery and refining, second-life assessment and repurposing, and research and development (Padmanabhan et al., 2024). The informal sector, which currently dominates battery collection, employs a significant workforce. Formalization through aggregation centers, licensing, and appropriate policy frameworks can improve working conditions, increase safety, and provide social security while preserving livelihoods (Gupt & Sahay, 2015; Scur et al., 2022).

India has the potential to become a global hub for battery recycling and circular economy innovation. The country's growing battery market, combined with its cost-competitive manufacturing base and engineering talent, creates favorable conditions for building a world-class recycling industry (Mukhuty et al., 2026; Patnaik et al., 2026). The domestic recycling industry can support the development of adjacent industries: precursor chemical manufacturing, equipment fabrication for recycling processes, testing and certification services, and second-life battery integration (Rautela et al., 2025; Upasani, 2026). The Budget has encouraged battery recycling and urban mining ecosystems, positioning circular recovery of lithium, cobalt, and nickel as a long-term pillar of India's energy transition and industrial resilience. With policy support, technological development, and market incentives aligned, India can transform its battery waste challenge into a strategic industrial opportunity (Choudhury et al., 2026; Dey et al., 2026).

CHAPTER

2

State of Battery Circularity in India

India's battery circularity landscape is characterized by a dynamic interplay of formal and informal actors, growing technological capability, and a rapidly evolving policy framework. To assess the current state of play, this study conducted semi-structured interviews (refer to [Annex 1: Methodology](#) for further details) with four Original Equipment Manufacturers (OEMs: OEM1, OEM2, OEM3, and OEM4), two producers (PROD1 and PROD2), and four recyclers (REC1, REC2, REC3, and REC4), representing a cross-section of the battery value chain (see [Fig. 2](#)). The findings from these stakeholder consultations (is discussed in the present section), contextualized within the broader policy and market environment, provide an introductory overview of the ecosystem, its current strengths, and its persistent weaknesses, setting the stage for a deeper examination of system gaps in [Section 3](#).

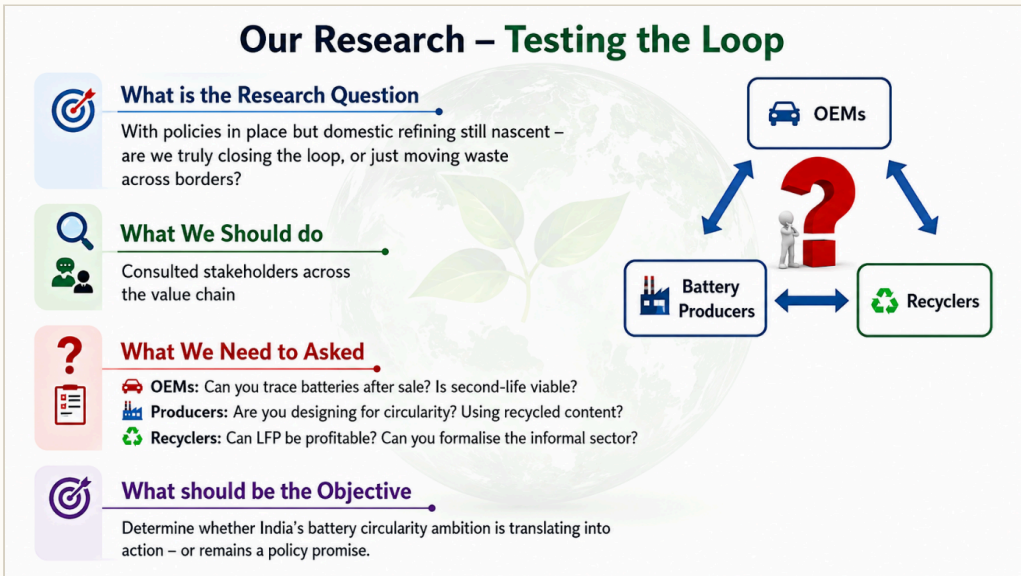


Fig. 2. Research flow illustrating the analytical framework guiding the stakeholder consultation process

2.1. Stakeholders in the Battery Ecosystem

2.1.1. OEMs (*Vehicle Manufacturers*)

India's leading electric vehicle OEMs are at the forefront of battery integration and represent the primary demand side of the battery ecosystem. Stakeholder consultations indicate that the OEMs interviewed currently import nearly all battery cells, with LFP chemistry dominating their product portfolios because of its safety, cost, and longevity advantages. While all participating OEMs are registered under the BWMR and have established EPR compliance mechanisms, their preparedness for battery circularity varies considerably. OEMs demonstrated differing levels of readiness in circular design, traceability, recycler engagement, and second-life applications. Several have begun integrating circular economy principles into product design and are actively collaborating with recyclers, whereas others face challenges with traceability, integration of recycled content, and the economic viability of second-life applications. Common challenges identified across the OEMs include complete dependence on imported battery cells, the absence of domestic cell manufacturing, and uneven readiness for battery traceability. Specific stakeholder experiences illustrate these broader patterns. One OEM (OEM2) has developed an integrated circular design framework (the Tatva framework²) and established active partnerships with recyclers, demonstrating comparatively higher readiness for circularity. In contrast, another OEM (OEM3) had developed a battery passport system but discontinued its implementation because value-sharing arrangements with recyclers proved commercially unviable, highlighting that governance and business incentives remain as important as technological capability. Similarly, one manufacturer (OEM4) reported limited opportunities for second-life applications because batteries used in three-wheeler applications reach approximately 70% State-of-Health (SoH) before replacement, leaving insufficient residual life for economical repurposing.

2.1.2. Producers (*Battery Manufacturers/Assemblers*)

Battery producers occupy a critical position in the value chain, as they are legally responsible for the batteries they place on the market under the EPR framework. Stakeholder consultations with two producers: one a large solar manufacturer planning cell production, and the other an established pack assembler, revealed substantial variation in circularity readiness, particularly in EPR compliance, traceability, and end-of-life engagement. Both producers share critical gaps: zero recycled content in their batteries and complete dependence on imported cells, consistent with broader industry observations. However, their approaches to circularity diverge significantly. One producer (PROD2) has established EPR registration, active take-back systems, and

a blockchain-based "Battery Aadhaar" traceability initiative, demonstrating comparatively higher readiness. This producer has also integrated modular architecture, standardized cell formats, and reversible fasteners into product design, reflecting a deliberate effort to incorporate circular principles. In contrast, the other producer (PROD1), a large solar manufacturer planning a 3.5 GWh cell plant, remains entirely unaware of its EPR obligations, with its respondent stating they were "not aware of the policy." This represents a significant regulatory blind spot among new entrants. This governance gap is compounded by the nature of current sustainability reporting frameworks. While PROD1's public sustainability claims (EcoVadis Gold, net-zero targets) align with voluntary reporting norms, these frameworks do not automatically translate into operational compliance with specific environmental regulations such as the BWMR. Under the Securities and Exchange Board of India's (SEBI) Business Responsibility and Sustainability Reporting (BRSR) framework, Scope 3 emissions reporting, including the "use of sold products" and "end-of-life treatment" categories, remains largely voluntary and is currently mandated only for the top 1,000 listed companies. For a company like PROD1, which is not within this mandatory reporting bracket, sustainability reporting and regulatory compliance operate in separate silos. This disconnect, which has also been observed in other emerging economy contexts (Gahlaut & Dwivedi, 2024), underscores the need for regulatory attention on two fronts: strengthening enforcement of BWMR registration and integrating EPR compliance metrics into mandatory sustainability reporting frameworks to ensure that public sustainability claims are grounded in operational reality.

2.1.3. Recyclers

The recycling sector spans a spectrum from new entrants to established players, with varying levels of technological sophistication. Stakeholder consultations with four recyclers revealed a sector characterized by significant heterogeneity in scale, technology, and regulatory compliance, yet united by common challenges. Across the recyclers interviewed, several patterns emerge. All recyclers source a significant portion of their feedstock, ranging from 60% to 90%, from the informal sector, highlighting the sector's dependence on informal collection networks. Technological capability varies considerably: more established recyclers have developed proprietary hydrometallurgical processes achieving 97–99% recovery rates for lithium, cobalt, and nickel with battery-grade purity ($\geq 99.5\%$), while newer entrants operate at the mechanical separation stage. Second-life readiness is also polarised, with some recyclers operating commercial second-life facilities, while others remain skeptical of market readiness. EPR compliance presents another area of variation: while the most mature recycler is fully compliant with R4 status (from collection to final refining), others are either in the application process or registered

but have yet to use the portal. This uneven compliance landscape allows non-compliant operators to undercut compliant ones, underscoring the need for stronger enforcement. Specific stakeholder experiences illustrate these broader patterns. One of the most mature recyclers (REC4) has achieved 97–99% recovery rates with battery-grade purity, developed proprietary low-temperature, low-pressure hydrometallurgy, and maintains partnerships across industries and institutions. Another recycler (REC2) operates a commercial 100 MWh second-life facility with AI/ML-based SoH estimation and has developed a unique mechanochemical lithium-first extraction process. In contrast, a newer entrant (REC1), operational for less than a year, claims a 12,000 tpa capacity but operates only at the mechanical separation stage, raising questions about the accuracy of its capacity claims. Another recycler (REC3) has adopted a vertically integrated model with 80% local fabrication, focusing on cobalt-rich chemistries. A notable finding across all recyclers is the unanimous consensus that LFP recycling is not economically viable under current conditions, that GST at 18% represents a universal barrier to formalization, and that domestic refining capacity remains a critical gap. These shared concerns underscore the need for policy intervention to address structural barriers that affect the entire recycling sector.

2.1.4. Policymakers

The regulatory landscape for battery circularity in India is shaped by multiple institutional actors operating at the central and state levels. The Ministry of Environment, Forest, and Climate Change (MoEFCC) serves as the primary regulatory authority, having notified the BWMR in 2022 and subsequently amended it in 2025. The Central Pollution Control Board (CPCB) administers the EPR portal, which has registered over 4,000 producers and 487 recyclers. Stakeholder consultations indicate that the CPCB has reportedly upgraded its portal based on recyclers' input, reflecting a positive trend in regulatory responsiveness (Hemavathi, 2025). The Ministry of Mines has launched the ₹1,500 crore Critical Mineral Recycling Incentive Scheme, which has approved 58 companies to develop domestic recycling capacity. Concurrently, NITI Aayog is deliberating a phased implementation framework for the battery passport, aligned with international best practices. State Pollution Control Boards (SPCBs) are responsible for ground-level implementation; however, recyclers consistently report significant gaps in SPCB capacity and enforcement. This multi-tiered governance structure creates both opportunities for coordination and risks of fragmentation (Ghosh et al., 2021; Rizos & Urban, 2024).

2.1.5. Informal Sector

Stakeholder consultations confirm that the informal sector is the backbone of India's battery collection system, managing an estimated 60-90% of end-of-life battery feedstock. Recyclers depend heavily on informal aggregators, with the share of informal feedstock ranging from 60% to 90% across the recyclers interviewed. The informal sector is not merely a "leak" to be eliminated; it is an integral part of the collection ecosystem that provides livelihoods, collection coverage, and feedstock to formal recyclers. Recyclers have developed diverse approaches to engaging with informal networks. One recycler (REC3) has adopted a unique social integration model that directly engages informal families, doubles their income, and supports children's education. Another recycler (REC4) takes a structured approach to education and aggregation, providing safety training and clear guidelines. Despite these varied approaches, all recyclers agree that formalization through aggregation centres, licensing, and appropriate policy incentives, particularly GST reduction, is the only viable path forward. This consensus affirms that integration, rather than elimination of the informal sector, is the preferred strategy (Varshney et al., 2020; Joshi et al., 2021).

2.2. Current Strengths

The Stakeholder consultations and policy analysis reveal three key strengths in India's battery circularity landscape: growing recycling capability, emerging traceability initiatives, and an expanding policy framework. These strengths collectively position India to become a significant player in the global battery recycling market; detailed below:

Growing Recycling Capability. India's recycling technology is advancing rapidly, with several recyclers demonstrating world-class capabilities. Stakeholder consultations indicate that advanced recyclers have achieved recovery rates of 97-99% for lithium, cobalt, and nickel with battery-grade purity ($\geq 99.5\%$), proving that high-quality material recovery is achievable domestically. Some recyclers have developed innovative processes, including mechanochemical lithium-first extraction with Artificial Intelligence/Machine Learning (AI/ML)-based SoH estimation for second-life applications, and have filed patents for these innovations. Others have achieved up to 80% local fabrication of hydrometallurgy equipment, reducing dependence on imported machinery and building domestic engineering capability. Significant investment in research and development, with some recyclers allocating 20-25% of revenue to R&D focused on battery-grade materials, graphite recovery, and chemistry-agnostic processing, further underscores the sector's commitment to innovation. These capabilities position India to reduce dependence on critical mineral imports while creating domestic value.

Emerging Traceability Initiatives. Traceability is gaining momentum through both public and private initiatives, reflecting growing recognition of its importance for circularity. The BWMR 2025 amendments mandate the use of barcodes/QR codes on all battery packs, and a technology demonstrator for "Battery Aadhaar" was launched in May 2025. Several stakeholders are actively developing traceability systems: one producer is implementing a blockchain-based Battery Aadhaar system with IoT integration, a recycler has developed a QR-based digital identity concept, and others strongly advocate for tracking to begin at the cell import stage. OEMs are exploring battery passport systems, and NITI Aayog is deliberating a phased implementation framework. The EU's Batteries Regulation, with its mandatory battery passport provisions set to take effect in February 2027, is also prompting Indian stakeholders to prepare for international compliance requirements (de Waal, 2025; Su et al., 2025).

Expanding Policy Framework. The policy architecture for battery circularity has expanded considerably in recent years, creating a comprehensive framework for transitioning from a linear to a circular battery economy. The BWMR 2022 established EPR obligations and collection targets, with 2025 amendments introducing stricter recovery targets (70% → 80% → 90%) and recycled content mandates from FY 2027-28. The ₹18,100 crore PLI-ACC scheme targets 50 GWh of domestic cell manufacturing capacity, creating potential demand for recycled materials. The ₹1,500 crore Critical Mineral Recycling Incentive Scheme has approved 58 companies to develop recycling capacity (Hemavathi, 2025). The Budget has encouraged battery recycling and urban mining ecosystems, positioning circular recovery of lithium, cobalt, and nickel as a long-term pillar of India's energy transition (Gahlaut & Dwivedi, 2024; Ghosh et al., 2021). Collectively, these policy instruments provide a foundation for transitioning from a linear to a circular battery economy, though implementation and enforcement remain critical challenges.

2.3. Current Weaknesses

Stakeholder consultations reveal three persistent weaknesses in India's battery circularity landscape: limited closed-loop material flows, weak traceability, and low uptake of recycled content. These weaknesses are not isolated but mutually reinforcing, collectively preventing the emergence of a truly circular battery economy; further detailed below:

Limited Closed-Loop Material Flows. Despite advanced recycling capabilities, India lacks the essential link to close the loop: domestic cell manufacturing. Stakeholder consultations confirm that all participating OEMs and producers import 100% of their battery cells. One producer has planned cell manufacturing by FY27 (3.5 GWh), but this remains aspirational and is accompanied by zero current EPR capability. Another assembles packs only, with cells imported at 100%. Recyclers can produce battery-grade materials, some achieving 99.5% purity, but there

are no domestic cell manufacturers to purchase them. Consequently, recovered materials are either exported as black mass or sold to international refiners, rather than flowing back into Indian battery production. This open-loop circularity means India is not capturing the full economic and strategic value of its battery waste, and the fundamental barrier posed by the absence of domestic cell manufacturing remains unresolved.

Weak Traceability. While traceability initiatives are emerging, no stakeholder has implemented an operational upstream traceability system (mine-to-cell). All participating OEMs agree that upstream traceability is "very difficult" or impossible without government intervention. One OEM had developed a working battery passport capability but discontinued it because recyclers would not share value, a business model misalignment that highlights the need for shared economic incentives. Among producers, one remains unaware of Battery Aadhaar, while another is actively implementing a blockchain-based system. Among recyclers, readiness varies considerably: some have high readiness but no live system in place, while others have low awareness or view implementation as a major challenge. Without a government-mandated, industry-wide system with clear standards and economic incentives for all parties, traceability will remain fragmented and ineffective.

Low Recycled-Content Uptake. Recycled content in new batteries is virtually non-existent across the stakeholder spectrum. Both producers use 0% recycled battery-grade material. Among OEMs, one uses 0% recycled content, another uses approximately 5% in some cells, and one claims 35% but lacks verification and active partnerships with recyclers. The claimed recycled content may come from non-battery streams (aluminum, steel) or supplier declarations without independent verification (Dunn et al., 2021). Several stakeholders have advanced circular design features, including modular design, standardized cell formats, and reversible fasteners, yet continue to use zero recycled content, demonstrating that design intent does not automatically translate into material procurement. A policy mandating minimum recycled content (e.g., 10% by 2030, 20% by 2035) would be needed to create demand for recyclers' outputs and to force OEMs and producers to verify their claims (Dunn et al., 2021; Zhang et al., 2026; Rizos & Urban, 2024).

NOTES

2. This is OEM2's proprietary circular design framework. While the detailed components are confidential, the framework incorporates principles of design for disassembly, vehicle-to-grid (V2X) capabilities, and lifecycle thinking into product development, aligned with global sustainability standards including the World Business Council for Sustainable Development (WBCSD) framework. ↩

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CHAPTER

3

System Gaps Holding Back Battery Circularity

The preceding section provided an introductory overview of India's battery circularity landscape, profiling stakeholders and identifying current strengths and weaknesses based on stakeholder correspondence and interaction. This section builds on that foundation by examining five critical system gaps in depth. The analysis is primarily driven by findings from stakeholder consultations, supported by contemporary studies that corroborate, contextualize, or contrast the empirical evidence. Each gap represents a structural barrier that prevents the emergence of a truly circular battery economy. The analysis moves beyond description to explore causal mechanisms, reinforcing feedback loops, and the interconnections between gaps. The five gaps, viz., the LFP paradox, open-loop circularity, traceability without incentives, informal collection with formal ambitions, and policy misalignments, are not independent problems but mutually reinforcing barriers that require coordinated policy intervention.

3.1. Gap 1: The LFP Paradox

Stakeholder consultations consistently revealed a fundamental paradox shaping India's battery circularity landscape: while LFP chemistry has become the dominant choice across the battery market, all recyclers interviewed, across all four recycling operations, concurred that LFP recycling is not economically viable under current conditions. As one recycler noted, "there's no economically compelling method to recover lithium from spent LFP batteries even though the market is shifting to them." This section examines why LFP has become dominant, why its recycling remains economically challenging, and what risks this paradox poses for India's circular economy ambitions, drawing primarily on stakeholder evidence and supported by recent studies.

Why Is LFP Dominant? Stakeholder consultations across OEMs and producers consistently identified cost, safety, and longevity as the primary drivers of LFP adoption. OEMs emphasized that LFP offers significant cost advantages over NMC alternatives, with Chinese manufacturers providing LFP at substantially lower per-kilowatt-hour costs (Goel et al., 2024).

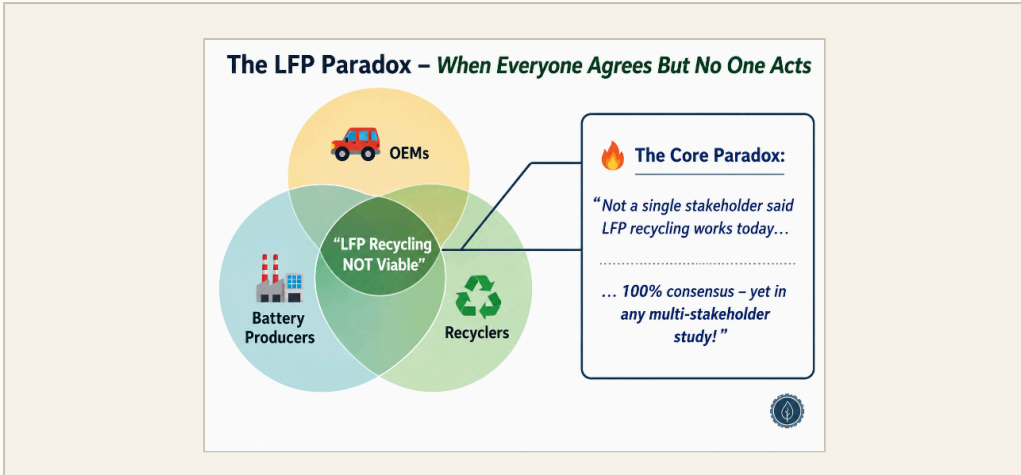
Manufacturers also highlighted that LFP provides approximately 95% of NMC's performance at considerably lower cost (Hemavathi, 2025). Several OEMs noted that India's diverse climatic conditions demand batteries capable of withstanding thermal stress, and LFP's superior thermal and chemical stability significantly reduces the risk of overheating and thermal runaway. Producers and OEMs alike pointed to LFP's substantially longer cycle life, typically 3,000 to 5,000 cycles compared to 1,000 to 2,300 for NMC, making it particularly suitable for high-mileage applications such as electric buses and shared mobility fleets (Sarkar et al., 2026). Crucially, several stakeholders emphasized that LFP eliminates dependence on cobalt, addressing ethical and supply chain concerns associated with cobalt mining. The market is responding decisively to these advantages. Globally, LFPs' share of EV batteries rose to 50% by the end of 2024, up from less than 20% in 2020, with projections suggesting 60% by 2026 (Goel et al., 2024). In India, the India Energy Storage Alliance projects LFP will account for over 60% of total battery demand by 2047 (Hemavathi, 2025). This trajectory was consistently confirmed by interviewed OEMs and producers, who indicated that their future battery procurement and manufacturing plans are overwhelmingly aligned with LFP chemistry.

Why Is LFP Recycling Difficult? Stakeholder consultations with recyclers revealed unanimous agreement on the fundamental challenge: LFP's chemistry makes recycling economically unattractive. Unlike NMC batteries, which contain valuable nickel, cobalt, and manganese, LFP batteries primarily contain iron and phosphorus, materials with low intrinsic value. Lithium content in LFP is also lower than in NMC cells, further weakening the recycling business case. One recycler noted that LFP contains only 1-2% lithium, making recovery economically unattractive. Conventional hydrometallurgical recycling is not profitable unless lithium prices rise substantially, a condition that recyclers indicated is unlikely to materialize in the near term. Recyclers further highlighted technical barriers. Existing recycling methods require significant energy, chemicals, and water. While hydrometallurgy can achieve lithium recovery rates exceeding 90%, it is plagued by high reagent consumption and the risk of secondary pollution. Pyrometallurgical methods are energy-intensive and struggle to recover low-value iron phosphate components. Most significantly, recyclers emphasized that the nascent recycling industry is equipped to handle NMC batteries, but the rapidly growing adoption of LFP requires an industrial and economic solution specifically designed for LFP, one that currently does not exist at a commercial scale (Lahan et al., 2026). One recycler observed, "The industry is set up for NMC, but the market is moving to LFP. We're heading towards a mismatch that will create a future waste crisis."

What Are the Future Risks? Stakeholders across the value chain expressed concern that the LFP paradox represents a classic market failure in which private choices create public liability. Despite LFP's environmental advantages during the use phase, outperforming NMC across air pollution, water pollution, and toxicity indicators, the end-of-life phase presents significant risks. Several recyclers noted that many LFP batteries currently end up in landfills because they do not contain high-value metals, and recyclers have limited economic incentive to process them. In landfills, moisture can break down the electrolyte salt, releasing hydrogen fluoride, a toxic gas that harms the human respiratory system and contaminates soil (Panda et al., 2023). India's growing dependence on imported lithium makes this failure to recycle a strategic vulnerability. Recycling provides a pathway to recover critical materials, cut carbon emissions, and reduce dependence on imported minerals. Without economically viable LFP recycling, India will either continue exporting its lithium resources embedded in spent batteries or lose them to landfills. One producer observed, "We're exporting black mass, but what we're really exporting is our strategic autonomy." Stakeholders also highlighted policy failures. India's EPR framework under the BWMR 2022 applies flat rates across different battery types, disadvantaging LFP compared to higher-value chemistries. As one recycler noted, "The EPR system should use different prices for different battery types, because flat rates disadvantage LFP batteries compared to higher-value ones." Producers and recyclers alike emphasized that while second-life applications yield a potential pathway, they are not a complete solution; the volume of batteries reaching EoL will eventually exceed second-life demand. Without appropriate policy mechanisms, viz., differentiated EPR fees, recycled-content mandates, or viability gap funding, the market will continue to favor LFP while failing to address its EoL implications, as also noted in the recent studies (Rizos & Urban, 2024; Gahlaut & Dwivedi, 2024).

Box 1: "The LFP Paradox"

India's dominant battery chemistry, LFP, provides compelling advantages in cost, safety, and longevity. Yet every recycler, producer, and OEM interviewed for this study agrees that LFP recycling is not economically viable under current conditions. This is not a technical problem awaiting a solution; it is a structural mismatch between market incentives and circular economy objectives. The more India embraces LFP, the greater the future liability, unless policy intervenes to align private choice with public interest.



3.2. Gap 2: Open-Loop Circularity

Despite Stakeholder consultations across the value chain consistently revealing a fundamental contradiction, recyclers have developed advanced capabilities to recover high-purity materials, yet these materials are not flowing back into Indian battery manufacturing. Instead, they are exported as black mass or sold to international refiners. This open-loop circularity, where materials are recovered but not returned to domestic production, represents a fundamental failure of the circular economy vision. Stakeholders identified three interlinked barriers perpetuating this open loop: the absence of domestic cell manufacturing, the lack of enforceable recycled-content mandates, and weak demand for recycled materials; detailed below:

No Domestic Cell Manufacturing. Stakeholders across all categories, OEMs, producers, and recyclers, unanimously identified the complete absence of domestic cell manufacturing as the most fundamental barrier to closed-loop circularity. All four OEMs and both producers import 100% of their battery cells, creating a structural barrier that prevents closed-loop material flows. One recycler observed that India’s approach to battery circularity is “akin to building a world-class recycling industry without ensuring there is a domestic manufacturing industry to consume its outputs.” Recyclers can produce battery-grade materials; one recycler achieves 99.5% purity, but there are no domestic cell manufacturers to purchase them. Stakeholders acknowledged that the policy response has been significant but insufficient. The PLI-ACC scheme aims to establish 50 GWh of domestic manufacturing capacity with an outlay of ₹18,100 crore (Hemavathi, 2025). However, as one producer noted, only 2.8% of the target capacity has been delivered, highlighting the gap between policy ambition and implementation reality. One

ibility that several stakeholders identified as a governance gap. This absence creates a vicious cycle that stakeholders described in consistent terms. Without domestic cell production, there is no demand for recycled battery-grade materials. Without demand, recyclers lack economic incentive to invest in refining capacity. Without refining capacity, India exports black mass instead of producing battery-grade materials locally. This cycle perpetuates import dependence and failure to capture the full economic value of battery waste. As one recycler observed, "We're stuck in a loop that we can't break without someone building the first cell plant."

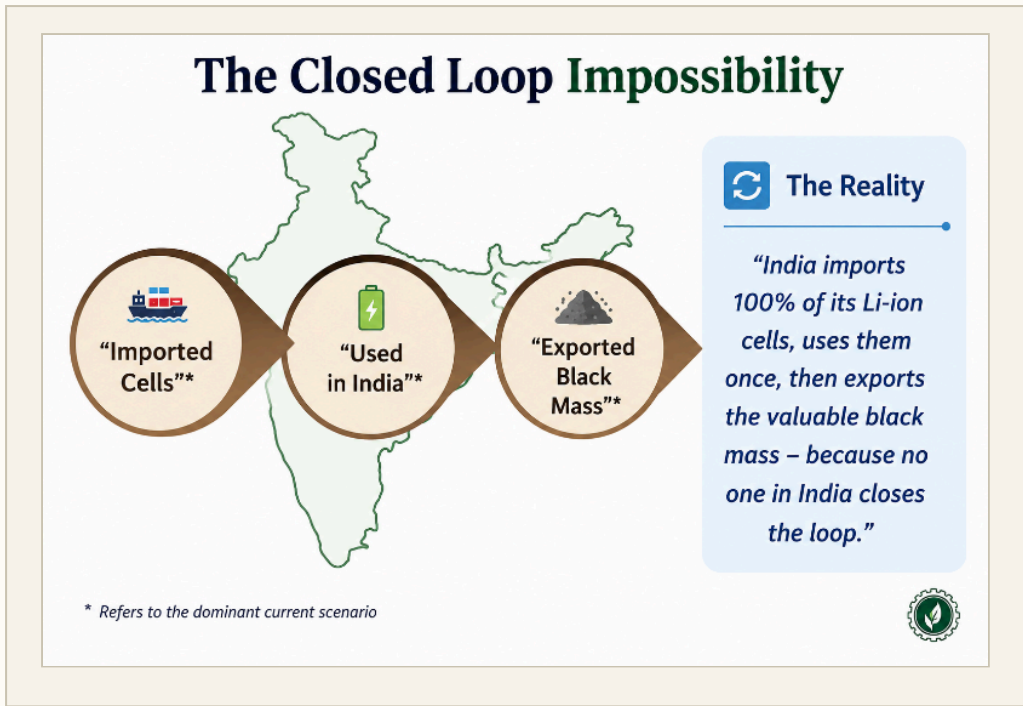
No Enforceable Recycled-Content Mandates. Stakeholders further identified the absence of mandatory recycled-content requirements for new batteries as a critical barrier. Producers and OEMs confirmed that currently, no regulatory framework mandates recycled-content requirements. The result is stark: both producers use 0% recycled battery-grade material; among OEMs, one uses 0% recycled content, another uses approximately 5% in some cells, and one claims 35% but lacks active partnerships with recyclers to substantiate this claim. Several stakeholders noted that the BWMR 2025 amendments have introduced recycled-content mandates from FY 2027-28, but specific percentages and enforcement mechanisms remain unclear. One producer observed that "recycled content mandates are essential to create demand for recyclers' outputs and to close the loop between recycling and manufacturing." Without clear, enforceable targets, producers have no regulatory push to incorporate recycled materials. The market continues to favor virgin materials, which are usually cheaper and more readily available than recycled alternatives. Stakeholders pointed to the EU's Batteries Regulation, which mandates minimum recycled content for cobalt (16%), lithium (6%), and nickel (6%) by 2031, with higher targets for 2036, as evidence that such mandates can catalyze investment and create markets (de Waal, 2025; Su et al., 2025). However, they emphasized that India's mandates will have a similar effect only if they are ambitious, enforceable, and accompanied by verification mechanisms.

Weak Demand for Recycled Materials. Even where recycled materials are available, stakeholders reported that demand from Indian manufacturers remains limited. Recyclers cited quality concerns, higher costs compared to virgin materials, and a lack of certification frameworks as key barriers. For LFP batteries, as discussed in Gap 1, recycling is not profitable under current economics (Panda et al., 2023; Kumar et al., 2025). One recycler noted that even achieving 99.5% battery-grade purity does not create a domestic market. Instead, black mass is exported to international refiners, who process it and sell it back to cell manufacturers, commonly Chinese companies that then supply Indian OEMs. One stakeholder observed, "By exporting black mass rather than refining it domestically, India is exporting both value and strategic autonomy." The Critical Mineral Recycling Incentive Scheme aims to address this, but stakeholders have indicated that the required investment scale is substantial. Consultations revealed divergent views on

black mass export restrictions: one recycler supports restrictions as they drive domestic value addition, while another reports negative impacts on contracts and unclear classification of black mass as waste versus a by-product. This tension, stakeholders noted, highlights the need for a transition pathway supporting both R2 recyclers (black mass producers) and R4 recyclers (refiners), a need which has been frequently reported in the recent literature (Deshwal et al., 2022; Kumar et al., 2025; Zhang et al., 2026). The absence of demand is also reflected in stakeholder behavior. One producer has advanced circular design features but zero recycled content, demonstrating that design intent does not translate into material procurement. One OEM claims 35% recycled content but has no active partnerships with recyclers, suggesting the material may come from non-battery streams or unverified supplier declarations. As one recycler observed, "We can recover battery-grade materials with 99.5% purity, but if there's no one in India to buy them, we're not closing the loop, we're just producing high-quality waste for export." Stakeholders across the value chain agreed that closing the loop requires coordinated action across three dimensions: building domestic cell manufacturing capacity, implementing mandatory recycled-content requirements, and creating market incentives that make recycled materials economically attractive relative to virgin materials.

Box 2: "Recycling Without Closure"

RECA recovers 97-99% of lithium, cobalt, and nickel from spent batteries, achieving 99.5% battery-grade purity. Yet India has no domestic cell manufacturers to purchase these recovered materials. Instead, black mass is exported to international refiners, who process it into battery-grade materials and sell it back to cell manufacturers, usually Chinese companies that then supply Indian OEMs. This is not a circular economy; it is a linear economy with an inefficient, export-oriented recycling step. Without domestic cell manufacturing and demand for recycled materials, India's recycling industry will remain a waste-management service rather than a circular-economy enabler.



3.3. Gap 3: Traceability Without Incentives

Stakeholder consultations consistently revealed that while India has made significant policy strides with Battery Aadhaar and the proposed battery passport, the gap between policy intent and operational reality remains wide. Across OEMs, producers, and recyclers, stakeholders identified traceability as a critical enabler of circularity, yet implementation remains stalled. This section examines why traceability initiatives remain fragmented, focusing on the incentive failures that undermine their implementation.

The Traceability Promise and Reality. Stakeholders acknowledged the potential of India's Battery Aadhaar framework, which introduces a unique 21-character Battery Pack Aadhaar Number (BPAN) for every EV and large industrial battery, built on a three-layer identification system: physical alphanumeric marking, QR code with static data, and a secure central server with dynamic lifecycle data. Each BPAN encodes origin, chemistry, configuration, safety class, and carbon footprint, while dynamic data such as SoH and EoL treatment are continuously updated. The framework mandates that producers or importers assign BPANs, with new BPANs issued for repurposing or recycling to ensure traceability across multiple life cycles. Complementing this, India's proposed battery passport, inspired by the EU's Batteries Regulation, aims to boost EV exports, ensure product safety, and improve battery quality (Dey

et al., 2026; de Waal, 2025; Su et al., 2025). Several OEMs noted that the system would help prevent unsafe practices, such as combining cells of different vintages, which can lead to performance imbalances and fire risks. However, one stakeholder cautioned that "without parallel investments in domestic exploration and beneficiation, Battery Aadhaar risks becoming a sophisticated ledger of dependence." Digital traceability alone, stakeholders emphasized, cannot change the underlying power dynamics of mineral access; it must be accompanied by investments in domestic value addition.

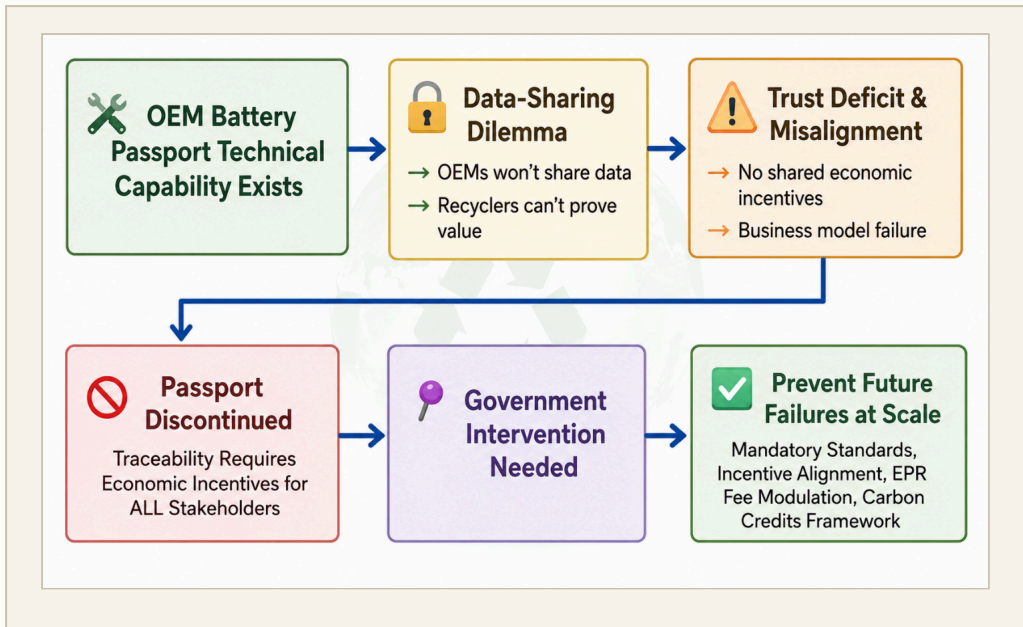
The Data-Sharing Dilemma. Despite the promise of these initiatives, stakeholders across the value chain identified a fundamental barrier: trust. One OEM observed, "The biggest barrier today is not technology; it is trust." OEMs hesitate to share sensitive data, while refurbishers cannot prove reliability without it. Strong frameworks of trust, backed by non-disclosure agreements and standardized data-sharing protocols, were identified as essential to unlock collaboration. Stakeholders noted that the battery supply chain spans multiple continents, mining in Africa and Australia, refining and manufacturing in China, and cell assembly in East Asia and Europe [also reported by Goel et al. (2024)]. With so many players involved, tracking material origins, manufacturing processes, and EoL outcomes has become increasingly difficult. Miners, manufacturers, recyclers, logistics companies, and regulators usually work in isolation or compete, raising concerns about intellectual property, trade secrets, cybersecurity, and the costs of digital systems, a concern raised in the recent literature as well (Rizos & Urban, 2024; Zhao et al., 2026). One illustrative stakeholder experience highlights this challenge. One OEM had developed a working battery passport capability but discontinued it because recyclers would not share value, a business model misalignment that underscores the need for shared economic incentives. Without economic value from data sharing, whether through EPR fee modulation, carbon credits, or shared value from second-life applications, traceability will remain a compliance burden rather than a value-creating tool. Several stakeholders noted that digital traceability initiatives, such as blockchain-based architectures, have been proposed, but their effectiveness depends on stakeholders' willingness to participate and share data. The technology for traceability exists; the incentives for adoption do not.

Stakeholder Polarization and System Fragmentation. Stakeholder consultations further revealed that readiness for traceability is highly polarized across the value chain, with significant variation in awareness, capability, and implementation. Among producers, one is actively implementing blockchain-based Battery Aadhaar, while another remains unaware of the initiative, describing it as "completely a new thing." Among recyclers, some have high readiness but no live system in place, while others have low awareness or view implementation as a major challenge. Across OEMs, there is consensus that upstream traceability (mine-to-cell) is "very difficult" or

impossible without government intervention. Stakeholders consistently emphasized that without a government-mandated, industry-wide system with clear standards and economic incentives for all parties, traceability will remain fragmented and ineffective. The effectiveness of Battery Aadhaar depends on close coordination between industry and government, particularly among OEMs, recyclers, and digital infrastructure providers. Key concerns identified by stakeholders include ensuring compatibility across different battery chemistries, designs, and usage patterns, as well as establishing secure, tamper-resistant data exchange while protecting sensitive commercial information. Digital technology adoption models emphasize that successful implementation requires addressing multiple enablers, including technological infrastructure, regulatory support, and stakeholder collaboration. As stakeholders across the value chain emphasized, digital traceability, recycled-content mandates, and targeted financial incentives are critical for facilitating a robust domestic recycling ecosystem. Without economic incentives for data sharing, traceability will remain a compliance burden rather than a value-creating tool. The technology exists; the incentives do not. Bridging this gap is essential for India's battery circularity ambitions, noted in the recent literature (Gahlaut & Dwivedi, 2024; Lahan et al., 2026; Mathiyalagan & Kandasamy, 2026; Zhao et al., 2026).

Box 3: "Why a Battery Passport Initiative Failed"

OEM3 had developed a working battery passport capability, but discontinued it because recyclers would not share value. This case illustrates a fundamental truth: traceability requires shared economic incentives. Without a business case for data sharing, whether through EPR fee modulation, carbon credits, or access to second-life value, traceability systems will remain fragmented and short-lived. Government intervention through mandatory standards and incentive alignment is essential to prevent such failures at scale.



3.4. Gap 4: Informal Collection, Formal Ambitions

Stakeholder consultations consistently revealed that India's battery collection ecosystem is dominated by a vast, decentralized informal sector handling an estimated 60-90% of EoL battery feedstock. Across all recyclers interviewed, dependence on informal channels emerged as a universal feature, with feedstock from informal sources ranging from 60% to 90%. This reality presents a fundamental tension: the informal sector is indispensable to the collection process, yet its operations are characterized by unsafe practices, limited material recovery, and regulatory evasion. This section examines the structural drivers of informal dominance, aggregator networks, and formalization pathways based on stakeholder evidence; detailed below:

Structural Drivers of Informal Dominance. Stakeholder consultations identified three interconnected factors driving the informal sector's dominance. First, informal collectors offer convenience and cash payments, appealing to consumers and small businesses. Second, unauthorized recyclers pay higher prices than formal channels because they avoid compliance costs associated with environmental and safety regulations. Third, the geographic reach of informal networks far exceeds formal collection infrastructure, particularly in rural and semi-urban areas. Several recyclers noted that this creates a self-reinforcing dynamic: informal channels are more accessible and economically attractive, which increases their feedstock volume, which in turn strengthens their market position. The consequences of informal dominance are significant. Recyclers consistently reported that informal operations often engage in unsafe practices, multi-

ng batteries in open furnaces, releasing toxic fumes, and endangering workers and the environment. Material recovery rates are typically lower than in formal recycling facilities, and valuable materials are lost. One recycler observed, "The informal sector is doing the collection, but they're also losing half the value." The lack of traceability means batteries entering informal channels cannot be tracked, complicating EPR compliance and undermining circularity goals. This represents a governance failure in which the absence of enforcement allows unsafe practices to persist and undercuts formal operators. OEM perceptions of informal leakage varied considerably during consultations. One OEM acknowledged high leakage for 2W and mobile batteries, noting that "for 4W negligible; for smaller batteries significant." In contrast, others claimed zero leakage, claims that recyclers viewed skeptically, noting that OEMs lack post-sale traceability to substantiate such assertions. Producers exhibited similar variation: one producer was very aware of leakage, acknowledging that "unauthorized recyclers pay more," while another had only limited awareness of informal channels.

Aggregator Networks and Stakeholder Engagement. Stakeholder consultations revealed that the informal sector is a complex network of actors operating at different levels. Individual collectors, "kabadiwalas", purchase spent batteries from consumers and small businesses, aggregating them for sale to larger intermediaries who supply recycling facilities. Recyclers have developed diverse approaches to engaging with these networks. One recycler works through channel partners and dealer networks, providing education and safety training. Another has developed a unique social integration model that directly engages informal families, doubles their income, and sends their children to school, demonstrating that formalization can be socially inclusive. Other recyclers rely on aggregators with formal contracts, without direct engagement with informal collectors. The effectiveness of aggregator networks depends on trust, transparency, and economic incentives. As noted in the traceability gap, stakeholders hesitate to share sensitive data without robust trust frameworks and standardized protocols. Without such frameworks, informal networks will continue to operate outside formal systems, limiting traceability and circularity. One recycler observed, "The aggregator model is essential, but we need to bring them into the formal system, not push them out."

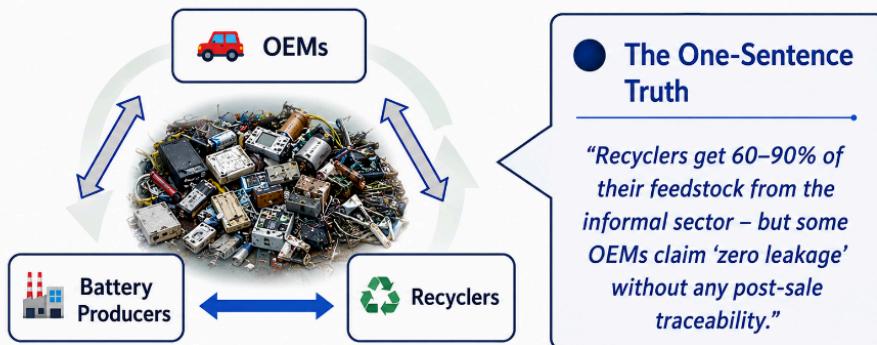
Formalization Pathways and Policy Levers. Stakeholders across the value chain agree on the need for formalization, but they differ on the mechanisms for achieving it. Four key pathways have emerged from stakeholder consultations: GST reduction, aggregation centres, licensing and certification, and EPR reform. Each addresses different dimensions of the formalization challenge, from economic incentives to institutional infrastructure. Stakeholders consistently emphasized that formalization is not about eliminating the informal sector, an impossible task given its scale and embeddedness, but about integrating it into a regulated, transparent, and safe

circular economy. As one recycler noted, "The informal sector is the backbone of collection. The question is not whether to include them, but how." The key understanding emerging from consultations is that formalization requires a combination of regulatory reform, institutional support, and economic incentives, not a single policy intervention.

Box 4: "Recycler Experiences with Informal Collection Systems"

Recyclers have developed diverse approaches to engaging with the informal sector. REC3 sources 90% of its feedstock from informal channels and has developed a unique social integration model: employing informal families directly, doubling their income, and sending their children to school. This approach recognizes that informal workers have valuable skills and local knowledge that should be preserved. In contrast, REC4 takes a structured education-and-aggregation approach, working with channel partners, OEM dealer networks, and aggregators to provide safety training and clear guidelines. REC4 expects formal share to become dominant within two years, reflecting confidence in its approach. REC1 and REC2 rely on aggregators with formal contracts, without direct engagement with informal collectors. All recyclers agree that formalization through aggregation, licensing, and GST reduction is the only viable path, rather than eliminating the informal sector. As one recycler observed, "The informal sector is the backbone of collection. The question is not whether to include them, but how."

The Informal Sector – *Everyone's Dirty Secret*



The reality: The informal sector is the invisible backbone of the battery value chain.



3.5. Gap 5: Policy and Market Misalignments

Stakeholder consultations consistently revealed that while India has built a comprehensive policy framework for battery circularity, the BWMR 2022, the PLI-ACC scheme, and the Critical Mineral Recycling Incentive Scheme, the market continues to favor linear over circular outcomes. Across all stakeholder groups, a consensus emerged that the fundamental problem is not the absence of policy but its misalignment: current incentives do not reward circularity and, in many cases, actively penalize it. This section examines four dimensions of this misalignment: EPR design flaws, GST barriers, financing challenges, and market uncertainty, and their cumulative effect on India's circular economy ambitions, based primarily on stakeholder evidence.

EPR Design Flaws: Stakeholders across OEMs, producers, and recyclers consistently identified fundamental design flaws in the EPR framework. First, collection targets are misaligned with battery lifespans. Several OEMs noted that mandating 70% collection within eight years is unrealistic for batteries with 10-15-year usable lives. One OEM observed, "You can't collect what hasn't reached end-of-life yet." Only one OEM, whose products may have shorter lifecycles, agreed with current targets, highlighting that a one-size-fits-all approach cannot accommodate the diversity of battery applications and lifespans. Second, stakeholders criticized the chemistry-agnostic approach, which applies uniform targets across LFP and NMC despite vastly different recycling economics. Recyclers and producers alike noted that this disadvantages LFP, as flat-rate EPR fees fail to reflect actual recycling costs [also noted by Lahan et al. (2026) and Joshi et al. (2021)]. One recycler emphasized, "The EPR system should use different prices for different battery types, because flat rates disadvantage LFP batteries compared to higher-value ones." Third, stakeholders reported that the EPR certificate market is not functioning effectively, with prices that may not cover actual recycling costs. Fourth, weak state-level enforcement allows non-compliant operators to undercut compliant recyclers. One recycler noted, "Registration alone doesn't mean compliance; you need enforcement." Research has shown that enforcement gaps consistently undermine EPR effectiveness across waste streams (Joshi et al., 2021; Sihag & Vipin, 2025; Tripathy et al., 2022).

GST Barriers. The GST regime represents the most urgent and unanimous policy barrier identified by recyclers. All recyclers interviewed explicitly demanded a GST reduction from 18% to 5% or removal. One recycler stated, "GST reduction is our top priority; it's the single most effective measure to formalize the sector." High GST makes formal recycling economically uncompetitive compared with informal operations that evade taxation, thereby driving batteries into the informal sector, as noted in recent studies (Rizos & Urban, 2024; Gahlaut & Dwivedi, 2024). Stakeholders explained that the 18% GST creates a significant cost disadvantage for form-

al recyclers, as unauthorized recyclers pay more for batteries by avoiding tax burdens. One producer acknowledged, "Unauthorized recyclers pay more for batteries, creating a powerful economic incentive to direct batteries to informal channels." Recyclers emphasized that rationalizing GST for industrial waste materials can dismantle systemic barriers and align fiscal policy with circular economy principles. Studies have shown that fiscal incentives can significantly improve the economic viability of recycling operations (Deshwal et al., 2022; Agarwal & Rastogi, 2026).

Financing Challenges. Stakeholder consultations revealed significant financing barriers that vary by business model. Data opacity impedes effective risk assessment, as lenders struggle to evaluate circular enterprises due to a lack of standardized information. One recycler faces high barriers due to banks' wariness of scrap-industry valuation risk; another faces moderate barriers due to deep-tech investors' wariness. Working capital constraints are acute for one recycler, with a procurement-to-sale gap of approximately one month. Interestingly, one recycler reported low barriers, suggesting business model presentation affects financing more than technology alone. Research has shown that information asymmetry and perceived technology risk are significant barriers to access to capital for circular economy ventures. Stakeholders noted that the ₹1,500 crore Critical Mineral Recycling Incentive Scheme faces implementation gaps, with upstream recyclers needing support to transition into the formal system. Coordination across multiple ministries was identified as essential for effective implementation, as noted in the recent studies (Hemavathi, 2025; Adegboye et al., 2024; Kaur et al., 2023).

Market Uncertainty. Market uncertainty compounds policy and financing challenges. Stakeholders across all recyclers identified feedstock availability as the #1 economic factor, yet it remains highly uncertain, as battery waste generation timing and location are unpredictable. One recycler observed, "We're investing in capacity, but we don't know when the feedstock will arrive." Black mass classification as waste versus by-product has significant implications for trade, taxation, and investment (Kumar et al., 2025; Verma et al., 2026). Stakeholders revealed divergent views: one recycler supports domestic value addition and export restrictions on black mass, while another seeks clarity on classification and trade rules. Price volatility, particularly for lithium, makes long-term investment decisions difficult. Research has shown that price volatility and regulatory uncertainty are significant barriers to investment in recycling infrastructure (Panda et al., 2023; Rautela et al., 2025; Deshwal et al., 2022; Xiao et al., 2026). Stakeholders emphasized that stable, long-term off-take agreements could help mitigate this uncertainty. The waste-versus-by-product distinction also affects international trade under the Basel Convention (Su et al., 2025; Zhong et al., 2025).

Box 5: "Producer Readiness Differences"

Stakeholder consultations revealed substantial variation in producer readiness for battery circularity. While some producers have established EPR compliance systems, battery passport initiatives, traceability mechanisms, and partnerships with recyclers, others remain at a much earlier stage of preparedness despite significant manufacturing expansion plans. These contrasting experiences suggest that regulatory awareness and organizational readiness are developing unevenly across the sector, highlighting the need for targeted capacity building alongside regulatory reforms.

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CHAPTER

4

A Roadmap for Circular Battery Value Chains in India

The preceding analysis has identified five critical system gaps holding back battery circularity in India. This section translates those findings into an implementable roadmap organized by time horizon. The recommendations are grounded in stakeholder evidence and designed to be practical, sequenced, and implementable, reflecting the urgent need to establish foundational infrastructure before battery waste volumes become unmanageable. The roadmap proceeds in three phases: short-term foundational facilitators (2026-2028), medium-term supply-side infrastructure (2028-2032), and long-term closed-loop integration (2032-2040).

4.1. Short Term (2026-2028)

The short-term window is decisive (see Table 1). India's battery waste volumes are growing exponentially, and foundational infrastructure must be established before the problem becomes unmanageable. Four priority actions address the most binding constraints identified by stakeholders: GST reform, Battery Aadhaar pilots, aggregation centres, and EPR revisions. These actions are mutually reinforcing: GST reform enables formalization, traceability enables verification, aggregation centres enable integration, and EPR revisions align incentives.

Table 1: Short-term priority actions (2026–2028)

Priority Action	Problem / Justification	Action / Mechanism	Lead Agencies	Expected Impact	Difficulty
GST Reform on Recycled Battery Scrap	18% GST makes formal recycling uncompetitive vs informal operations that evade taxation, driving batteries to the informal sector	Reduce GST to 5% on battery scrap and black mass; complement with accelerated depreciation for recycling equipment and priority sector lending	GST Council, Ministry of Finance; support from MoEFCC, CPCB, IESA, MRAI, NETRA	Immediate increase in formal collection; reduced informal advantage; increased government revenue through formalisation; catalyst for investment	Medium (fiscal coordination)

Priority Action (continued)	Problem / Justification	Action / Mechanism	Lead Agencies	Expected Impact	Difficulty
Battery Aadhaar Pilots	No operational upstream traceability; fragmented initiatives without government mandate	Phased deployment of 21-character BPAN with three-layer architecture: physical marking, QR code, central server	MoEFCC, CPCB, NITI Aayog, Ministry of Road Transport and Highways; support from OEM2, OEM3, PROD2, REC2, REC4	Lifecycle tracking; EPR verification; SoH assessment for second-life; curbing counterfeit products	Medium (coordination required)
Aggregation Centres for Informal Integration	Informal sector handles 60–90% feedstock; formalization through aggregation is the only viable path	Establish government-facilitated centres providing infrastructure, technology, training, and formal market linkages; integrate the MSME Cluster Development scheme	MoEFCC, Ministry of MSME, CPCB; support from SPCBs, REC3, REC4, industry associations	Formalization of informal collection; improved traceability; reduced environmental/safety risks; livelihood preservation	Medium (state-level coordination)
EPR Revisions	Unrealistic targets (70% in 8 years vs 15-year life); chemistry-agnostic; certificate prices too low	Shift to performance-based, chemistry-specific targets; differentiate fees by chemistry; centralized credit clearing house with floor/ceiling prices	MoEFCC, CPCB; support from OEM2, OEM3, OEM4, PROD2, REC4, NITI Aayog	Realistic, enforceable targets; level playing field across chemistries; economic viability for LFP recycling; reduced informal leakage	High (policy redesign requiring consensus)

These four actions address different dimensions of the circularity challenge. GST reform creates economic incentives for formalization. Battery Aadhaar enables traceability and EPR verification. Aggregation centers provide institutional infrastructure for informal integration. EPR revisions align regulatory incentives with circular economy objectives. Together, they form the foundation for a circular battery economy. Research on circular economy transitions has consistently emphasized that coordinated, multi-dimensional interventions are more effective than isolated policy measures. The BWMR 2025 amendments have already introduced stricter recovery targets (70% → 80% → 90%) and recycled-content mandates from FY 2027-28, providing a regulatory foundation on which these short-term actions can build (Chizaryfard et al., 2022; Park & Inoue, 2025; Munonye et al., 2026; Hemavathi, 2025).

4.2. Medium term (2028-2032)

Building on the foundational reforms introduced during the short-term phase, the medium-term period (2028–2032) should translate policy intent into industrial reality (see [Table 2](#)). By this stage, the phased collection targets under the BWMR will be approaching their most demanding levels, while the recycled-content mandates introduced from FY 2027–28 will require vigorous enforcement and market infrastructure. The priority actions in this phase address the binding supply-side constraints that prevent recycled materials from flowing back into battery manufacturing, while simultaneously expanding the collection infrastructure needed to feed the recycling value chain. The four priority actions, viz., recycled-content mandates, refining capacity, testing infrastructure, and collection network expansion, are interdependent and must proceed in parallel (Kaur et al., 2023; Adegboye et al., 2024).

Table 2: Medium-term priority actions (2028-2032)

Priority Action	Problem / Justification	Action / Mechanism	Lead Agencies	Expected Impact	Difficulty
Recycled-Content Mandates	Producers currently use 0% recycled battery-grade material; no demand-side pull for recyclers' outputs	Strengthen and enforce FY 2027-28 mandates with clear percentages (e.g., 10% by 2030, 20% by 2035); develop verification and certification mechanisms; differentiate by chemistry	MoEFCC, CPCB; support from producers, OEMs, recyclers, BIS, testing laboratories	Creation of a domestic market for recycled materials; reduced import dependence; economic viability for recycling investments	Medium (enforcement and verification)
Refining Capacity	Black mass is exported rather than refined domestically; no domestic battery-grade material production	Scale up Critical Mineral Recycling Incentive Scheme (₹1,500 crore); support R2 to R4 transition; clarify black mass classification; incentivise precursor synthesis	Ministry of Mines, MHI, MoEFCC; support from recyclers, research institutions, financial institutions, technology partners	Domestic production of battery-grade salts; reduced import dependence; high-value employment in refining; closed-loop material flows	High (capital-intensive)
Testing Infrastructure	Lack of testing equipment, separation science capacity, and solvent manufacturing; quality assurance gaps for recycled materials	Establish common facility centres; invest in laboratory accreditation; develop indigenous testing equipment; support BIS standards implementation	Ministry of S&T, CSIR, BIS; support from IITs, recyclers, industry associations, National Test House	Quality assurance for recycled materials; reduced import dependence; enhanced confidence in domestic recycled content	Medium (investment and capacity building)

Priority Action (continued)	Problem / Justification	Action / Mechanism	Lead Agencies	Expected Impact	Difficulty
Collection Network Expansion	Informal sector handles 60–90% feedstock; formal collection channels capture only a fraction	Scale aggregation centre model nationwide; integrate dealerships, service centres, and aggregators; leverage India-EU TTC initiative (₹169 crore) for digitalized collection systems	CPCB, SPCBs; support from OEMs, producers, recyclers, logistics providers, informal sector	Higher collection rates; reduced informal leakage; improved traceability; enhanced feedstock supply for recyclers	High (infrastructure and coordination)

These four actions address the supply-side constraints that currently prevent the implementation of closed-loop material flows. Recycled-content mandates create demand-side pull, thereby linking design intent to material procurement. Refining capacity converts black mass into battery-grade salts, reducing dependence on exports and capturing domestic value. Testing infrastructure ensures quality assurance for recycled materials, building confidence among manufacturers. Collection network expansion scales formal collection to meet increasingly demanding BWMR targets. The Critical Mineral Recycling Incentive Scheme, with a tenure from FY 2025-26 to FY 2030-31, aims to develop 270 kilotonnes of recycling capacity annually, resulting in 40 kilotonnes of annual critical mineral production (Hemavathi, 2025). The scheme has approved 58 companies to develop recycling capacity. Private investment is following suit, for example, REC1 plans to invest over ₹100 crore in a critical minerals refining facility in Odisha, expected to be operational by FY 2028-29, expanding capacity from 12,000 to 24,000 tpa by 2027. The India-EU joint initiative, launched under the Trade and Technology Council with a budget of ₹169 crore, will focus on developing safe, digitized collection systems, high-efficiency material recovery, and pilot-scale demonstrations of innovative processes (Kaur et al., 2023; Goel et al., 2024). The transition from R2 recyclers (black mass producers) to R4 recyclers (end-to-end refiners) requires a clear regulatory framework that classifies black mass and provides a transition pathway. REC4 supports black mass export restrictions as they drive domestic value addition, while REC2 reports negative impacts on its contracts, highlighting the need for a balanced approach that supports both segments. Testing infrastructure development must address separation science as a critical skill gap in India, a skill gap, not a money problem. The Bureau of Indian Standards (BIS) has already mandated rated capacity verification for LiB, requiring third-party laboratory testing from April 30, 2027, which will drive the establishment of advanced battery testing centers (Hemavathi, 2025).

4.3. Long Term (2032-2040)

The long-term horizon represents the culmination of India's transition from a linear to a circular battery economy (see Table 3). By this stage, the foundational reforms of the short-term phase should be fully operational, and the supply-side investments of the medium-term phase should be delivering battery-grade materials at scale. The priority actions in this phase focus on the final integration of the circular value chain, transforming India from a collection-and-export model to a truly closed-loop system in which materials flow continuously from recycling back into domestic battery manufacturing. The three priority actions, viz., closed-loop manufacturing, domestic precursor industries, and circular battery markets, are interdependent and represent the final frontier of India's circularity journey.

Table 3: Long-term priority actions (2032-2040)

Priority Action	Problem/Justification	Action/Mechanism	Lead Agencies	Expected Impact	Difficulty
Closed-Loop Battery Manufacturing	No domestic cell manufacturing; recycled materials exported as black mass; open-loop circularity persists	Integrate domestic cell production with recycled material supply; operationalize PLI-ACC capacity (50 GWh, ₹18,100 crore); establish industry-wide circular design standards; implement full Battery Passport system	Ministry of Heavy Industries, MoEFCC; support from cell manufacturers, recyclers, OEMs, producers, BIS	True circular economy with materials flowing from recycling back into new batteries; reduced import dependence; enhanced resource security; globally competitive domestic battery industry	Very High (integration, investment, coordination)
Domestic Precursor Industries	No domestic production of cathode/anode active materials or precursor chemicals; multiple points of supply chain vulnerability	Develop CAM and AAM production from recycled black mass; integrate the Critical Mineral Recycling Incentive Scheme; invest in chemical manufacturing; establish R&D funding and common facility centres	Ministry of Mines, MHI, Department of Chemicals and Petrochemicals; support from the chemical industry, recyclers, and research institutions	Complete domestic value chain from recycling to cell manufacturing; reduced import dependence for precursors; high-value employment in chemical manufacturing	Very High (capital-intensive, technology development)

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Priority Action (continued)	Problem/Justification	Action/Mechanism	Lead Agencies	Expected Impact	Difficulty
Circular Battery Markets	Immature markets for EPR certificates, second-life batteries, and carbon credits; economic incentives for circularity are absent	Operationalize centralized EPR credit clearing house with floor/ceiling prices; scale second-life markets with standardized testing and certification; develop carbon credit methodologies for recycling	MoEFCC, CPCB, Ministry of Finance; support from all stakeholders, including producers, OEMs, recyclers, second-life operators, and financial institutions	Self-sustaining circular economy; diversified revenue streams (materials, EPR certificates, second-life, carbon credits); reduced need for government subsidies; India as global leader	High (market development, regulatory clarity)

These three actions represent the final integration of the circular value chain. Closed-loop manufacturing ensures that recycled materials flow directly back into domestic cell production, eliminating the current open-loop dynamic. Domestic precursor industries develop production of cathode and anode active materials, completing the value chain from recycling to cell manufacturing. Circular battery markets, including mature EPR certificate trading, second-life battery markets, and carbon credits, create diversified revenue streams that make circularity economically self-sustaining. The PLI-ACC scheme's requirement for a minimum domestic value addition of 50% creates a natural pull for domestically sourced materials, including recycled inputs (Hemavathi, 2025). In the long term, producers such as PROD1 would manufacture cells at a commercial scale, creating the missing link between recycling and manufacturing. Recyclers such as REC4 would supply these manufacturers with battery-grade materials at 99.5% purity, closing the loop. Industry-wide standards for recycled materials, developed through the BIS, would facilitate this integration. The circular design framework would be supported by a fully operational Battery Passport system that contains detailed information on battery composition and facilitates recyclers to optimize recovery processes. The passport would also enable lifecycle assessment and carbon footprint tracking, supporting sustainability claims and facilitating participation in carbon credit markets. The EPR certificate market would create price signals that reflect the true cost of recycling, thereby incentivizing investment and innovation. Second-life battery markets would be operational at scale, with batteries flowing from first use to second-life applications to recycling, maximizing value extraction. The BWMR 2025 amendments, which require a minimum five-year warranty for second-life batteries, provide a foundation for this framework. Carbon credit methodologies for battery recycling would create additional revenue streams and incentivize low-carbon recycling processes (Dunn et al., 2021; Gahlaut & Dwivedi, 2024).

framework creates favorable conditions for market development. The success of this transformation will determine whether India's battery revolution delivers on its promise of sustainability, resource security, and economic opportunity.

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CHAPTER

5

Implementation Framework

The roadmap presented in the preceding section comprises a sequenced set of actions across three time horizons. This section translates those actions into a consolidated implementation framework, providing policymakers, industry leaders, and financiers with a clear reference for execution. More specifically, this section focuses on implementation risks, dependencies, funding mechanisms, and governance arrangements, complementary information that adds practical value for execution. To this end, [Table 4](#) identifies key implementation risks and dependencies associated with each priority action, along with proposed mitigation strategies. This framework facilitates stakeholders to anticipate challenges and plan proactively.

Table 4. Implementation risks, dependencies, and mitigation strategies for priority actions

Priority Action	Key Implementation Risks	Critical Dependencies	Mitigation Strategies
SHORT TERM (2026-2028)			
Reduce GST on recycled battery scrap from 18% to 5%	Fiscal resistance; industry opposition from the informal sector	GST Council consensus; Ministry of Finance clearance	Phased implementation; stakeholder consultations; impact assessment
Launch Battery Aadhaar pilots with phased deployment	Data-sharing hesitancy; technology fragmentation; industry resistance	Industry cooperation; technology standards; data protection framework	Incentive alignment, clear standards, phased rollout
Establish government-facilitated aggregation centres	State-level implementation gaps; coordination challenges	State government buy-in; SPCB capacity; informal sector engagement	Pilot testing; capacity building; public-private partnerships
Revise EPR framework to be performance-based and chemistry-specific	Industry pushback; complexity of design; enforcement challenges	Stakeholder consensus; regulatory capacity; monitoring systems	Multi-stakeholder consultation; phased implementation; robust monitoring
MEDIUM TERM (2028-2032)			

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Priority Action <i>(continued)</i>	Key Implementation Risks	Critical Dependencies	Mitigation Strategies
Strengthen and enforce recycled-content mandates	Verification challenges, fraudulent claims, supply constraints	Testing infrastructure; certification mechanisms; industry compliance	Third-party verification; blockchain-enabled traceability; penalties for non-compliance
Develop domestic refining capacity for battery-grade materials	High capital requirements; technology gaps; investor risk perception	Long-term policy stability; off-take agreements; R&D support	Blended finance, government guarantees, public-private partnerships
Invest in testing infrastructure and common facility centers	Funding constraints, coordination across institutions, and skill gaps	Inter-ministerial coordination; industry collaboration	Shared facilities; PPP models; skill development programs
Scale up the collection network nationwide	Infrastructure gaps; informal sector resistance; funding constraints	State-level coordination; logistics infrastructure	Phased expansion; MSME cluster approach; informal sector integration
LONG TERM (2032-2040)			
Establish closed-loop battery manufacturing	Market uncertainty; technology evolution; investment risk	Domestic cell manufacturing; recycled material supply; policy stability	Long-term policy commitment; investment guarantees; international partnerships
Develop domestic precursor industries	Technological complexity, high capital intensity, and global competition	R&D capacity; chemical industry capability; technology transfer	International collaboration; R&D funding; technology incubation
Mature circular battery markets	Market liquidity, price volatility, and regulatory uncertainty	Regulatory clarity; market infrastructure; stakeholder participation	Phased market development; price stabilization mechanisms; regulatory sandboxes

Implementation Risks and Mitigation Strategies. Successful implementation requires anticipating and mitigating key risks. Short-term actions face risks, including fiscal resistance to GST reform, hesitancy to share data for Battery Aadhaar pilots, state-level coordination challenges for aggregation centers, and industry pushback on EPR revisions. Medium-term actions pose verification challenges for recycled-content mandates, high capital requirements for refining capacity, coordination gaps in testing infrastructure, and informal-sector resistance to collection network expansion. Long-term actions carry the highest risks: market uncertainty in closed-loop manufacturing, technological complexity in precursor industries, and regulatory ambiguity in circular battery markets. Each risk requires targeted mitigation strategies, including phased implementation, stakeholder consultation, blended finance, and regulatory sandboxes.

Funding Mechanisms and Resource Mobilization. Funding mechanisms must be mobilized across public, private, and international sources. Public funding includes the ₹ 18,100-crore PLI-ACC scheme, the ₹ 1,500-crore Critical Mineral Recycling Incentive Scheme, the

India-EU TTC initiative (₹169 crore), multilateral development bank financing, and climate finance. Blended finance mechanisms, such as government guarantees, viability gap funding, priority sector lending, and carbon credit markets, can further de-risk investment.

Implementation Principles. Successful execution requires adherence to five implementation principles. (1) Phased sequencing ensures that short-term actions enable medium-term investments, which enable long-term integration. Attempting to implement long-term actions before short-term foundations are in place risks failure. (2) Stakeholder coordination across multiple ministries, viz., MoEFCC, Ministry of Finance, Ministry of Mines, Ministry of Heavy Industries, and Ministry of MSME, is critical, with an inter-ministerial steering committee recommended to ensure alignment and prevent fragmentation. (3) Resource mobilization must match ambition. While some actions are primarily regulatory, others require significant investment. The existing schemes provide a foundation, but additional resources will be needed. (4) Monitoring and evaluation mechanisms with clear milestones and performance indicators should be embedded in each action to facilitate course correction and accountability. The BWMR's phased collection targets provide a model, complemented by process indicators tracking traceability and formalization. Adaptive governance is essential as India's battery market evolves rapidly. The EPR framework must be periodically reviewed to reflect evolving chemistry mixes, recycling costs, and market conditions. Similarly, the Battery Aadhaar framework must be adaptable to new battery chemistries, form factors, and applications. International examples demonstrate that adaptive governance approaches, with regular review cycles and stakeholder feedback mechanisms, are more effective than static policy frameworks

Monitoring Progress. Monitoring indicators are recommended for each time horizon. In the short term (2026-2028): GST notification issued, Battery Aadhaar pilots launched, aggregation centres established, and EPR framework revised. In the medium term (2028-2032): refining capacity increase, testing facilities established, collection rates achieved, and recycled-content compliance rates. In the long term (2032-2040): volume of recycled materials in domestic manufacturing, proportion of precursor chemicals produced domestically, value of EPR and second-life markets, and India's position in global battery circularity rankings.

The implementation framework provides a structured pathway to translate India's battery circularity vision into reality. Success requires sustained political will, institutional coordination, and stakeholder alignment. The framework's phased sequencing, foundational enablers in the short term, building the circular battery ecosystem in the medium term, and closed-loop integration in the long term, ensures logical progression, minimizing the risk of premature investm-

ent. The stakes are high: India's battery revolution will either deliver on its promise of sustainability, resource security, and economic opportunity, or create a mounting waste liability and perpetuate import dependence.

CHAPTER

6

Conclusion

India's battery circularity challenge is not simply a recycling challenge. It is a value chain coordination challenge that requires alignment among industry, regulators, financiers, and technology providers. The evidence gathered through stakeholder consultations with four OEMs, two producers, and four recyclers reveals a complex landscape where technological capability exists, but policy misalignment, market failures, and coordination gaps prevent the emergence of a truly circular battery economy. The analysis has identified five critical system gaps that must be addressed. The LFP paradox, in which India's preferred battery chemistry lacks an economically viable end-of-life pathway, is a classic market failure in which private choice creates public liability. Open-loop circularity persists because recovered materials are exported rather than returned to domestic manufacturing, and there is no domestic cell production to close the loop. Traceability initiatives such as Battery Aadhaar and battery passports have been developed but remain fragmented and unimplemented, stalled by data-sharing barriers and misaligned incentives. The informal sector remains the backbone of battery collection, handling 60-90% of feedstock, yet operates outside formal regulatory frameworks. Policy and market misalignments, including chemistry-agnostic EPR targets, GST at 18%, weak enforcement, and financing barriers, compound these challenges. Yet the analysis also reveals significant strengths that India can build upon. Advanced recyclers achieve 97-99% recovery with battery-grade purity, demonstrating that world-class material recovery is achievable domestically. The policy framework is expanding, with BWMR amendments introducing stricter recovery targets and recycled-content mandates, while the Critical Mineral Recycling Incentive Scheme and PLI-ACC scheme provide financial support for capacity building. Emerging traceability initiatives, including Battery Aadhaar pilots and the proposed battery passport, signal India's commitment to digital infrastructure for circularity.

The roadmap presented in this research translates these findings into an implementable, sequenced set of recommendations. In the short term (2026-2028), GST reform, Battery Aadhaar pilots, aggregation centres, and EPR revisions must establish the foundational enablers of circularity. In the medium term (2028-2032), recycled-content mandates, refining capacity, testing infrastructure, and collection network expansion must be built to enable closed-loop material flows. In the long term (2032-2040), closed-loop battery manufacturing (Gigafactory), domestic precursor industries, and mature circular battery markets must complete the transition to a self-sustaining circular economy. The implementation framework provides a practical tool for translating these recommendations into implementation. By mapping each recommendation to lead agencies, supporting actors, timelines, expected impacts, and implementation difficulty, the framework facilitates stakeholders to identify their roles, assess resource requirements, and track progress. The success of this framework depends on phased sequencing, stakeholder coordination, resource mobilization, monitoring and evaluation, and adaptive governance.

India stands at a decisive moment. The country's battery revolution is gathering pace, and the choices made today will determine whether it delivers on its promise of sustainability, resource security, and economic opportunity or creates a mounting waste liability and perpetuates import dependence. The technology exists. The policy foundations are being laid. The stakeholder consensus is emerging. What remains is the political will and institutional capacity to coordinate action across the value chain. The opportunity is clear. By building a circular battery economy, India can secure its critical mineral supply, create green jobs, reduce carbon emissions, and position itself as a global leader in battery circularity. The alternative of continuing on a linear path risks trading one form of import dependence for another, while creating environmental liabilities that will burden future generations. The choice is India's to make. The roadmap is before us. The time to act is now.

ANNEXES

Annex 1: Methodology

Research Design and Objective

This white paper is based on a mixed-methods research study conducted as part of the HSBC India - supported project on battery circularity and sustainable energy transitions at the Indian Institute of Technology Madras. The study adopted a stakeholder-centric approach, recognizing that battery circularity is fundamentally a value-chain coordination challenge requiring alignment among manufacturers, producers, recyclers, and policymakers. The primary objective was to move beyond policy analysis and secondary literature by generating empirical evidence through direct stakeholder engagement. Specifically, the study sought to understand the current state of battery circularity in India, identify key barriers across the battery value chain, and develop practical policy recommendations to accelerate the transition towards a circular battery ecosystem.

Stakeholder Identification and Data Collection

Stakeholders were selected using purposive and snowball sampling to ensure representation across key segments of India's battery value chain. The final sample comprised ten organizations, including four Original Equipment Manufacturers (OEMs), two battery producers, and four battery recyclers, representing diverse business models, battery chemistries, and levels of operational maturity. Semi-structured interviews were conducted between July 2025 and April 2026 with senior representatives responsible for sustainability, technology, research and development, or business strategy. Interviews typically lasted between 60 and 120 minutes and explored topics including Extended Producer Responsibility (EPR), battery traceability, circular design, recycling, second-life applications, informal-sector engagement, localization, and future policy priorities. Interview findings were supplemented through a review of publicly available sustainability reports, annual reports, regulatory documents, and company publications to improve data completeness and contextual understanding.

Data Analysis

Interview responses were analyzed using a structured qualitative approach involving thematic coding and comparative analysis across stakeholder groups. This process enabled the identification of recurring challenges, areas of consensus and divergence, and broader system-level barriers affecting battery circularity in India. The analysis focused on understanding how stakeholder experiences and perspectives collectively shape the performance of the battery value chain. These findings formed the basis for the policy insights and phased implementation roadmap presented in this report.

Integration of Stakeholder Evidence and Secondary Literature

Stakeholder findings were triangulated with recent academic literature, government policy documents, industry reports, and publicly available market analyses published between 2020 and 2026. The literature review focused on battery circularity, electric vehicle transitions, critical minerals, battery recycling, traceability, Extended Producer Responsibility, and related policy developments in India and internationally.

The secondary literature served three purposes:

- to validate stakeholder observations against published evidence;
- to provide broader policy and market context; and
- to strengthen the evidence base underpinning the recommendations presented in this report.

The references cited throughout the white paper are drawn from this supporting literature.

Limitations

Several limitations should be acknowledged. First, while the selected stakeholders represent important segments of India's battery value chain, the findings may not capture the full diversity of perspectives across the sector. Second, the study reflects stakeholder views during the data collection period and therefore may not fully capture rapidly evolving technological, regulatory, and market developments. Third, the analysis primarily reflects the perspectives of formal-sector organizations; although informal-sector issues were discussed extensively by recyclers, direct engagement with informal collectors was beyond the scope of this study. Finally, the findings are specific to the Indian context and should be interpreted accordingly.

Despite these limitations, the study provides an evidence-based assessment of India's battery circularity landscape and offers practical recommendations to support policymakers, industry leaders, and financiers in strengthening the country's transition towards a circular battery economy.

Annex 2: Glossary of key battery circularity terms

Aggregation Centre: A government-facilitated facility that provides infrastructure, technology, and formal market linkages for informal collectors and small-scale recyclers to integrate into the formal battery recycling value chain.

Atmanirbhar Bharat: India's self-reliance initiative, in the context of battery circularity, refers to reducing dependence on imports of critical minerals and building domestic manufacturing and recycling capabilities.

Battery Aadhaar: India's proposed digital identity system for batteries, featuring a unique 21-character Battery Pack Aadhaar Number (BPAN) assigned to each battery pack, aiding lifecycle traceability from production to end-of-life.

Battery Passport: A digital documentation system containing comprehensive information about a battery's composition, origin, usage history, state of health, and end-of-life pathway, enabling transparency and circularity across the value chain.

Black Mass: The crushed and processed material recovered from shredded lithium-ion batteries, containing valuable metals including lithium, cobalt, nickel, and manganese that can be further refined into battery-grade materials.

BWMR (Battery Waste Management Rules): India's primary regulatory framework governing battery waste management, originally notified in 2022 and amended in 2025, establishing Extended Producer Responsibility obligations and collection targets.

Circular Design: Product design principles that facilitate repair, reuse, remanufacturing, and recycling, including modular architecture, standardized interfaces, reversible fasteners, and the use of recyclable materials.

Closed-Loop Circularity: A system where materials recovered from end-of-life products flow back into the manufacturing of new products, eliminating waste and reducing dependence on virgin materials.

CPCB (Central Pollution Control Board): India's apex pollution control authority responsible for administering the EPR portal, registering producers and recyclers, and enforcing battery waste management regulations.

Critical Minerals: Minerals essential for clean energy technologies, including lithium, cobalt, nickel, graphite, and rare earth elements, whose supply chains are concentrated and geopolitically sensitive.

EoL (End-of-Life): The stage in a battery's lifecycle when it can no longer serve its primary application and must be repurposed, recycled, or disposed of.

EPR (Extended Producer Responsibility): A policy approach where producers are legally and financially responsible for the end-of-life management of the products they place on the market, including collection, recycling, and environmentally sound disposal.

EPR Certificate: A tradable certificate issued to recyclers for collecting and recycling battery waste, which producers can purchase to meet their EPR obligations under the BWMR framework.

Gigafactory: A large-scale battery manufacturing facility with production capacity measured in gigawatt-hours (GWh), critical for building domestic cell manufacturing and closing the battery loop.

GST (Goods and Services Tax): India's comprehensive indirect tax system, with the current 18% rate on recycled battery scrap identified as a significant barrier to formalization and circularity.

Hydrometallurgy: A metal recovery process using aqueous chemistry to extract valuable metals from battery black mass, achieving high recovery rates but requiring significant chemical inputs and generating wastewater.

Informal Sector: Unregulated actors in the battery collection and recycling ecosystem, including individual collectors, kabadiwalas (scrap dealers), and aggregators who handle an estimated 60-90% of India's end-of-life battery feedstock.

LFP (Lithium Iron Phosphate): A battery chemistry using lithium iron phosphate as the cathode material, offering advantages in cost, safety, and longevity but presenting significant recycling challenges due to low material value.

Li-ion (Lithium-Ion) Battery: A rechargeable battery technology using lithium ions as the primary charge carriers, currently the dominant chemistry for electric vehicles and energy storage applications.

Mechanochemical Extraction: An advanced recycling technology using mechanical and chemical processes to selectively extract lithium and other valuable metals from battery materials with lower environmental impact than conventional methods.

NMC (Nickel Manganese Cobalt): A battery chemistry using nickel, manganese, and cobalt in the cathode, offering higher energy density and more valuable recyclable materials than LFP, but with higher cost and supply chain concerns.

Open-Loop Circularity: A system where materials are recovered from end-of-life products but flow into different applications or are exported, rather than returning to the same product value chain.

Precursor: Intermediate chemical compounds used to produce cathode active materials and anode active materials for battery manufacturing, representing a critical supply chain segment where India currently lacks domestic production.

Pyrometallurgy: A metal recovery process using high-temperature smelting to extract metals from battery waste, energy-intensive and less selective than hydrometallurgical methods.

R2 Recycler: A recycler that processes batteries to produce black mass, which is then sold to refiners for further processing rather than refining to battery-grade materials in-house.

R4 Recycler: An integrated recycler that performs end-to-end processing from collection and dismantling through to refining to battery-grade salts and metals, achieving higher value capture.

Recycled Content Mandate: A regulatory requirement that a minimum percentage of materials in new batteries must be derived from recycled sources, with India's mandate beginning FY 2027-28.

Second-Life Battery: A battery that has been removed from its original application (typically an electric vehicle) but retains sufficient capacity (typically 70–80% SoH) to be repurposed for less demanding applications such as stationary energy storage.

SoH (State of Health): A measure of a battery's remaining capacity and performance relative to its original specifications, used to assess suitability for second-life applications.

Traceability: The ability to track a battery's journey through the value chain from mineral extraction to manufacturing, use, repurposing, and recycling, enabled by digital identification systems.

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Closing the Loop

A Roadmap for Building Circular Battery Value Chains in India



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