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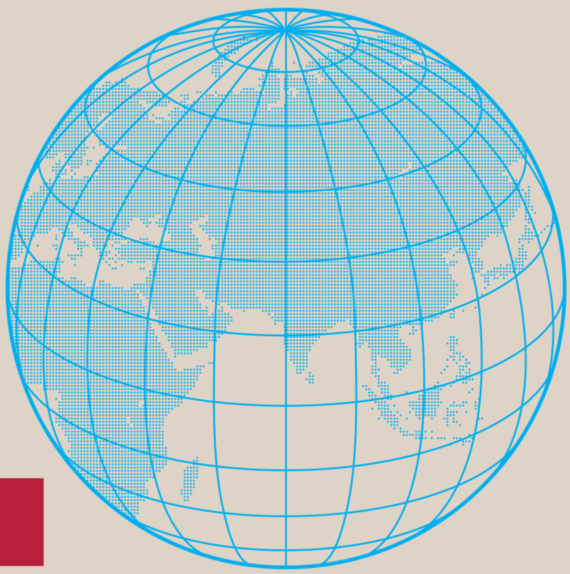
# Battery Circularity in India—A Billion-Dollar Long-Term Opportunity

## The Case of EV Batteries


Shyamasis Das

Kartik Nair

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# Battery Circularity in India—A Billion-Dollar Long-Term Opportunity

## The Case of EV Batteries

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# Abbreviations

| | |
|---|---|
| **2W** | Two-Wheeled Vehicle |
| **3W** | Three-Wheeled Vehicle |
| **BIS** | Bureau of Indian Standards |
| **BWMR** | Battery Waste Management Rules |
| **CAGR** | Compound Annual Growth Rate |
| **CapEx** | Capital Expenditure |
| **EoL** | End of Life |
| **EPR** | Extended Producer Responsibility |
| **EV** | Electric Vehicle |
| **GIZ** | Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH |
| **GoI** | Government of India |
| **Hz** | Hertz |
| **ICE** | Internal Combustion Engine |
| **IEA** | International Energy Agency |
| **IIT** | Indian Institute of Technology |
| **IMF** | International Monetary Fund |
| **IS** | Indian Standard |
| **ISO** | International Organization for Standardization |
| **LFP** | Lithium Iron Phosphate |
| **LiB** | Lithium-ion Battery |
| **MeitY** | Ministry of Electronics and Information Technology |
| **MHI** | Ministry of Heavy Industries |
| **MoEFCC** | Ministry of Environment, Forest and Climate Change |
| **MoHUA** | Ministry of Housing and Urban Affairs |
| **MoRTH** | Ministry of Road Transport and Highways |
| **NCA** | Nickel Cobalt Aluminium |
| **NCMM** | National Critical Mineral Mission |
| **NDC** | Nationally Determined Contribution |
| **NITI** | National Institution for Transforming India |
| **NMC** | Nickel Manganese Cobalt |
| **OpEx** | Operational Expenditure |
| **PCPS** | Primary Commodity Price System |
| **PIB** | Press Information Bureau |
| **PM E-DRIVE** | PM Electric Drive Revolution in Innovative Vehicle Enhancement |
| **RE** | Renewable Energy |
| **SoH** | State of Health |
| **TIA** | Transport Initiative for Asia |
| **Y-o-Y** | Year-on-Year |

# Executive Summary

India's electric vehicle (EV) transition is accelerating rapidly, with nearly 8 million EVs added between financial year (FY) 2016–17 and FY 2025–26, the majority of which are electric two-wheeled (2W) and electric three-wheeled (3W) vehicles. Considering that the EV share of total vehicle sales is still in the single digits (estimated at 8.25% in FY 2025–26), there is considerable headroom for the EV market to grow further in the country. This transition is significantly increasing the deployment of lithium-ion batteries (LiBs), creating both an environmental challenge and an economic opportunity. As EV batteries reach end-of-life (EoL), they can either become a hazardous waste stream or serve as a valuable secondary source of critical minerals, such as lithium, nickel, cobalt, copper, and manganese.

India currently depends heavily on imports for battery minerals and advanced battery cells. Lithium, nickel, cobalt, copper, and graphite have been identified by the Ministry of Mines as critical and strategic minerals. For three of these—lithium, nickel, and cobalt—the country is 100% import-dependent. Developing a domestic EV battery recycling ecosystem can therefore strengthen supply-chain security, reduce import dependence, support industrial growth, and contribute to climate and sustainability goals.

This study assesses India's EV battery circular economy opportunity through FY 2040–41 by analysing EV sales trajectories, battery chemistry trends, recoverable mineral volumes, recycling capacity requirements, and associated investment needs. It reviews the country's policy landscape relevant to used EV battery recycling, examines the key recycling methods, projects the potential volume of EoL EV batteries available for recycling, and estimates the capital expenditure (CapEx) required to set up recycling facilities.

## EV Sales Trajectory

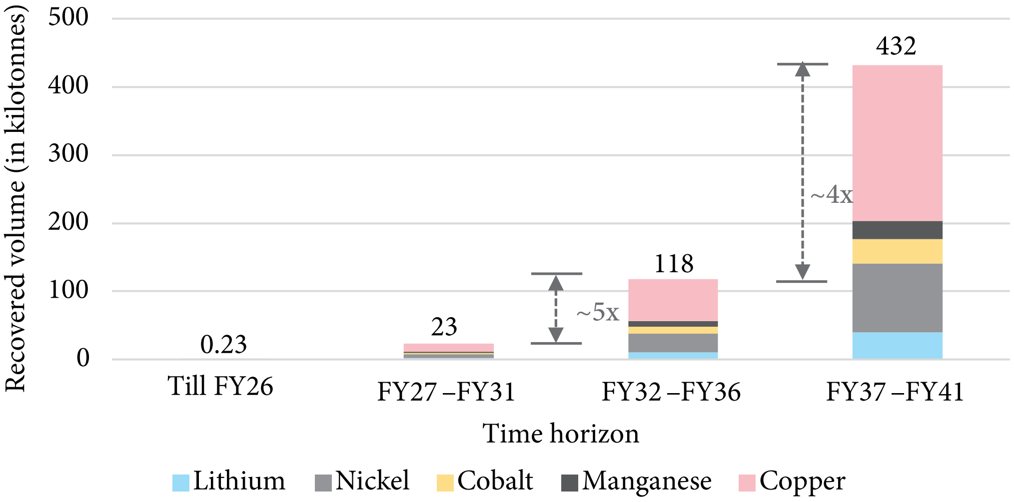
Total EV sales are projected to reach about 9.1 million in FY 2030–31, increasing further to nearly 49.9 million by FY 2037–38. Electric two-wheeled vehicles account for the dominant share, rising from about 7.1 million in FY 2030–31 to about 40.1 million in FY 2037–38. By contrast, electric buses and medium- and heavy-duty electric trucks remain much smaller in absolute numbers, though they may still contribute materially to future recycling volumes because of their larger battery pack sizes.

These differences in EV adoption rates matter for battery circularity because they shape not only the number of batteries entering circulation but also the timing, battery chemistry, and mineral profile of future EoL streams.

## Key Findings

The projected EoL battery flows indicate that India's EV battery recycling opportunity remains limited in the near term but is expected to rise sharply after 2030 (Figure ES–1). The projection indicates that the total recoverable mineral volume is expected to reach about 573 kilotonnes (kt) over the assessment period, from FY 2026–27 to FY 2040–41.

**Figure ES–1: Projected Recoverable Mineral Volume From End-of-Life EV Batteries**




*Source: Authors' analysis.*

*Note: FY = financial year. FY26 refers to FY 2025–26; FY27–31 refers to FY 2026–27 to FY 2030–31; FY32–36 refers to FY 2031–32 to FY 2035–36; FY37–41 refers to FY 2036–37 to FY 2040–41.*

Copper accounts for the largest share of recovered battery minerals by quantity across the assessment horizon. This shows that the recycling opportunity is likely to be driven not only by high-value critical minerals but also by bulk minerals embedded in LiBs. Further, the analysis shows that, in a scenario where sales of two-wheeled and three-wheeled vehicles reach a 100% electric share by FY 2037–38 (i.e., the end of the EV projection period), the quantity of recoverable battery minerals may increase by 445 kt over the entire assessment period.

In sync with the trajectory of the recoverable quantity of battery minerals, the economic value of recovered minerals is also projected to rise sharply over time. The estimated value of recycled battery minerals is about ₹1,01,491 crore (US$11,941 million)[1] over the assessment period, from FY 2026–27 to FY 2040–41. Unlike the quantity of recovered minerals, the economic value of EV battery recycling is driven by high-value critical minerals. Lithium contributes the largest share of the recoverable value across the period, even though copper dominates in terms of quantity. In a 100% EV penetration scenario for two-wheeled and three-wheeled vehicle segments, the recycling industry can potentially unlock approximately ₹73,600 crore (US$8,661 million) in additional economic value.

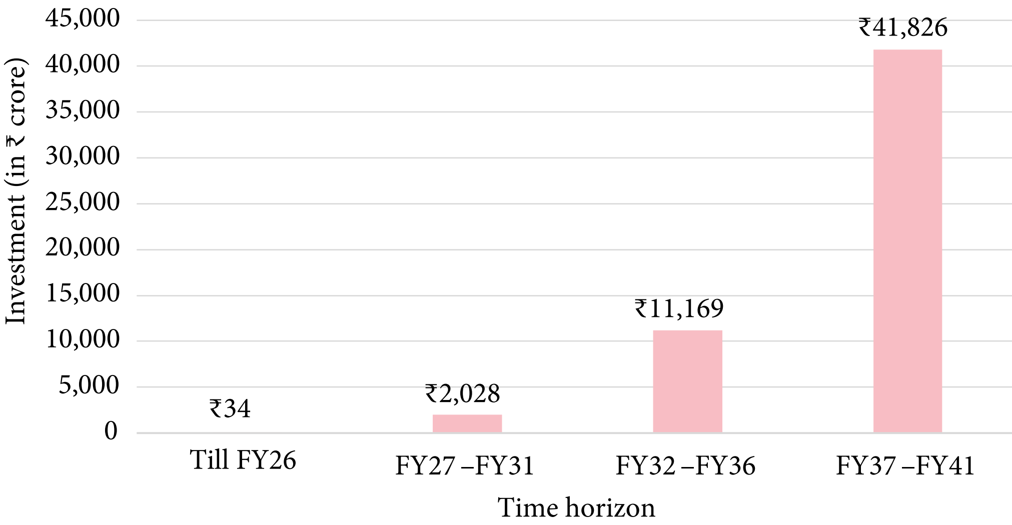
The study finds that recycling can meet about 10% of the lithium demand for EV battery manufacturing from FY 2026–27 to FY 2030–31. The contribution increases to around 12% over the next five years (FY 2031–32 to FY 2035–36) as the quantity of recycled minerals increases.

[1] All calculations conducted in this paper assume US$1 = ₹85.

Among the vehicle segments, electric two-wheeled vehicles make the largest contribution—about 57%—to the quantity of minerals available for recycling. In contrast, medium- and heavy-duty EVs (which include electric buses and electric trucks) together have a small share, around 1.2% of the total minerals available for recycling.

Processing the projected EoL EV battery volumes would entail a cumulative requirement of about 3,315 kt of recycling capacity across the periods assessed. This would require capital investment of about ₹55,057 crore (US$6,477 million) (Figure ES–2).

**Figure ES–2: Estimated Capital Expenditure Required to Scale EV Battery Recycling Infrastructure**




*Source: Authors' analysis.*

*Note: FY = financial year. FY26 refers to FY 2025–26; FY27–31 refers to FY 2026–27 to FY 2030–31; FY32–36 refers to FY 2031–32 to FY 2035–36; FY37–41 refers to FY 2036–37 to FY 2040–41.*

## Challenges and Policy Recommendations

Realising the recycling potential of India's growing stock of EV batteries will require addressing several market and policy barriers. This study recommends 10 key interventions to strengthen the country's EV battery circularity ecosystem.

i. **Mandate sourcing of recycled critical and strategic minerals as part of the effort to create the national critical minerals stockpile.**

India needs a stronger policy signal to create a domestic demand for recycled minerals. The National Critical Mineral Mission (NCMM) advocates institutionalising the National Critical Mineral Stockpile Programme to stockpile critical and strategic minerals and avoid disruptions in mineral supply for domestic utilisation. The

Mission should mandate that recycled critical and strategic minerals comprise a minimum share of the proposed minerals stockpile. This would create demand for domestically recovered minerals.

***Responsible stakeholder:*** Ministry of Mines.

ii. **Revisit the existing provisions in the Battery Waste Management Rules, 2022 to align timelines for EV battery collection targets with actual battery life and set mineral-specific recovery targets.**

Current Extended Producer Responsibility (EPR) provisions under the Battery Waste Management Rules, 2022 (BWMR) may induce "forced" early retirement of EV batteries, as these are based on conservative assumptions about battery life. Therefore, the timelines for achieving battery collection targets should be revisited based on the actual longevity of the EV batteries recorded in the Indian market across vehicle categories.

BWMR also lacks mineral-specific recovery targets, potentially limiting incentives for recyclers to recover minerals rather than stop at producing "black mass". Such targets would complement BWMR's existing minimum recycled-content provisions by linking demand for secondary materials with verified domestic mineral recovery. Currently, the Rules stipulate an overall minimum recovery target for battery materials based on the percentage of total recovered materials relative to the dry weight of a battery.[2]

***Responsible stakeholder:*** Ministry of Environment, Forest and Climate Change.

iii. **Develop and notify standards for battery characterisation, repurposing, and recycled mineral quality.**

There are currently no notified standards for battery circularity, while BWMR does not specify technical requirements for evaluating batteries or verifying the quality and purity of recycled minerals. Necessary standards should therefore be developed for battery characterisation, warranty, repurposing, and recycled mineral quality. This would give battery manufacturers greater confidence in repurposing and help producers ensure that recovered minerals meet the required grades for use in new EV battery cells.

***Responsible stakeholders:*** Bureau of Indian Standards (BIS), Ministry of Electronics and Information Technology (MeitY), and Ministry of Mines.

iv. **Introduce buy-back or take-back programmes for spent EV batteries.**

The current spent EV battery collection system remains fragmented, making it difficult to channel waste batteries to authorised recyclers—and this is a challenge for both the manufacturers and EV users. EV makers can introduce take-back or buy-back mechanisms for retired EV batteries, with dealers and authorised service

[2] In the case of EV batteries, the targets for 2024–25, 2025–26, and from 2026–27 onwards are 70%, 80%, and 90%, respectively.

centres being the interface between vehicle customers and makers, thus playing a pivotal role in sensitising and guiding users and facilitating participation in these programmes.

***Responsible stakeholders:*** EV owners, EV manufacturers, automobile dealers, service providers, and battery recyclers.

v. **Introduce standards to support ease of battery circularity at the design and manufacturing stage.**

There is currently no standard supporting the principle of "Design for Repurposing and Recycling" that promotes consideration of the ease of repurposing and/or recycling at the battery pack design and manufacturing stage. Standards should be introduced to allow for efficient, safe, and economical repurposing and/or recycling of used EV batteries.

***Responsible stakeholders:*** BIS, MeitY, and Ministry of Road Transport and Highways (MoRTH).

vi. **Develop testing infrastructure for battery characterisation to support repurposing and recycling.**

Characterisation and evaluation of battery health are important to determine whether an EV battery can be repurposed or should be sent directly for recycling. This requires state-of-the-art testing facilities across the country. Budgets allocated under EV programmes could fund the development of this infrastructure. PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE), the flagship central government scheme supporting EV adoption, has a budgetary allocation of ₹780 crore for upgrading testing agencies.

***Responsible stakeholder:*** Ministry of Heavy Industries (MHI).

vii. **Monitor black mass movement and limit exports to ensure domestic mineral recovery.**

Domestic utilisation of black mass for mineral recovery is of strategic importance. Stronger enforcement and monitoring are needed to prevent the unauthorised movement of black mass and increase its availability to domestic processing units for mineral recovery. Domestic mineral recovery remains important even in the absence of a sizeable LiB cell manufacturing capacity. Exporting recovered minerals instead of black mass would also constitute a higher-value export.

***Responsible stakeholder:*** Ministry of Commerce and Industry.

viii. **Build recycling capacity, collection, and transportation networks before retirement volumes grow dramatically.**

The analysis indicates that sizeable quantities of recoverable minerals are expected to become available over the next decade. Recycling capacity and investment should therefore be planned well in advance. Establishing collection and transportation networks, building recycling facilities, and stabilising process lines for mineral recovery take time to reach commercial scale. The findings also emphasise the need for a targeted approach to used-battery collection and handling as some EV segments, such as electric two-wheeled vehicles, have an outsized share in EoL battery volume.

***Responsible stakeholder:*** Battery recyclers.

ix. **Harmonise regulations for safe collection, storage, and transportation of used EV batteries.**

As EV battery waste volume increases, regulations governing the safe collection, storage, and transportation of used LiBs will become increasingly important. These batteries can pose fire and safety risks if they are damaged, improperly segregated, poorly stored, or mishandled during collection and transport.

Since fire-safety requirements are often governed at the state or urban local body level, varying regulations across states can create compliance uncertainty for industry. Harmonised regulations would help industry meet safety requirements more consistently, reduce fire risks, and improve compliance.

***Responsible stakeholders:*** Petroleum and Explosives Safety Organisation and state governments.

x. **Encourage long-term agreements between manufacturers and recyclers.**

Uncertainty around used-battery sourcing, management, volumes, and price affects both EV and battery manufacturers and recyclers. Long-term contracts between manufacturers and recyclers can improve predictability. Drawing from international experience, EV and battery makers should explore developing industry-level alliances or common platforms to manage the collection, second-life use, and recycling of waste batteries.

***Responsible stakeholders:*** EV manufacturers and battery recyclers.

Allied actions to address the gaps in the existing broader recycling ecosystem in the country, including research and development of mineral recycling technologies, skill development, industry policy, and awareness generation, would also benefit EV battery recycling. Today's preparedness will determine whether EoL EV batteries will become a useful "resource" for the economy as the EV population in the country grows.

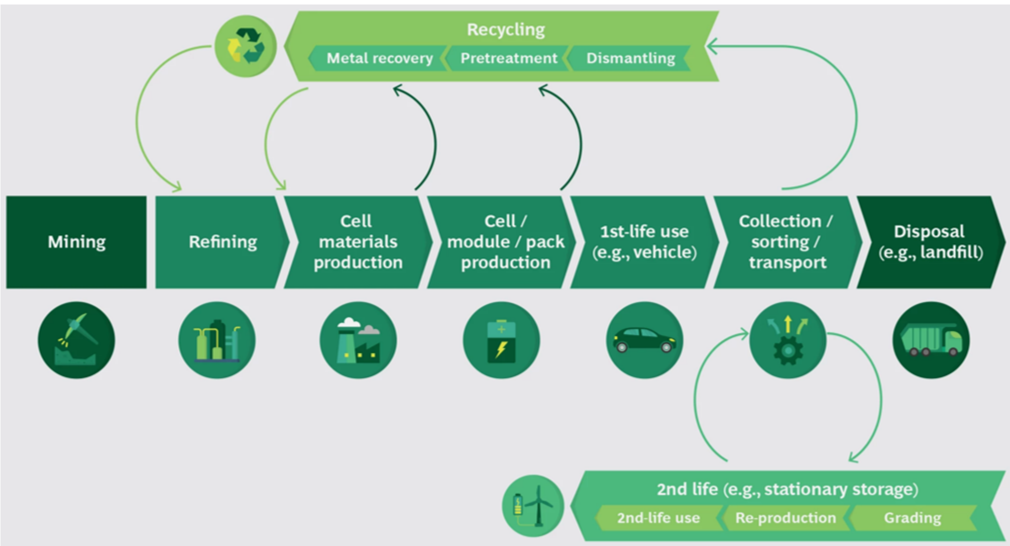
# 1. Battery Circularity—An Emerging Opportunity for India

Adoption of EVs in India is gaining momentum with every passing year. From FY 2016–17 to FY 2025–26, about 8 million EVs have come onto Indian roads at a significant annualised growth rate of over 50%[3]. Despite this high rate of adoption, the EV sales share in total vehicle sales is still in the single digits (estimated to be 8.25% in FY 2025–26). This shows there is a lot of headroom left for the EV market to grow further in the country. As the country rapidly electrifies its motorised road transport, LiBs that power these EVs have become an indispensable part of this transition. While the technology shift sounds exciting, there is a discomforting side of the story. Each of these batteries has a finite mobility life. EV LiBs are typically considered unfit for mobility applications at 70% to 80% of their original capacity (International Electrotechnical Commission, 2024).[4] The years of useful life vary depending on the vehicle use-case, LiB chemistry, and other factors.

As LiBs reach EoL, they pose a growing waste-management challenge for the country. These batteries can potentially cause irreversible ecological impacts and associated public health challenges if left unmanaged. Also, LiBs can pose fire and explosion hazards if not properly handled.

Streams of end-of-mobility-life LiBs also open a prospect for the economy to unlock value by adopting sound circularity practices, i.e., through effective repurposing of these used batteries or recycling and reusing the embedded materials. Figure 1 provides a schematic representation of the circular economy in the case of EV batteries.

**Figure 1: Flowchart of Circular Economy in Case of EV Batteries**




*Source: Niese et al. (2020).*

[3] The high growth rate is partly due to the low-base effect since the number of EV sales was a little over 50,000 in FY 2016–17 as compared to 2.5 million in FY 2025–26. The majority of these EVs are in the form of electric 2W and electric 3W vehicles.

[4] However, battery retirement effectively depends on when it no longer satisfies the travel requirements of an EV user. Therefore, the mobility life of an EV battery varies.

Repurposing entails re-engineering a used EV battery for an application different from the original use-case to utilise the residual battery capacity. One such secondary use can be in the form of stationary energy storage where the size of the system does not matter much (lower energy delivery of degraded batteries can be overcome by simply adding more of them). This extends the functional life of batteries.[5]

Recycling a spent EV battery involves recovering and reusing the embedded valuable materials. LiBs are essentially made of certain minerals that can be recovered and refined to grades suitable for industry reuse. The recovered minerals can be potentially reused to produce either new LiB cells or other market products like specialised ferrous and non-ferrous alloys, ceramic materials, and speciality chemicals. This is particularly important for India in order to fortify its supply chain given the scarcity of some of these minerals along with the geographic concentration of their supply chains. India's current heavy reliance on imports of these vital natural resources, along with LiB cells,[6] potentially exposes the country to supply and economic risks. Even in a scenario of limited domestic cell manufacturing capacity, recovery of the precious minerals offers an opportunity to export them as well as to develop in-house mineral-processing capability[7], both of which are of strategic importance. Table 1 shows that India currently sources the minerals that are relevant for LiB cell making from countries afar. These minerals include lithium carbonate and lithium oxides and hydroxides (together commonly referred to as lithium mineral), nickel oxides and hydroxides and nickel sulphate (together commonly referred to as nickel mineral), copper ores and concentrates and copper oxides and hydroxides (together commonly referred to as copper mineral), cobalt oxides and hydroxides[8] (together commonly referred to as cobalt mineral), and natural graphite. Even though India does not have a sizeable LiB cell manufacturing capacity currently, trade data indicate that the economy is importing these minerals. This implies that with the possible increase in domestic LiB cell production capacity, the import dependence of the country will potentially become more prominent.

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[5] Refurbishing of LiBs has not been considered here because of quality control concerns and lack of a strong case to justify the need. Refurbishing a LiB involves restoring its capacity and performance through different techniques. This process typically includes disassembling the battery, inspecting individual cells, replacing the degraded cells, rebalancing the battery, and reassembling it. The goal is to extend the battery's lifespan. This requires technical expertise, careful component sourcing, and quality control to ensure the rebuilt battery meets the original manufacturer's specifications and quality standards, which is a major challenge.

[6] A battery module is made of several cells. Multiple modules, in turn, are assembled to make a battery pack, which is used in EVs or other energy-storage applications.

[7] Currently, India lacks an established mineral-processing industry.

[8] This may also include sulphates.

**Table 1: India's Imports of Battery-Relevant Minerals by Source Countries From 2019 to 2024**

| **Lithium Carbonate** | **Qty (kg)** | **Lithium Oxides and Hydroxides** | **Qty (kg)** |
|---|---|---|---|
| Ireland | 20,00,000 | Russian Federation | 35,36,453 |
| Belgium | 12,39,251 | China | 20,06,076 |
| Netherlands | 11,00,200 | Belgium | 20,01,004 |
| Chile | 7,21,700 | Chile | 12,54,000 |
| USA | 4,83,104 | Latvia | 6,28,000 |
| | | | |
| **Nickel Sulphate** | **Qty (kg)** | **Nickel Oxides and Hydroxides** | **Qty (kg)** |
| Belgium | 60,60,405 | Australia | 9,47,37,536 |
| Japan | 19,98,816 | Sweden | 14,12,396 |
| Taiwan | 16,84,585 | China | 12,79,460 |
| South Africa | 7,08,328 | Indonesia | 4,27,761 |
| Finland | 2,78,000 | Philippines | 3,72,200 |
| | | | |
| **Copper Ores and Concentrates** | **Qty (kg)** | **Copper Oxides and Hydroxides** | **Qty (kg)** |
| Chile | 2,33,82,70,000 | Norway | 9,64,000 |
| Indonesia | 1,13,28,18,720 | USA | 2,75,853 |
| Peru | 59,23,43,309 | United Arab Emirates | 1,40,403 |
| Australia | 49,12,04,660 | Singapore | 1,39,301 |
| Panama | 27,21,01,500 | Netherlands | 1,30,003 |
| | | | |
| **Cobalt Oxides and Hydroxides** | **Qty (kg)** | **Natural Graphite** | **Qty (kg)** |
| Finland | 9,12,510 | China | 12,72,02,802 |
| Belgium | 6,90,588 | Madagascar | 9,14,50,962 |
| South Africa | 4,45,895 | Mozambique | 5,23,96,043 |
| China | 3,36,587 | United Rep. of Tanzania | 84,11,339 |
| Germany | 1,40,503 | Vietnam | 48,95,060 |

*Source: Authors' compilation based on the UN Comtrade database, United Nations Department of Economic and Social Affairs, Statistics Division (n.d.).*

In view of the rising use of scarce minerals in the economy, the Ministry of Mines, Government of India (GoI), released a list of 30 critical and strategic minerals in June 2023 to identify those essential to various industrial sectors and to guide policy formulation, strategic planning, and investment decisions in the mining sector (Press Information Bureau [PIB], 2023). These minerals are defined as those "which are essential for economic development and national security, and the lack of availability of these minerals or even concentration of existence, extraction or processing of these minerals in few geographical locations may lead to supply chain vulnerability and disruption" (Ministry of Mines, 2023, p.8). Lithium, nickel, cobalt, copper, and graphite (henceforth referred to as battery minerals) are on this list of critical and strategic minerals. For three of these—lithium, nickel, and cobalt (henceforth referred to as precious critical minerals because of their greater market value than other battery minerals)—India is 100% import-dependent (Ministry of Mines, 2023).[9]

Disruptions in the supply of minerals of economic significance are increasing due to geopolitical conflicts, resource nationalism, trade restrictions, and transport infrastructure bottlenecks. Hence, building resilience to mineral supply shocks is imperative for India's EV sector.

Whether EoL batteries will end up in landfills or become a useful "resource" for the economy is going to decide the fate of the growing population of EV batteries. Adopting sound material circularity practices in this regard is key not only to managing downstream waste effectively but also to securing the LiB value chain, which is strategically important for an economy increasingly moulded by climate obligations. After all, the circular economy prolongs the effective use, i.e., the "life" of the materials and other resources consumed in manufacturing the batteries and thus reduces the ecological footprint of mining and battery manufacturing.

## 1.1 Objective and Scope of the Study

Given the importance for India to develop a thriving battery circular economy as it continues to make considerable progress in the EV transition, it is useful to have a clear understanding of the scale of the opportunity. For instance, what quantities of battery minerals could India recover from the EoL EV battery stock over a time period, and what would be the corresponding economic value? If significant potential for LiB circularity in the country is identified, it would be imperative to plan the associated infrastructure and investment needs. Building an effective battery recycling ecosystem will require the establishment of advanced EoL battery treatment and mineral recovery facilities. The latter particularly would necessitate substantial capital investment, a part of which has to be front-loaded so that the processing facilities are up and running as streams of retired EV batteries become available for recycling.

Against this backdrop, this research seeks to provide a range of insights into the circular economy potential in India associated with retired EV batteries and what it would take to unlock this opportunity in terms of required infrastructure and corresponding investment.

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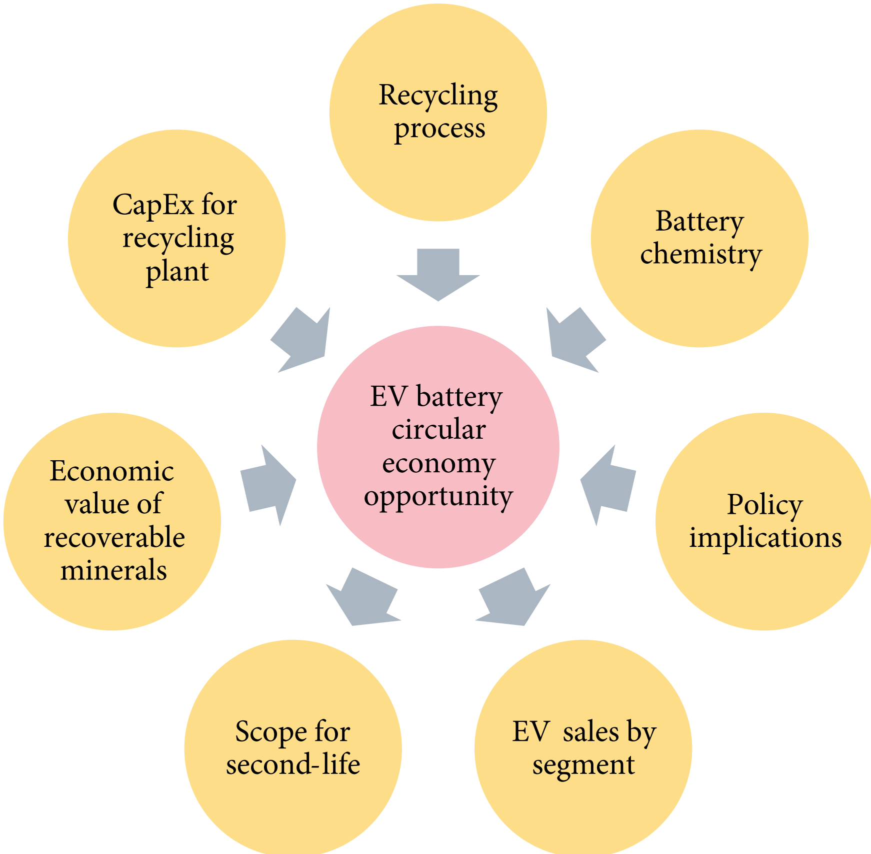
[9] Nickel and cobalt are used to make a class of LiBs commonly called nickel manganese cobalt (NMC) batteries. Lithium is a common ingredient across the LiB family of advanced-chemistry cell batteries.

To carry out the assessment, the study considers the time horizon up to FY 2040–41. While the period is long enough to get a judicious medium- to long-term view of the sector, it is also possible to undertake the necessary projection exercise with reasonable confidence. The degree of uncertainty rises with time. For example, new battery chemistries or technologies with different characteristics and performance may get a sizeable share in India's EV market in the distant future, which may alter the scope for circularity. Moreover, it would be challenging to project the EV sales trajectory over a very long time. Both EV adoption and battery chemistry strongly influence the timing, scale, and mineral profile of the recycling opportunity. Hence, extending the analysis further would require more speculative assumptions.

The study reviews the country's policy landscape relevant for used EV battery recycling, examines the key recycling methods, projects the potential volume of EoL EV batteries available for recycling, and estimates the CapEx requirement to set up recycling facilities (as shown in Figure 2).

**Figure 2: Multidimensional Approach to Assess EV Battery Recycling**




*Source: Authors' construction.*

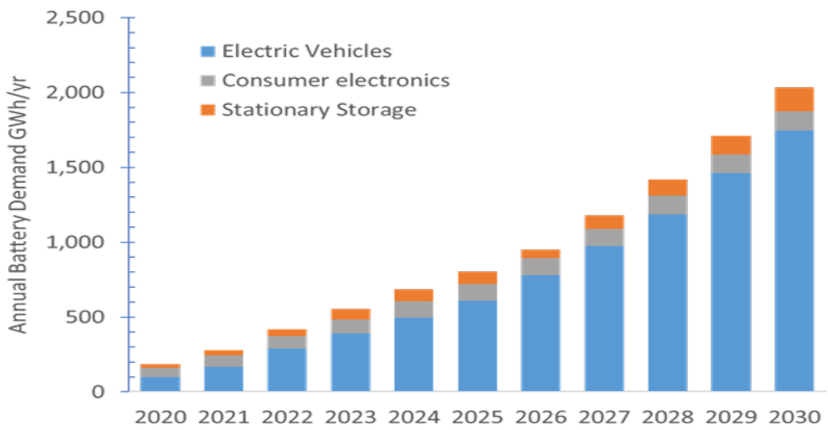
*Note: CapEx = capital expenditure; EV = electric vehicle.*

The time-series analysis potentially helps policymakers and other stakeholders to develop a long-term, well-sequenced strategy for EV battery circularity in India, which can keep pace with the rising EV adoption while strengthening resource security and serving sustainability objectives.

## 1.2 Why Do Retired EV Batteries Merit Immediate Attention?

Spent LiBs from EVs are envisaged to constitute the bulk of the emerging stream of used batteries[10] in India for the foreseeable future. LiB deployment in stationary energy storage systems, a growing application in the country, is expected to be lower than LiB deployment in EVs over the next decade or so (Figure 3). Moreover, due to the controlled operating conditions that help maintain battery health, the first life of LiBs in stationary energy storage is likely to be longer than that of batteries used in EVs. This limits the volume of batteries from the electricity sector feeding into the circular economy in the country.

**Figure 3: Annual Battery Demand From Key Applications (Actual Values Till 2023 and Projection Till 2030)**




*Source: Abhyankar et al. (2025).*

*Note: GWh/yr = gigawatt-hour per year.*

Production scrap from LiB cell manufacturing can also be a noteworthy secondary source of battery minerals. Scrap includes excess foil cuttings, electrode trimmings, by-products from cathode active material production, and parts which fail to meet quality standards.

Also, some batteries are meant for testing and research and development and are never intended for sale. These are scrapped after their purpose is fulfilled and become available for recycling immediately. The share of production scrap in recycling feedstock can be substantial during the early years of the cell manufacturing

[10] This is over and above the batteries used in electronic appliances.

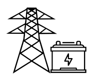
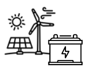
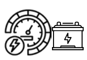
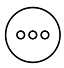
industry in a country. Production scrap from battery pack assembly is limited. In India's context, there is high uncertainty regarding when production scrap can be a major secondary source of minerals given the limited cell manufacturing base currently and the lack of clarity regarding the timeline of commissioning of upcoming cell production capacity. Nearly the entire LiB industry in the country is based on battery pack assembly.

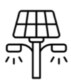
Thus, in India, EVs are expected to account for a major part of the volume of spent LiBs.

## 1.3 Second Life of EV Batteries—An Opportunity With a Caveat

When LiBs are retired from electric drivetrain applications, they may still retain sufficient capacity for less-demanding energy storage purposes. This principle helps extend the useful life of the batteries. The possible use-cases of LiB repurposing are highlighted in Figure 4.

**Figure 4: Potential Use-Cases of Battery Repurposing**

| Stationary Storage Applications for Grid Support | | |
|---|---|---|
|  | **Grid Support and Management** | Helps maintain grid stability, manage demand, and optimise grid operations. |
|  | **RE Capacity Firming** | Stores excess renewable energy and delivers it when generation is low. |
|  | **Peak Shaving** | Stores energy during off-peak hours and supplies during peak demand to reduce strain on the grid. |
|  | **Frequency Support** | Responds quickly to frequency fluctuations and helps maintain grid frequency stability. |
|  | **Power (Load) Backup** | Provides reliable backup power during outages for critical and essential loads. |
|  | **And More** | Other emerging grid support applications as per evolving needs. |

| Mobile and Off-Grid Applications | | |
|---|---|---|
|  | **Street Lamps** | Provides reliable and maintenance-friendly energy storage for smart and solar street lighting. |
|  | **Forklifts** | Powers electric forklifts for material handling in warehouses, logistics and industrial facilities. |
|  | **Refrigerated Vehicles** | Supports clean and efficient cooling for temperature-sensitive transportation. |
|  | **Agricultural Pumpsets** | Stores energy to power irrigation pumps and support reliable farming operations, especially in off-grid areas. |

*Source: Authors' analysis based on literature review.*

*Note: Hz = hertz; RE = renewable energy.*

Batteries retired from quality-sensitive EV segments (for example, high-end passenger electric cars) or high-duty-cycle[11] EV fleets can also be potentially used in less-demanding mobility use-cases like hyperlocal two-wheeled or three-wheeled delivery fleets. This is treated as repurposing as well (also called battery reuse).

### *Battery Repurposing Sounds Simple but Involves Complexities*

LiB repurposing broadly follows a series of complex steps which include screening (to assess the state of health [SoH][12] of the retired battery pack and identify the degraded and damaged cells), disassembling (i.e., opening the battery pack, removing the mechanical and electrical connections between various components and the auxiliary electronic parts), reconfiguring or reconditioning, along with any necessary repairs (involving cell balancing and replacement of defective cells), reassembling (reverse of disassembling along with modifying the battery management system depending on the battery second life), and pre-deployment testing (to validate the desired performance of the repurposed battery pack). Because similar steps are followed, battery refurbishing and repurposing overlap in practice and are often treated interchangeably.

Adapting retired battery packs for second-life use thus requires time, expense, and serious technical expertise. There are several barriers that limit the feasibility of mainstreaming battery repurposing, which are highlighted in Appendix A.

In a nutshell, although repurposing used EV batteries truly serves sustainability objectives, the real-world scalability of the opportunity to pitch it as a mainstream waste-battery management strategy should be considered with a lot of caution. Since this study intends to be as realistic as possible from a research point of view, it does not focus on this element of the battery circular economy.

## 1.4 Positive Multiplier Effect of Battery Minerals Recycling

Material circularity in the case of EV batteries is potentially beneficial for stakeholders across the battery and EV value chain, especially in a country like India, which is presently heavily reliant on imports of both LiB cells and essential raw materials for cell manufacturing. Table 2 captures the key benefits for the different actors in the ecosystem, from upstream players to consumers to downstream players.

[11] Duty cycle is synonymous with operational requirement.

[12] Mathematically, the SoH of a battery is the ratio of its remaining capacity to the original battery capacity.

**Table 2: Benefits for Stakeholders in India From Effective EV Battery Minerals Recycling**

| Stage of the Value Chain | Type of Stake-holder | Potential Benefit of Battery Minerals Recycling |
|---|---|---|
| **Upstream** | **Battery cell manufac-turers** | • Recycled minerals from EoL batteries are a useful secondary source of raw materials to manufacture cells.<br>• Secondary sources of critical minerals can feed into the strategic stockpiling of minerals for the country, safeguard resource availability, and mitigate supply chain disruptions. |
| **Mid-stream** | **EV makers** | • A dependable battery supply chain provides supply certainty and price predictability to EV makers.<br>• There is less need for EV makers to make substantial financial provisions to account for volatility in input (battery) costs triggered by raw-material supply disruptions, allowing better EV pricing. |
| **End-use** | **EV owners** | • The additional monetary value realised from battery circularity is passed on to EV owners as a benefit through mechanisms such as buy-back as they return the used batteries to the automakers or downstream players.*<br>• A predictable and moderate battery cost scenario potentially leads to attractive pricing of EVs, which reduces the cost of adoption by interested vehicle buyers. Currently, the higher upfront cost of EVs compared with that of conventional vehicles is a barrier to large-scale EV uptake in the price-sensitive Indian market. |
| **Down-stream** | **Players managing EoL batteries** | • Battery circular economy opens up new business opportunities and leads to the emergence of a new set of industry players like recyclers, refurbishers, and repurposers, and helps formalise and deepen the country's solid waste handling and management sector, which is largely informal in nature at present.<br>• There is potential for employment generation in ancillary services associated with EoL battery diagnosis, safe handling, data traceability, recycled minerals commodity trading, etc.<br>• Experience garnered in battery minerals recovery during recycling is crucial for developing mineral-processing capability. |

| Stage of the Value Chain | Type of Stake-holder | Potential Benefit of Battery Minerals Recycling |
|---|---|---|
| **Ecosystem** | **Policy-makers (GoI)** | • An effective battery circular economy helps tackle the issue of e-waste from used EV batteries, which would otherwise have been a major governance challenge.<br>• LiB recycling potentially cushions India's import dependence on some of the precious critical minerals and thus supports India's National Critical Mineral Mission (NCMM), whose objectives are to secure the country's critical mineral supply chain by ensuring mineral availability from domestic and foreign sources and strengthening the value chains by, among several interventions, recycling.<br>• EV battery recycling potentially offers the opportunity to export sought-after precious minerals, which opens the possibility of international trade and strengthens foreign exchange reserves.<br>• Developing mineral-processing capability is of strategic importance for India as the country intends to acquire mines of precious critical minerals and build processing units for these minerals.<br>• Battery circularity directly contributes to the cause of "Sustainable Development Goal 12 – Responsible Consumption and Production", one of the 17 Goals that are part of the United Nations' 2030 Agenda for Sustainable Development to which India is committed.<br>• Attractive EV pricing potentially enthuses vehicle buyers to shift away from ICE vehicles to the electric format. Large-scale vehicle electrification is one of the key pillars identified by the government to realise three major policy objectives: strengthening energy security, reducing vehicular emissions, and achieving the 2070 net-zero goal. |

*Source: Authors' analysis.*

*Note: *denotes that some EV manufacturers in India have introduced benefit schemes to encourage their customers to return unfit LiBs to them.*
*EoL = end of life; EV = electric vehicle; GoI = Government of India; ICE = internal combustion engine; LiB = lithium-ion battery; NCMM = National Critical Mineral Mission.*

It is evident that India has major stakes in seriously pursuing recycling and reuse of the minerals recoverable from EV batteries. Recognising this importance, GoI has established a regulatory framework in the form of BWMR. These Rules, notified by the MoEFCC, GoI, intend to put in place a fundamental system to manage EoL batteries from different applications, including EVs (more details in Section 2.3).

## 1.5 Existing Research and Need for a 360-Degree Assessment

Although there are several studies that have analysed the battery circularity opportunity, their objectives and adopted approaches differ. The majority of them focus on explaining the different pillars of the battery circular economy, i.e., refurbishing, repurposing, recycling, and reuse, and assessing the technology or the technical aspects of the subject (Beermann et al., 2022; Li et al., 2024; Transport & Environment, 2024).

At a global level, in 2023, a report released by the International Council on Clean Transportation estimated the volumes of EoL vehicle batteries that could be reused in second-life applications up to 2050 and assessed the impact of reuse and recycling based on the global demand for LiBs for light-duty and heavy-duty EVs (Tankou et al, 2023). The report also described the opportunities and challenges in the 2022 market and developed a policy framework for scaling up battery reuse and recycling practices. It provided an overview of policy approaches seen in China, the European Union (EU), and the United States (US). The study does not cover the Indian market.

In 2024, the International Energy Agency (IEA), the global energy think tank, published the World Energy Outlook Special Report on *Recycling of Critical Minerals*, which evaluated the current status of recycling and urban mining for materials containing minerals critical to the energy transition (IEA, 2024). It shed light on the various recycling technologies in use for different clean energy applications, projected the secondary supply of minerals at a regional level, and outlined certain policy recommendations to accelerate the uptake of recycling and urban mining. The IEA report made an important observation that India's domestic recycling capacity can process only 5% of available feedstock, which indicates a major capacity deficit. It added that the limited material recovery capacity is one of the major reasons behind the high share of exports of black mass[13] to East Asia.

There have been a handful of attempts to study the battery circularity ecosystem in the context of India. As part of the India component of "Nationally Determined Contribution (NDC)–Transport Initiative for Asia (TIA)" programme, Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) published a series of studies on issues related to EV batteries and recycling (Changing Transport, n.d.). A significant report, also one of the earliest evaluation efforts, prepared in 2022 by Deloitte Touche Tohmatsu India and published by GIZ, carried out a landscaping assessment covering the EV battery technologies and elements of the battery value chain, i.e., manufacturing, disposal, recycling, and reuse, to understand the technological and policy landscape in India (Deloitte, 2022; Mandal et al., 2022). Regarding recycling, it detailed the workflow of LiB recycling and the diverse types of mineral recovery processes, viz., pyrometallurgy, hydrometallurgy, and direct recycling. It also highlighted the advantages and disadvantages of each of these techniques.

[13] Black mass has been explained in Section 2.2.

As far as the market size of EV battery recycling in India is concerned, it attempted to make a rough estimation of LiB availability (expressed in gigawatt-hours [GWh]) for recycling in two milestone years—2031 and 2036. However, given the nascency of the sector at the time of preparation of the report, some of the underlying assumptions are found to be dated. The report also introduced the concept of battery reuse (involving reconditioning, refurbishing, repurposing, and reusing) and explained the usefulness and the practical challenges. The study is still a go-to resource for understanding the issue of the EV battery circular economy.

In a joint effort with Agora Verkehrswende and the Indian Institute of Technology (IIT) Bombay, GIZ also published, in 2022, an international review of the recycling ecosystem of EV batteries where it documented the battery recycling ecosystem in Germany and the rest of the EU, California in the US, China, Japan, and South Africa (Bej et al., 2022). The report gives an overview of the policies and regulations pertaining to the recycling of batteries and the roles and responsibilities of stakeholders involved in these countries. This study did not evaluate the recycling market opportunity.

Another report released by GIZ aimed to provide guidance to new entities foraying into battery recycling or refurbishing (Sinha et al., 2023). It identified the stakeholders in the ecosystem, highlighted the permits required to set up a battery recycling or refurbishing facility, identified the possible risks involved, and developed a standard operating procedure for safe handling of batteries.

In 2025, the Indian Council for Research on International Economic Relations published the report *Technology Roadmap for EV Battery Recycling: Ensuring Circularity of EV Battery Supply Chain*, which shed light on the recycling methods and forecast battery waste volume generated from India's EV sector up to 2030 (Singh et al., 2025). It recommends the most efficient recycling technologies as per the battery chemistry in the Indian ecosystem. As far as the market assessment is concerned, the considered time horizon is found to be too short to help in planning. Moreover, the study applies the past compound annual growth rate (CAGR) to forecast the flow of EoL EV batteries. This is a limitation because this approach is likely to inflate the projected EV sales since the growth rate is high due to a low base value.

Another noteworthy assessment was done by Rocky Mountain Institute, titled *Charting a Circular Battery Future for India* (McNamara et al., 2025). The study modelled the impact of battery repurposing and recycling. It projected the volume of batteries available for repurposing and the quantity of EV batteries entering the recycling stream up to 2050, with a strong emphasis on battery repurposing. Although the results of the study are useful, the assessment does not account for differences among recycling methods in its projections. The underlying assumptions are also not clearly presented.

In 2025, PricewaterhouseCoopers India carried out a study, commissioned by the EU-India Clean Energy & Climate Partnership, to develop an action plan for the Ministry of New and Renewable Energy, GoI, for implementing battery waste circularity in India (Vaibhav et al., 2025). The assessment covers EoL batteries from both EV and stationary energy storage applications. The report examined the lifecycle of batteries, from manufacturing to EoL management, assessed the current ecosystem, highlighted the EU best practices, and identified the gaps and challenges.

More recently, the National Institution for Transforming India (NITI) Aayog published the report titled *Advancing Circular Economy of Waste Electronic and Electrical Equipment (E-waste) and Lithium-Ion batteries in India* in January 2026 (Verma et al., 2026). The report provides a broad assessment of India's e-waste and EoL LiB ecosystem, covering the policy landscape, global best practices, gaps in formal collection, and recommendations for strengthening the circular economy. It also sheds light on battery recycling technologies and black mass processing. While the report presents aggregate projections of EoL LiB availability and compares them with announced recycling capacity, the underlying projection methodology and assumptions are not presented. Further, it does not base its assessment of the EV battery-recycling opportunity on a vehicle-segment-specific and mineral-level assessment or estimate the corresponding recycling capacity and investment requirements.

These studies have contributed significantly to the understanding of EV battery circularity. However, there is a need for a holistic assessment that considers the technology as well as policy dimensions of the issue, apart from other practical aspects (refer to the analytical framework applied for the analysis in this paper).

## *Why This Study Stands Out*

This research paper is able to add value to the existing body of literature on the issue of EV battery recycling in India. Three key aspects of the study truly stand out in this regard.

**(i) Segment-specific approach to reflect differences in battery characteristics and useful lives**

The assessment considers the EV sales trajectory, representative battery pack size, battery chemistry, and minimum mobility life separately for each vehicle segment. It also factors in the possible changes in battery capacity and chemistry over the assessment period. Such disaggregation avoids a homogeneous treatment of vehicle segments and allows differences in battery characteristics and useful lives to be reflected in the assessment.

**(ii) Linking of EoL battery flows, including possible repurposing, with material recovery and associated requirements**

The study estimates the availability of EoL batteries after accounting for their minimum mobility life and possible use in second-life applications. These battery flows are linked with chemistry-specific mineral intensity, energy density, recycling process shares, and recovery rates to estimate recoverable mineral volumes and their economic value. The resulting projections are further used to assess the recycling capacity and corresponding capital investment required over the assessment period.

**(iii) Transparent assumptions and an assessment framework amenable to periodic updates**

The study clearly sets out the assumptions used at different stages of the assessment, including those related to EV sales, battery characteristics, useful lives, possible repurposing, mineral intensity, recovery rates, recycling processes, capacity, and investment. The granularity and transparency of the assessment allow the analysis to be revisited as new data and evidence become available. This makes the methodology amenable to periodic updates by relevant stakeholders.

## *Exclusion From the Study*

The assessment does not include LiBs deployed at swapping stations due to a lack of data on sales of EVs with swappable batteries, batteries in use at swapping stations, and the average useful life of these batteries.[14] It is understood that the share of EVs with swappable batteries is many times lower than that of EVs with fixed batteries in the Indian market. Hence, excluding the LiBs used in swapping stations does not impact the outcome of this study.

Lead–acid batteries present in EV stock too have not been studied here because of the insignificant value of the concerned materials (compared to the minerals in LiBs) for the economy and the dwindling population of these EVs in the market.

To make the findings of the study accessible to a wide audience, from policymakers to industry to financiers, the paper consciously avoids covering unnecessary technological and process details associated with batteries and recycling without ignoring their implications on the results of the assessment. Nevertheless, it is desirable that a reader possesses a fair level of understanding of EVs and batteries.

## *Flow of the Paper*

This paper is structured as outlined below.

Section 2 sheds light on the minerals present in LiBs and distinguishes those with relatively high market value (termed minerals of interest in this study), outlines the principal recycling techniques, and lays out the relevant policy and regulatory landscape.

Section 3 discusses the methodology employed to carry out the necessary assessment to meet the research objective, including tracing vehicle sales and EV batteries through to recycled battery minerals and their value in a step-by-step logical manner. It also clarifies the different dimensions of the analysis to help readers interpret the results.

Section 4 explains India's EV battery recycling opportunity by presenting a range of insights, from the quantity of recoverable minerals and the economic value of recycling to the contribution of recycling to battery cell manufacturing and the importance of a targeted battery collection and handling approach, and much more.

[14] The average mobility life of swappable batteries is considered longer than that of fixed batteries.

Section 5 highlights the requirement for recycling capacity and corresponding CapEx to realise the full scale of the EV battery-recycling opportunity.

Section 6 conducts a review of the salient practices in major EV markets at various stages of the battery circularity value chain and derives some key learnings for India.

The research paper concludes with Section 7. Based on the findings of the study, it recommends 10 key interventions towards supporting India's EV battery recycling, along with identifying the responsible actors.

# 2. Battery Minerals and Recycling Processes

To appreciate the potential for battery mineral recovery from the EV sector, it is important to first understand the EV battery chemistries and the processes through which these minerals can be reasonably recovered.

## 2.1 Minerals of Interest

LiBs used in EVs contain a range of minerals and materials which influence the motivation for recycling (Goel, Moerenhout, & Bollini, 2024). The mineral content of a battery varies with its chemistry. EV batteries in India are currently dominated by two broad chemistries: nickel manganese cobalt (NMC) and lithium iron phosphate (LFP). NMC batteries typically contain nickel, manganese, and cobalt in the cathode, whereas lithium, iron, and phosphate are present in the cathode of LFP batteries. Both chemistries have graphite in the anode and lithium salts in the electrolyte. The market values of these minerals differ significantly. Based on the average prices reported for 2024 and 2025 in the International Monetary Fund (IMF) Primary Commodity Price System (PCPS), the selling price of lithium is about ₹8,468 per kilogram (kg), and for nickel and cobalt, the prices are nearly ₹1,500 per kg and ₹2,690 per kg, respectively. Thus, the embedded mineral profile of a LiB influences recyclers' interest in recovering certain minerals rather than all those present.

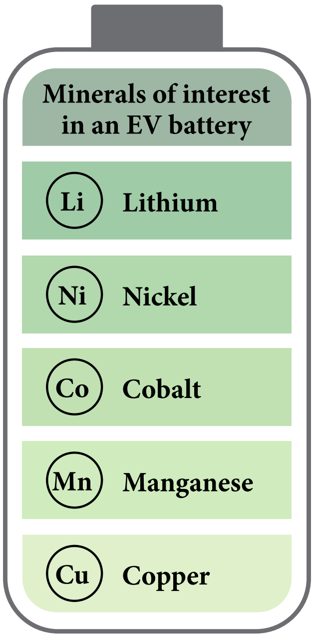
Based on current practices in the recycling industry, the principal minerals of interest are lithium, nickel, cobalt, manganese, and copper, as highlighted in Figure 5**.**

It is important to underline here that the mineral composition of a LiB varies considerably with battery chemistry. The details of the minerals present in salient LiB chemistries are given in Appendix B.

The EV batteries in circulation in the country also contain other minerals such as phosphorus and graphite in considerable quantities. However, the presence of a mineral in a battery does not automatically imply that it is commercially recovered. Unattractive resale values of these minerals are a major reason for recyclers' lack of interest. Some minerals are also hard to recover meaningfully through current recycling techniques due to process limitations.[15] Distinguishing between minerals of interest and other battery minerals helps avoid overstating the recycling opportunity in purely technical terms.

[15] There is considerable loss of these minerals during the process as they get converted to slag, an inert by-product, which is hard to treat.

**Figure 5: Minerals of Interest in an EV Battery**

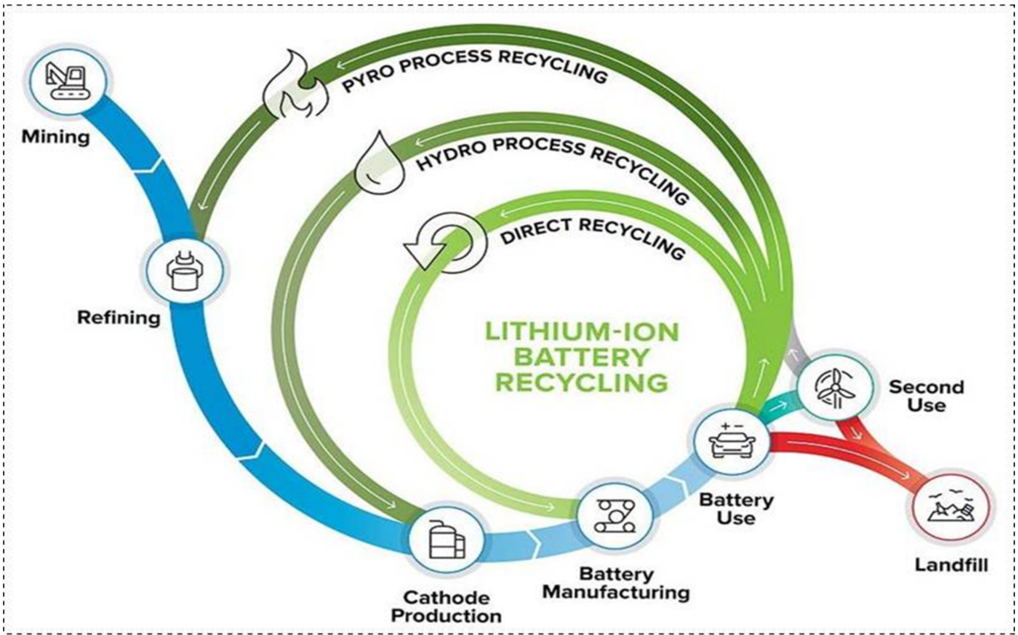



*Source: Authors' illustration.*

## 2.2 Pathways for Minerals Recovery

A battery that enters the recycling stream can be processed through different techniques. Broadly, these include pyrometallurgy, hydrometallurgy, and direct recycling; each of these entails a unique circularity pathway (Figure 6).

**Figure 6: Different Recycling and Reuse Pathways**




*Source: Gutiérrez (2021).*

Pyrometallurgy entails processing spent LiB cells at high temperatures without mechanical pretreatment and loading the batteries directly into the smelter; hydrometallurgy employs mechanical pretreatment and metal recovery from black mass by means of leaching, precipitation, solvent extraction, ion-exchange resins, and bioleaching. Black mass serves as the intermediate process feedstock for hydrometallurgical recycling processes that recover the metal salts and battery-grade minerals. Box 1 captures the key details about black mass.

**Box 1: A Brief on Black Mass**

Black mass is a fine powder mixture containing the cathode and anode materials. It is produced once EoL batteries undergo shredding and separation during the pretreatment stage. The typical black colour is due to graphite, which has a shiny, dark black texture, in the anodes. Black mass represents about 40% to 50% of the dry weight of an EV battery. It has varying compositions depending on the chemistries of the spent batteries.

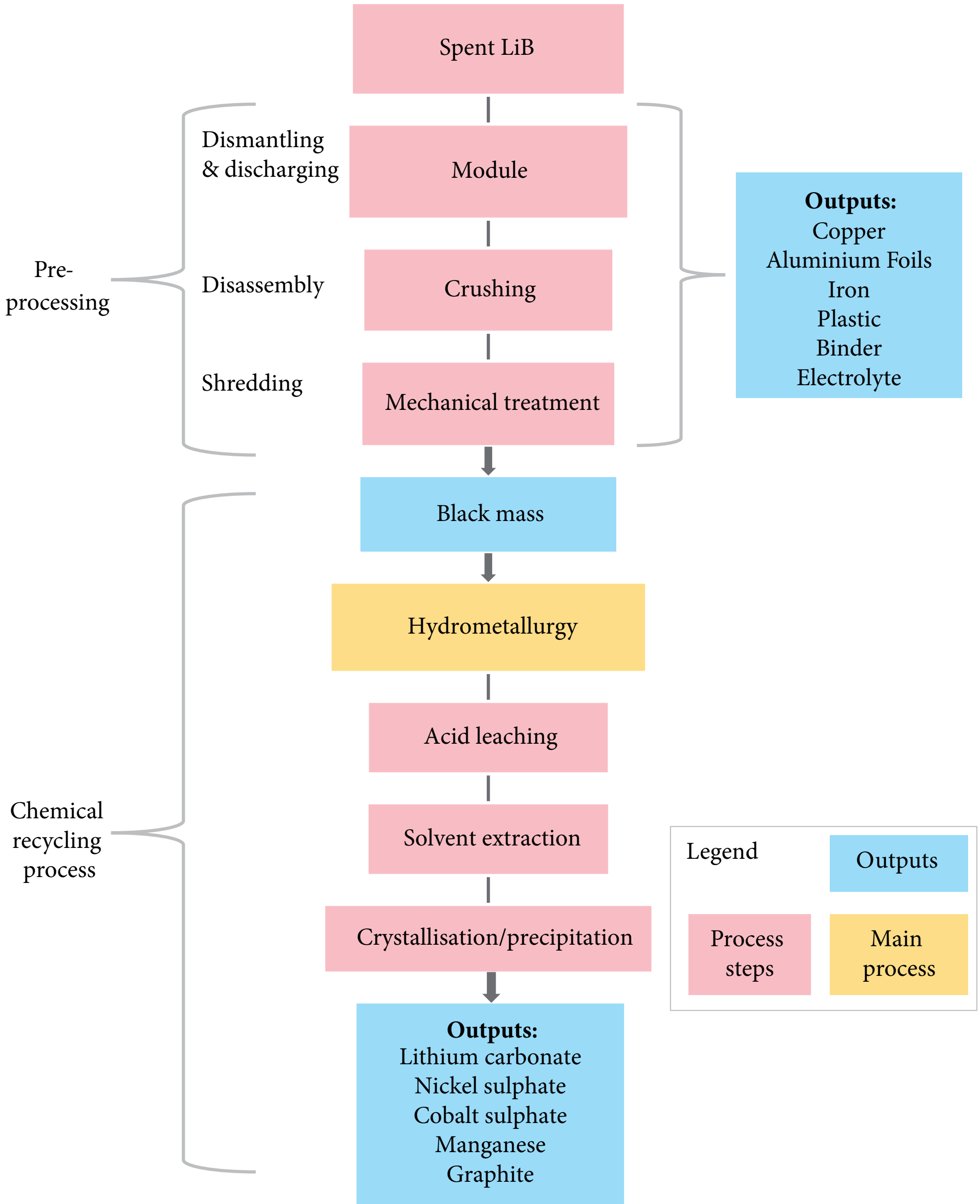
Direct recycling is a novel process in which the cathode and anode active materials within EoL batteries are regenerated without breaking them down into individual battery chemicals, which is otherwise required in the case of traditional battery-recycling methods. Thus, direct recycling can result in a higher recovery rate than that of other methods such as hydrometallurgy. However, its commercial adoption is currently limited since the technology is at a nascent stage and the method requires well-sorted waste streams, which are difficult to achieve at scale.

These three broad routes of recycling differ in technical complexity, recovery profile, associated costs, and recycled mineral grades.[16] Hydrometallurgy is currently the dominant recycling technique used by industry globally and in India for mineral recovery from spent LiBs. As per the indicative global benchmarks, a hydrometallurgical process can yield reasonably high recovery rates for lithium, nickel, cobalt, manganese, and copper, which explains why this technique is widely preferred (Singh et al., 2025).

Figure 7 presents the key steps followed in the hydrometallurgical process of LiB recycling.

[16] The grade of a mineral is a determining factor for its reuse in a specific application like LiB cell manufacturing.

**Figure 7: Key Steps in Hydrometallurgy**




*Source: Authors' construction.*

*Note: LiB = lithium-ion battery.*

## 2.3 Policy and Regulatory Context

India's emerging battery circularity ecosystem is already shaped by a policy framework that provides a head start to battery collection, traceability, refurbishment, and recycling. BWMR, 2022 establishes the principal regulatory architecture for waste batteries in India. The framework places producer responsibility at its core through EPR obligations. As defined in the rules, EPR means the responsibility of any producer of batteries for environmentally sound management of retired batteries. This is important because EV batteries may otherwise leak into informal channels at EoL. By assigning responsibility to producers, BWMR creates a compliance pathway. Further, it sets rules for the collection and recycling of waste batteries and links collection obligations with batteries placed on the market earlier. It also includes provisions relevant to EV batteries, such as segment-specific collection timelines, which are used to infer minimum mobility-life assumptions for different EV categories, and recycled-content requirements for new batteries (MoEFCC, 2022).

The relevant BWMR provisions on collection, material recovery, and minimum use of recycled materials are listed below.

- Annual collection targets start at 70% and increase up to 100% by the end of the vehicle segment-specific compliance cycle.
- Minimum recovery of EV battery materials starts at 70% from FY 2024–25 and increases to 90% from FY 2026–27 onwards.
- Minimum use of recycled materials in EV batteries starts at 5% in FY 2027–28 and increases to 20% from FY 2030–31 onwards.

These provisions are important for the present study because they influence both the timing of battery availability for recycling and the broader compliance environment within which battery circularity is expected to evolve.

A second important policy development is the Ministry of Mines' Critical Mineral Recycling Scheme, 2025 (Ministry of Mines, 2025), which seeks to promote recycling-based recovery of critical minerals from spent LiBs, e-waste, and other eligible scrap streams. The scheme provides an indicative outlay of ₹1,485 crore to support 270 kilotonnes of processing capacity, distinguishes between large established players and smaller or newer entities, and links support with actual mineral recovery rather than production of black mass alone. The scheme also provides a mix of CapEx reimbursement and sales-linked operational expenditure (OpEx) support.

The regulatory landscape may further evolve with the proposed Battery Aadhaar framework, which seeks to strengthen battery traceability through unique identifiers and digital lifecycle information (GoI, 2026). Such a framework could support second-life use, improve compliance monitoring, and facilitate more efficient recycling by strengthening visibility over the movement of batteries across their lifecycle.

These policy developments show that India's battery circularity landscape is no longer at a purely conceptual stage. A regulatory foundation already exists for collection, recycling, mobility-life, recycled content, etc., while the recent financial support initiative signals a growing emphasis on domestic mineral recovery. The next section builds on the technical and regulatory context to estimate the scale, timing, and material composition of India's EV battery recycling opportunity.

# 3. Framework to Assess India's Battery Circularity Opportunity

Taking cognisance of the fact that the opportunity for a circular economy is dependent on a range of factors (as highlighted in Figure 2), the research employs a well-rounded analytical framework, as elucidated below.

## *EV Stock Disaggregation into Segments*

The analysis links EV sales with the quantity of minerals that can feasibly be recovered through recycling up to FY 2040–41 through a step-by-step method. The study disaggregates the country's EV stock into eight different segments, such as two-wheeled vehicles, passenger e-rickshaws, three-wheeled vehicles,[17] passenger cars, minitrucks, standard- and midi-size buses, and medium- and heavy-duty trucks.

Consideration of the different EV segments is the bedrock of this assessment. It allows the study to account for the diversity in terms of battery size, share of chemistries, mobility life and possible second life, and energy density. These underlying parameters influence not only the amount of embedded minerals available for recycling but also when they would be coming to the waste stream for recycling. Moreover, the growth in EV uptake varies considerably between these segments. For example, while electric two-wheeled vehicles have registered an annualised growth rate of about 86% from FY 2014–15 to FY 2025–26, the rate is around 68% in the case of electric passenger cars. The total sales of these EVs, of course, differ as well.

Passenger e-rickshaws with LiBs have been separately considered because of the sizeable population of this EV type and, consequently, the potential stream of spent batteries that can be tapped despite the relatively smaller battery packs. This segment has remained relatively under-considered in earlier assessments. Electric medium- and heavy-duty trucks have been included as an emerging segment. These EVs are characterised by large-sized batteries that make them an interesting segment from a battery circularity point of view, although their share in the total EV stock is small. Disaggregation by type of EV, thus, helps align the analysis with the transition trajectories across different segments.

## *EV Sales—Today, Tomorrow*

EV sales are a key input for assessing the flow of spent batteries. Depending on the average first life of EV batteries, there is a lag between the quantity of LiBs entering circulation and their retirement from mobility applications. Taking this into account, the study considers EV sales data till FY 2037–38 to project the size

[17] Three-wheeled vehicles cover both passenger and freight sub-segments.

of the battery circular economy till FY 2040–41. Based on the availability of data, the assessment uses actual EV sales statistics from FY 2014–15, which is treated as the inception year for the country's EV transition, to FY 2025–26, the latest year for which sales data were available when this research was conducted.

### *EV Battery Chemistry*

Battery chemistry determines the profile of minerals embedded in it. It is the underlying factor that drives the circular economy in electric mobility. Although LFP and NMC are the two predominant LiB chemistries used in EVs,[18] their shares of the EV stock differ by segment and change over the years. Moreover, new LiB chemistries may emerge, albeit starting with small shares.

### *Regulatory Implications*

As stated before, BWMR, 2022 provides the regulatory framework for battery recycling in India. The provisions of the Rules, particularly related to two specific clauses of EPR, are critical for the assessment of the battery recycling opportunity. First, the study considers the minimum mobility life of an EV battery based on the provision in BWMR, specifically clause (i) of Schedule II. Second, the time-series analysis of the volume of the spent battery stream becoming available for recycling or a second-life application during the assessment period is anchored to the BWMR provision concerning the minimum yearly collection targets for used batteries (MoEFCC, 2022). As a 70% battery collection rate has been considered in line with BWMR-set targets, the estimates of the recycling opportunity derived in this study can be treated as conservative. Considering the possible leakage in the EV battery circularity pathway, i.e., retired LiBs not reaching the formal recycling industry or being dumped as waste, the projected results may be reflective of the ground reality.

## 3.1 A 10-Step Methodology

The applied methodology to evaluate the opportunity for an EV battery-based circular economy comprises 10 key steps, as presented in Figure 8.

[18] A few other fringe battery chemistries have very small shares and are limited to specific EV types.

**Figure 8: The 10-Step Methodology Followed in Assessing EV Battery Circularity Opportunity**

| | |
|---|---|
| **Collation of annual EV sales (FY 2014-15 to FY 2025-26)** | Actual EV sales compiled for each vehicle segment using Vahan dashboard data. |
| **Projection of EV sales** | EV sales for different segments projected based on expected penetrations. |
| **Estimation of battery capacity introduced into circulation** | EV sales multiplied by battery pack size to estimate annual battery stock entering use (changes in pack capacity over time considered). |
| **Allocation of battery stock by chemistry type** | Battery capacity introduced into circulation split into LFP, NMC and NCA+Others using segment specific chemistry and mineral intensity factors. |
| **Consideration of minimum mobility life** | Minimum mobility life assigned by vehicle segment based on provisions in BWMR and relevant secondary literature. |
| **Evaluation of EoL battery availability** | Possible opportunity for repurposing of batteries considered for certain segments. |
| **Estimation of battery mass available for recycling** | EoL battery capacity by chemistry type converted into battery mass based on chemistry specific energy density. |
| **Assessment of mineral recovery opportunity by FY 2040-41** | Recovery rates and technology shares applied to estimate recoverable mineral quantities. |
| **Economic valuation of recoverable minerals** | Value of recovered minerals estimated based on current market prices. |
| **Estimation of required recycling capacity and investment** | Projections based on recycling opportunities till FY 2040–41. |

*Source: Authors' analysis.*

*Note: BWMR = Battery Waste Management Rules; EoL = end of life; EV = electric vehicle; FY = financial year; LFP = lithium iron phosphate; NCA = nickel cobalt aluminium; NMC = nickel manganese cobalt.*

First, actual annual vehicle sales have been collated for each EV segment using data from the Vahan Dashboard (MoRTH, n.d.). Second, EV sales have been projected for future years using segment-specific penetration[19] or growth trajectories instead of taking a straitjacket approach for the entire EV market. In the third step, EV sales have been translated into battery capacity (expressed in kilowatt-hours [kWh]) introduced into circulation using segment-specific representative battery pack sizes. The fourth step applies segment-specific battery-chemistry shares to the battery stock to determine the batteries' mineral profile (Singh et al., 2025). This is followed by consideration of the minimum mobility life of the batteries based on the provisions of BWMR (MoEFCC, 2022) and a review of the relevant secondary literature. The sixth step accounts for the possibility of extending the useful life of batteries in second-life applications. Converting battery capacity to battery mass is important to evaluate the mineral content of the batteries. This has been done in the next step based on chemistry-specific energy density values. Taking into account the applicable recycling processes and the relevant minerals recovery rates, the study estimates the quantity of minerals that can be potentially recovered (Singh et al., 2025). The mineral recovery rates are assumed to be on a par with the global industry benchmark. Based on the market prices of the recovered minerals, the economic value of battery recycling is then derived. In the last step, the study estimates the recycling capacity and corresponding CapEx that are required to unlock the EV battery recycling opportunity in the country.

It is worth highlighting here that the calculation model factors in the possible changes in values of a range of input parameters over time (year). These parameters, including average battery capacity and chemistry (by type of EV) and the recycling process, are expected to evolve with EV adoption over the years.

The detailed input data and assumptions used in the analysis are provided in Appendices B–M. Together, these appendices provide the supporting basis for estimating EoL battery availability, recoverable mineral volumes, economic value, and required recycling capacity and investment.

## 3.2 EV Sales Trajectory

Segment-specific EV sales are critical because historical sales are an input to, and projected annual sales are an output from, the calculation.

Depending on recent sales trends, expected EV adoption and growth drivers, and the availability of the necessary data, the projection calculation adopts a segment-specific approach to project EV sales over the assessment period.

For electric two-wheeled vehicles, electric three-wheeled vehicles, electric passenger cars, and electric minitrucks, the projection takes into account corresponding EV penetration in a future year, in this case FY 2034–35, based on a KPMG analysis (KPMG, 2025). This is then applied to expected total vehicle sales, including sales

[19] Here, EV penetration in a certain segment implies the share of sales of EVs in total vehicle sales in the segment in a year.

of conventional vehicles.[20] To account for the adoption curve between FY 2025–26, i.e., the latest year when actual sales data are available, and the future year (FY 2034–35), the calculation applies a logistic model (O'Rear et al., 2023). With this triangulation of three factors, the study projects EV sales up to FY 2034–35. For the remaining years of the assessment, i.e., till FY 2037–38, the EV sales projection has been extrapolated (for more details, refer to Appendix M).

For electric buses, the projection considers the existing national schemes since this segment is largely driven by government programmes. The projection draws on the announced and sanctioned volumes under schemes like PM e-Bus Sewa (MoHUA, 2023) and PM E-DRIVE (PIB, 2024). This is a conservative estimate because additional state-led procurement may materialise outside central schemes. However, it is challenging to include the state-level electric bus additions due to a lack of clarity on state procurement plans.

For passenger e-rickshaws and medium- and heavy-duty electric trucks, the current trajectory has been extended based on a moving average of recent adoption.[21]

The estimates should be interpreted as indicative projections rather than precise forecasts. The scale and timing of the recycling opportunity will depend on how EV adoption, battery chemistry, collection, repurposing practices, recovery technologies, and market prices evolve over time. The analysis, therefore, provides an assessment of the likely order of magnitude and direction of the opportunity under stated assumptions, rather than a definitive prediction of future recycling volumes. Nevertheless, the adopted methodology offers scope for future updates of projection results based on the latest data and fresh evidence.

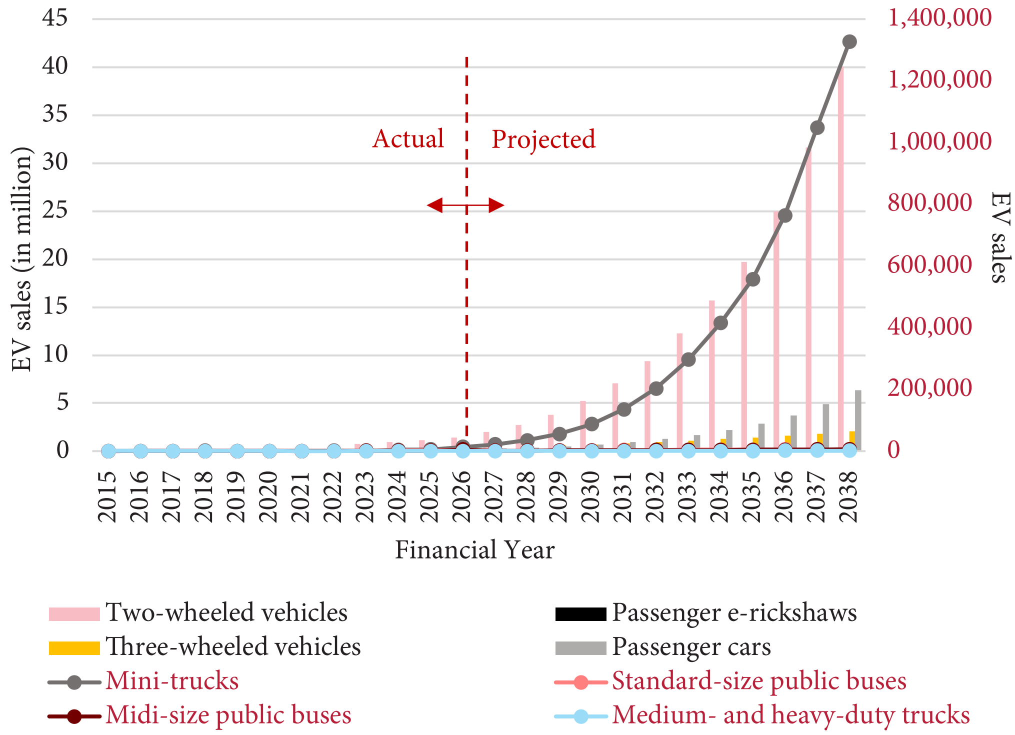
Figure 9 presents the historical and projected EV sales across the vehicle segments. Total EV sales are projected to reach about 9.1 million in FY 2030–31, increasing further to nearly 49.9 million by FY 2037–38, implying an annualised growth rate of about 27.5% over this period. Electric two-wheeled vehicles account for the dominant share, rising from about 7.1 million in FY 2030–31 to about 40.1 million in FY 2037–38, at an annualised growth rate of about 28%. Electric passenger cars rise from about 1.0 million to about 6.3 million over the same period, registering an annualised growth rate of about 30%, while electric three-wheeled vehicles rise from about 0.8 million to about 2.0 million, at an annualised growth rate of about 14%. By contrast, electric buses and medium- and heavy-duty electric trucks remain much smaller in absolute numbers, though they may still contribute materially to future recycling volumes because of larger battery pack sizes (for details, refer to Appendix N and Appendix O).

20 The future vehicle sales growth numbers have been drawn from multiple public sources.

21 Considering a high share of lead-acid batteries alongside lithium-ion batteries, a battery chemistry split of 90:10 between lead-acid and lithium-ion batteries is assumed for this segment. Only lithium-ion batteries have been considered in the assessment.

These differences in EV adoption rates matter for battery circularity because they shape not only the number of batteries entering circulation but also the timing, battery-chemistry mix, and mineral profile of future end-of-life streams.

**Figure 9: Actual and Projected EV Sales by Segment, Financial Year 2014–15 to 2037–38**




*Source: Authors' analysis.*

*Note: EV = electric vehicle.*
*The indicated time-axis (horizontal) is in terms of financial years; the vehicle segments plotted as lines against the right-hand axis of the graph are marked in red for easier identification.*

## 3.3 Caveats to Consider

Battery circularity involves several moving parts, and, to make it happen, these components have to work in tandem. Hence, the projection results presented in this paper are contingent on these moving parts, which are essentially dynamic parameters. One should be mindful of the following aspects of this study that can potentially alter the outcome.

- The battery circularity opportunity is highly dependent on how EV uptake in the country takes shape in future. EV sales trends across segments are a key input in deriving the volume of LiBs in circulation, which in turn affects the size of the circularity opportunity. Future EV sales are considered an exogenous factor in the projection exercise conducted in the study. Although a major effort has been made to project the EV sales trajectory across segments, this analysis is not the core of this study.

- There are multiple stages of the battery circular economy primarily centred around battery repurposing and recycling (as shown in Figure 1). Each stage influences the next stage in the battery-circularity value chain. For example, the opportunity for LiB repurposing shapes the timing of the battery-recycling opportunity. Considering the current maturity of the battery repurposing market, it is challenging to account accurately for these impacts.
- The estimates of recovered minerals, a key part of this study, are conditional on a range of factors, from the salient LiB chemistry mix in the EV market to the extraction processes employed by the industry to the EV battery profiles (capacity, energy density, longevity, etc.). How these elements will evolve over time is hard to anticipate. The presented findings, being based on time-series analysis, have a high degree of uncertainty.
- As stated in the paper, the economic value of battery recycling is contingent on the market prices of the recovered minerals. As commonly understood, these market prices depend on the commodity market, which, like any trading platform, is dynamic and difficult to forecast. The calculation in the study considers the market prices of these minerals reported in the IMF PCPS at the time of the analysis. The results are expected to vary considerably over time, depending on the supply and demand for minerals in the commodity market.

Therefore, the findings of the study should be treated as indicative and interpreted with caution.

# 4. Stakes for India to "Mine" EV Batteries Over the Next Decades

EV battery recycling is potentially the new frontier of opportunity for India. However, it may turn out to be a challenge for the country unless one plans according to the scale of the task at hand. Here, the scale may be interpreted in various ways, such as the volume of spent EV batteries, the amount and market value of the minerals that can be extracted and reused, and what that means in terms of producing new LiBs.

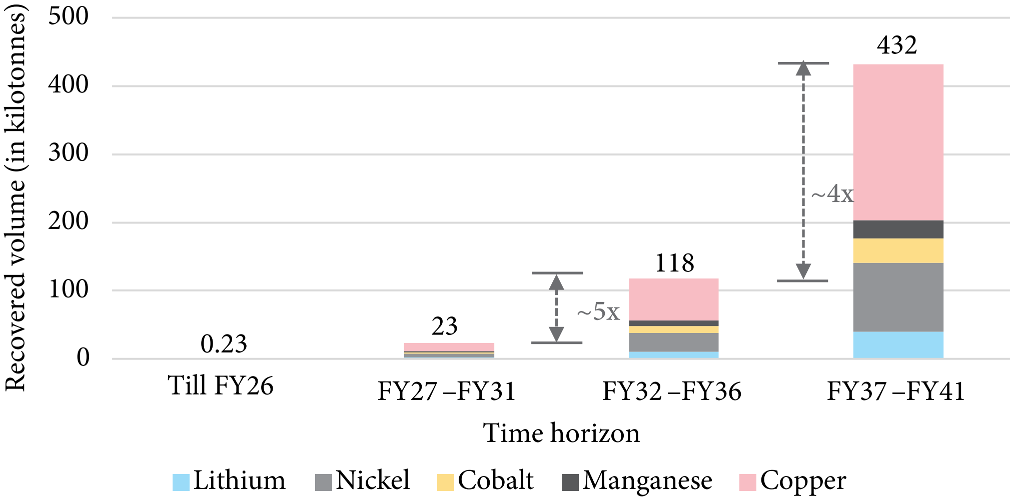
## 4.1 Tonnes of Opportunity for Mineral Recovery

The projected EoL battery flows indicate that India's EV battery recycling opportunity remains limited in the near term but is expected to rise quite sharply post-2030. Figure 10 presents the projected recoverable volumes of minerals of interest, i.e., lithium, nickel, cobalt, manganese, and copper till FY 2040–41. The results have been presented in blocks of five years based on yearly estimates. Five-year intervals are more meaningful for investment planning.

The projection indicates that total recoverable mineral volume remains insignificant up to FY 2025–26, rises to about 23 kilotonnes (kt) over the period from FY 2026–27 to FY 2030–31, jumps five-fold to about 118 kt during the next five years (from FY 2031–32 to FY 2035–36), and then climbs to about 432 kt over the period from FY 2036–37 to FY 2040–41.

Copper accounts for the largest share of recovered battery minerals by quantity across the assessment horizon. This shows that the recycling opportunity is likely to be driven not only by precious critical minerals but also by bulk minerals embedded in LiBs. Recovered lithium, nickel, and cobalt reach sizeable quantities in later years, reflecting the time lag between the high growth of EV adoption in the current decade and battery retirement, which is influenced by the possibility of battery repurposing.

**Figure 10: Projected Recoverable Mineral Volume From End-of-Life EV Batteries**




*Source: Authors' analysis.*

*Note: FY26 refers to FY 2025–26; FY27–31 refers to FY 2026–27 to FY 2030–31; FY32–36 refers to FY 2031–32 to FY 2035–36; FY37–41 refers to FY 2036–37 to FY 2040–41.*
*FY = financial year; kt = kilotonne.*

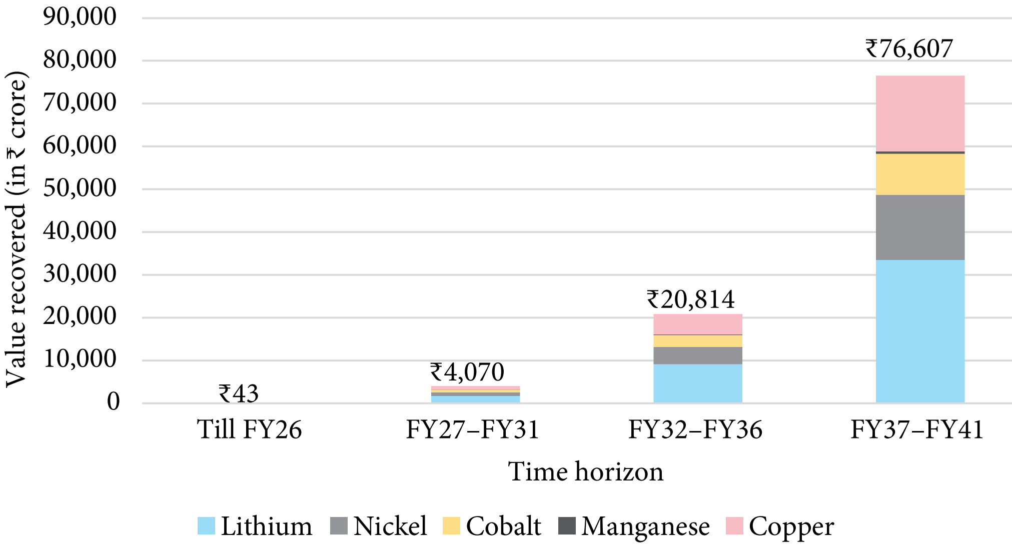
## 4.2 Economic Value of Recycling Contingent on Precious Critical Minerals

In sync with the trajectory of the recoverable quantity of battery minerals, the economic value of recovered minerals is also projected to rise sharply over time. Figure 11 shows that the estimated value of recycled battery minerals is about ₹4,070 crore (US$479 million[22]) during the period from FY 2026–27 to FY 2030–31, which then increases to ₹20,814 crore (US$2,449 million) over the next five years, and reaches about ₹76,607 crore (US$9,013 million) towards FY 2040–41.

[22] All calculations conducted in this paper assume US$1 = ₹85.

Unlike in the case of the quantity of recovered minerals, the economic value of EV battery recycling is a key factor in the critical minerals play. Lithium contributes the largest share of the recoverable value across the period, even though copper dominates in terms of quantity. This indicates that the economic attractiveness of battery recycling is shaped not only by the quantity of minerals available for recovery but also by their relative market value.

**Figure 11: Estimated Value of Recoverable Mineral Volumes From End-of-Life EV Batteries**




*Source: Authors' analysis.*

*Note: Values are estimated using the average 2024 and 2025 mineral prices reported in the International Monetary Fund Primary Commodity Price System. FY26 refers to FY 2025–26; FY27–31 refers to FY 2026–27 to FY 2030–31; FY32–36 refers to FY 2031–32 to FY 2035–36; FY37–41 refers to FY 2036–37 to FY 2040–41.*

## 4.3 Recycling Market in an Accelerated EV Adoption Scenario

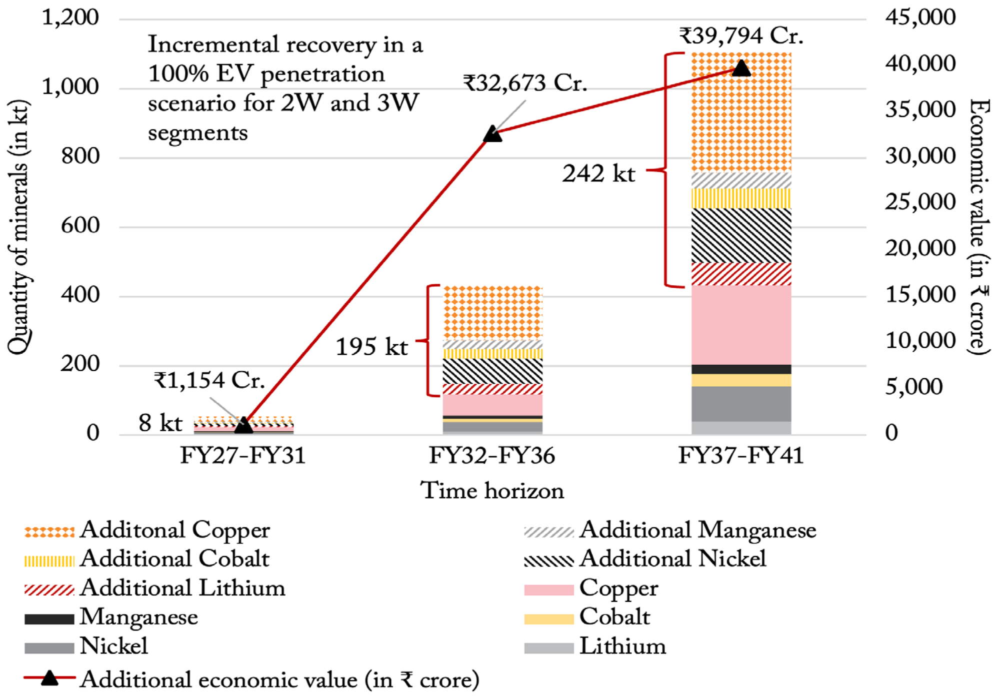
Rising geopolitical conflicts have significantly constrained global petroleum trade in recent times and increased international crude oil price volatility. This has highlighted the energy security risk on account of crude oil import dependence of an economy like India. The crisis has made a compelling case to accelerate the transition to EVs. The GoI has made a strong pitch for a swift EV shift. With EV adoption already showing momentum in the country, the boost to EV sales induced by oil-supply shocks is expected to be more pronounced in the light EV segments, i.e., electric two-wheeled and electric three-wheeled vehicles. Therefore, it is important to consider a scenario of accelerated growth in EV uptake in these segments within a time frame shorter than previously anticipated. This will consequently lead to a greater number of EV batteries entering circulation and eventually retiring and becoming available for recycling.[23]

[23] The lifespans of these batteries are relatively short and these end-of-mobility-life batteries are unsuitable for repurposing.

Hence, the study has estimated the possible increment in the quantity of recoverable battery minerals and corresponding additional economic value that can be tapped over the assessment period in a high EV sales scenario.

Analysis shows that in a scenario where sales of two-wheeled and three-wheeled vehicles reach 100% electric share by FY 2037–38 (i.e., the end of the EV projection period), the quantity of recoverable battery minerals may increase by 8 kt during the period from FY 2026–27 to FY 2030–31 and by as much as 242 kt towards FY 2040–41 (Figure 12).

**Figure 12: Mineral Recovery and Economic Value Under a 100% Electric Share in Two-Wheeled and Three-Wheeled Vehicle Sales**




*Source: Authors' analysis.*

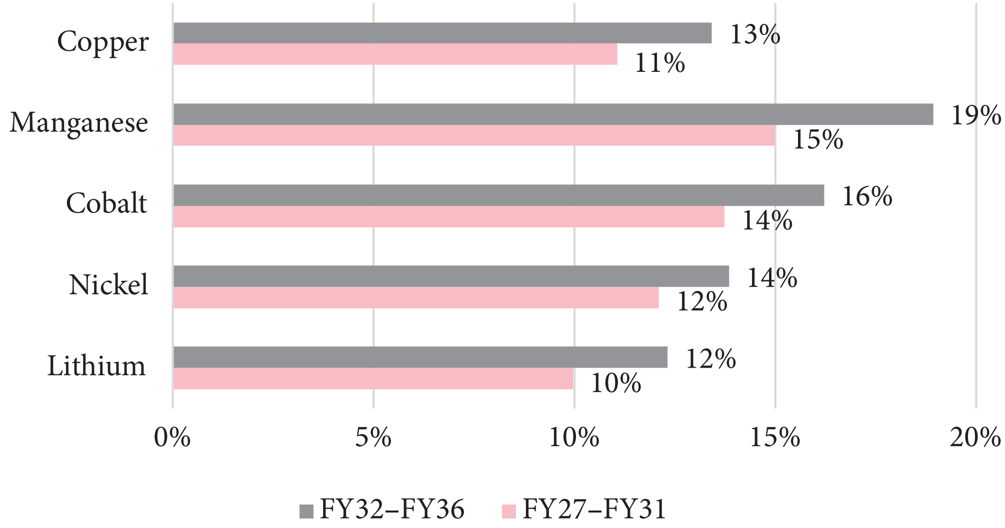
*Note: 2W = two-wheeled vehicle; 3W = three-wheeled vehicle; EV = electric vehicle; FY = financial year; kt = kilotonne.*

In this scenario, owing to the greater quantities of recoverable minerals from the EV batteries, the recycling industry can potentially unlock about ₹74,000 crore (US$8,661 million) in additional economic value over the assessment period (from FY 2026–27 to FY 2040–41).

## 4.4 Sufficiency of Recycled Minerals to Meet Demand for EV Battery Manufacturing

The study also attempts to quantify the impact of EV battery recycling on battery manufacturing. It finds that recycling and reusing battery minerals can meaningfully supplement primary mineral requirements for EV battery manufacturing. For example, recycling can meet about 10% of the lithium demand for EV battery manufacturing during the period from FY 2026–27 to FY 2030–31 (as shown in Figure 13). The contribution goes up to around 12% over the next five years (FY 2031–32 to FY 2035–36), with an increase in recycled minerals. The potential share of recycled minerals is highest in the case of manganese, 15% during the time frame from FY 2026–27 to FY 2030–31, and 19% during the next five-year period.

**Figure 13: Share of Recycled Minerals in Mineral Requirements for EV Battery Manufacturing**



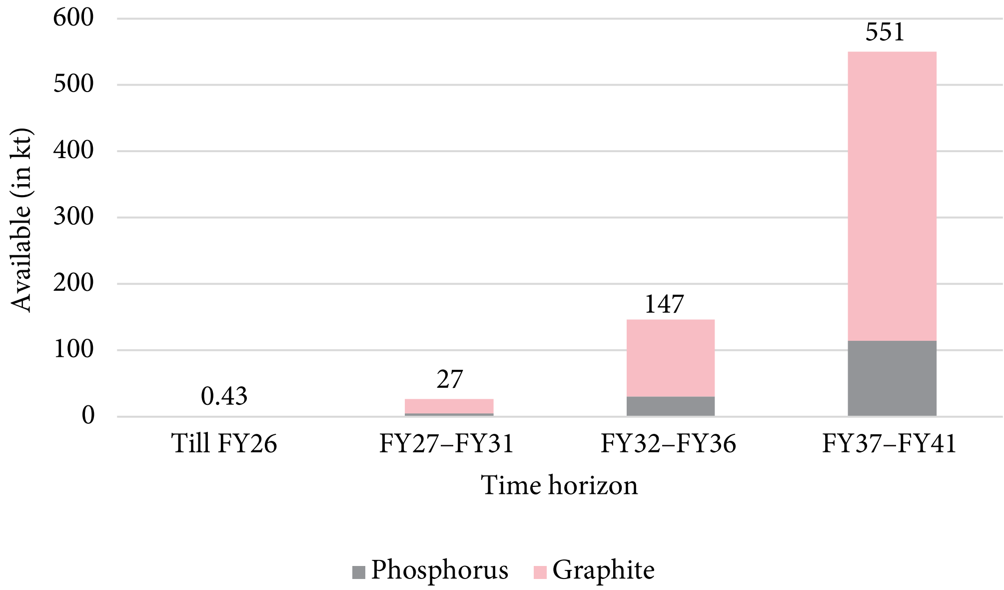

*Source: Authors' analysis.*

*Note: FY = financial year. FY27–31 refers to FY 2026–27 to FY 2030–31; FY32–36 refers to FY 2031–32 to FY 2035–36.*

## 4.5 Some Battery Minerals Falling Out of Favour

Depending on the value or resale value of the minerals, the recycling industry takes a differentiated approach when it comes to recycling batteries. Limitations of current extraction processes also play a role. Certain minerals, such as phosphorus and graphite, are largely left untapped in the current recycling practice despite their non-trivial share of the minerals embedded in EV batteries, as shown in Figure 14. Their recovery is constrained by a combination of low resale values in international markets, insufficient purity of recovered minerals, and losses during recovery processes. There is a lack of commercial justification to carry out additional processing to separate these minerals to a high degree of purity. Recyclers prioritise minerals with stronger recovery economics, such as lithium, nickel, cobalt, manganese, and copper.

**Figure 14: Mineral Streams in EV Batteries That Remain Unrecovered**




*Source: Authors' analysis.*

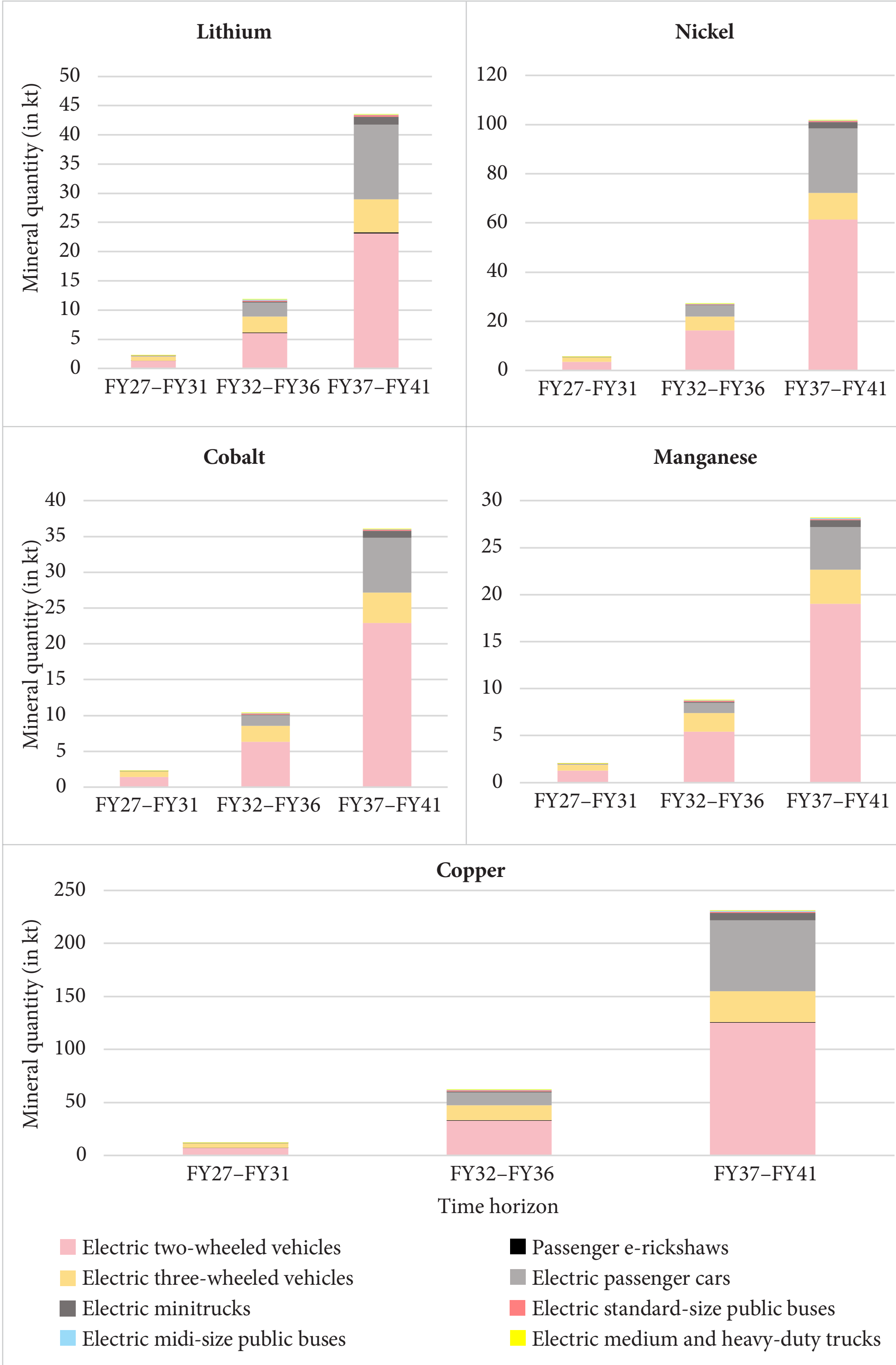
*Note: FY = financial year; kt = kilotonne. FY26 refers to FY 2025–26; FY27–31 refers to FY 2026–27 to FY 2030–31; FY32–36 refers to FY 2031–32 to FY 2035–36; FY37–41 refers to FY 2036–37 to FY 2040–41.*

It is important to consider that synthetic graphite, as a substitute for natural graphite, has multiple industry use-cases. Recycled graphite, which is a form of synthetic graphite, therefore, potentially has demand in the market. Some recyclers are developing processes to recover graphite from LiBs.

## 4.6 Which EV Segments Are Important?

A strategy for accessing, collecting, handling, and managing end-of-mobility-life batteries should be cognisant of the source EV segments because the EV market characteristics, including the EV users, battery profiles, opportunity for battery repurposing or recycling, and all other aspects of circularity differ from one EV segment to another.

**Figure 15: Contribution of Different EV Segments to Availability of Battery Minerals for Recycling**




*Source: Authors' analysis.*

*Note: FY = financial year; kt = kilotonne.*

Figure 15 shows the quantities of battery minerals available for recycling by vehicle segment. Among the vehicle segments, electric two-wheeled vehicles have the largest share over the entire assessment period (from FY 2026–27 to FY 2040–41), contributing about 57% of the cumulative quantity across the five battery minerals. This is attributed to the higher adoption of these EVs, the possibly shorter mobility life of their batteries, and the limited scope for repurposing, which together increase the mineral availability for recycling. The electric 2W vehicle segment is followed by electric passenger cars. The latter contribute 24%, while electric 3W vehicles (excluding e-rickshaws) account for 15% of the total quantity of minerals.

Medium- and heavy-duty EVs (which include electric buses and electric trucks) together account for around 1.2% of the total minerals available for recycling. This is because their sales are dwarfed by those of other EV segments, and these batteries enter the EoL battery stream later, owing to their longer mobility life and greater potential for second-life applications (due to greater battery capacities).

Over the assessment period, electric two-wheeled vehicles are also found to contribute the largest share of precious critical minerals. They account for about 53% of lithium availability, around 60% of nickel, and about 63% of cobalt available for recycling.

The above results portray a picture of substantial opportunity for India's EV battery recycling in the medium to long run, which requires concerted planning and preparatory actions today. Otherwise, it may turn out to be a missed opportunity for the industry. Considering the realisable scale of the recycling sector, a roadmap for investments in battery circularity is the need of the hour.

# 5. What Will It Take to Unlock the Opportunity?

Realising the recycling opportunity outlined in the previous section will require timely investments in processing capacity. Processing capacities need to be planned in sync with the possible quantity of waste-battery streams over the years. As projected in the previous section, the flow of spent EV batteries is not constant, and battery characteristics will also evolve, opening new opportunities and challenges for investment in the battery circular economy.

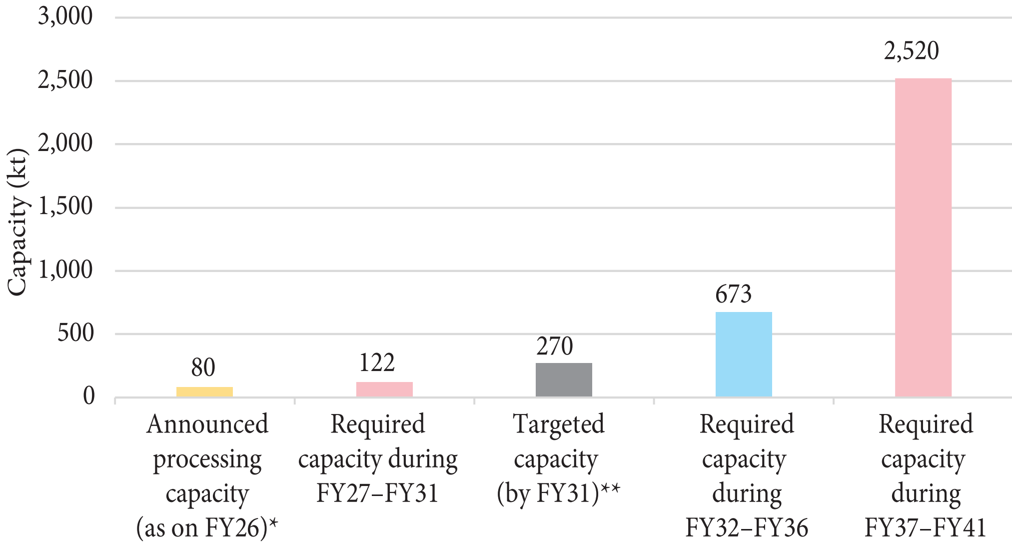
## 5.1 Recycling Capacity in Sync With the Flow of Retired EV Batteries

The required battery recycling capacity to process projected EoL EV battery volumes is expected to increase sharply over the assessment horizon. Here, the capacity of a recycling facility is expressed in terms of the quantity of retired batteries that it can process. Figure 16 presents the estimated recycling capacity across successive time periods. The results show that the cumulative capacity requirement rises from about 122 kt during the first five years (FY 2026–27 to FY 2030–31) to about 673 kt during the period from FY 2031–32 to FY 2035–36 and then increases further to about 2,520 kt over the next five-year period, i.e., from FY 2036–37 to FY 2040–41.

In comparison, the announced processing capacity as of FY 2025–26 is about 80 kt, while the targeted processing capacity by FY 2030–31 under the Critical Mineral Recycling Incentive Scheme is about 270 kt (Ministry of Mines, 2025; Verma et al., 2026). At first glance, these capacity announcements may appear sufficient to meet initial recycling demand. A much larger scale-up in capacity may be required in later years as retired battery volumes rise.

It is also important to note here that the targeted processing capacity under the recycling incentive scheme is not intended exclusively for EV batteries. The scheme is expected to support processing of feedstocks from e-waste and other scrapped battery streams as well. The recycling capacity planning has to take this into account.

**Figure 16: Battery Recycling Capacity Required to Process Projected End-of-Life EV Battery Volumes**




*Source: Authors' analysis.*

*Note: FY = financial year; kt = kilotonne; LiB = lithium-ion battery.*

**NITI Aayog's report: Advancing Circular Economy of Waste Electronic and Electrical Equipment (E-waste) and LiBs*
***Ministry of Mines' Scheme Guidelines for Critical Mineral Recycling Incentive Scheme (2025). Following evaluation of proposals, 58 entities have been chosen as eligible to participate, with a pledged capacity of about 850 kt.*

## *Why Is It Important to Start Preparing Early?*

The above estimates indicate the required magnitude of recycling capacity over the assessment period. It is important to consider here that starting commercial recycling operations at this scale "just in time", while establishing the logistics network needed to match projected waste-battery volumes, is unlikely to be feasible in practice. Setting up a recycling facility may take multiple years, depending on the availability of technical expertise and a skilled workforce, land acquisition, regulatory approvals, equipment procurement, sourcing chemicals, etc. Moreover, starting full-scale commercial operation of a recycling facility takes months, as the mineral-recovery line (in the case of hydrometallurgical extraction) takes time to stabilise. A recycler has to carry out multiple trials to achieve the desired throughput rates, process efficiency, recovery rates, and mineral grades. Typically, process performance improves after feedstock supply and extraction processes reach some consistency. This implies recycling plants may run below optimal utilisation during the initial years. Therefore, capacity planning needs to be done in advance, i.e., ahead of the expected surge in spent battery volume, rather than waiting for recycling demand to become visible.

## 5.2 Investment Requirement

The capital investment required to develop the necessary recycling capacity has been estimated, as presented in Figure 17. The investment estimate is based on hydrometallurgy as the representative recycling technique.[24]

The results show that, in line with the projected trend in required capacity, the required investment increases from ₹2,028 crore (US$239 million) over the period from FY 2026–27 to FY 2030–31, to about ₹11,169 crore (US$1,314 million) during the next five years (FY 2031–32 to FY 2035–36), and then climbs steeply to nearly ₹41,826 crore (US$4,920 million) over the period from FY 2036–37 to FY 2040–41.

The projected CapEx requirement underlines that India's battery recycling ecosystem will need to move beyond pilot-scale or early commercial capacity to absorb future EoL battery flows. The scale of investment needed in the later years also suggests that delays in capacity planning could increase the risk of a mismatch between the availability of spent EV batteries and the infrastructure to process them.

It is noted that some recyclers are not investing in setting up the full recycling processing line to recover minerals and instead are producing and exporting black mass, an intermediate product, mostly to China, which has a mature battery-recycling ecosystem. Continuing this practice will be akin to letting precious resources leave the country's shores. This will limit the domestic recycling market, prevent the EV and battery industries in the country from becoming more resilient to supply-chain disruptions, weaken strategic autonomy, and prevent the country from benefiting from other positive multiplier effects of a circular economy.[25]

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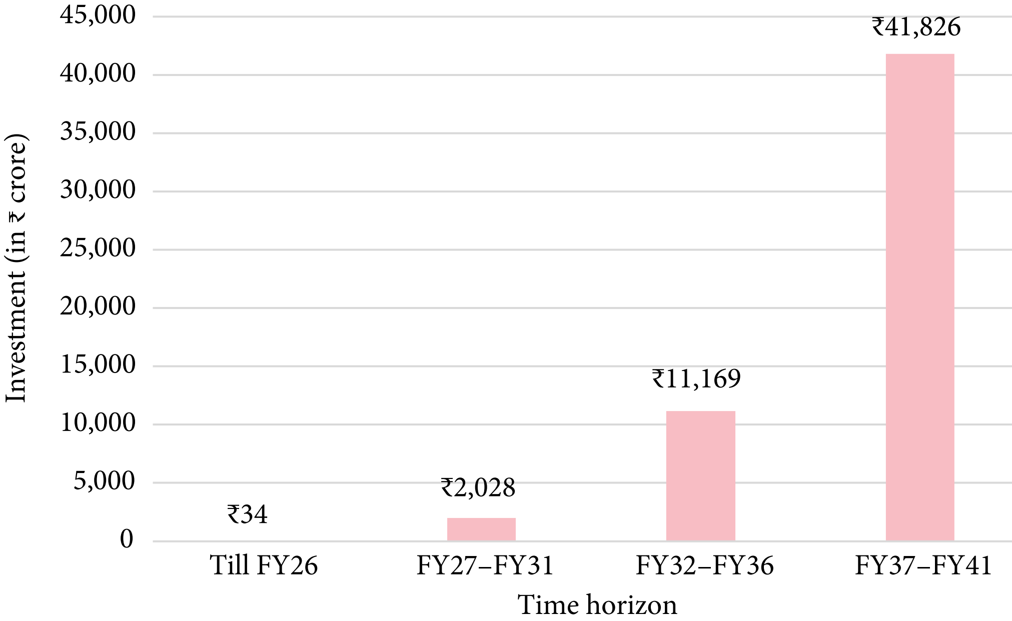
[24] Although the mineral recovery projection considers the possible commercialisation of direct recycling technology, which is a promising novel technique, towards 2040, it is not possible to account for its CapEx. Direct recycling has not yet achieved commercial-scale deployment and hence reliable financial value for this technology is not currently available.

[25] India should be prepared to avoid the fate of the European recycling market. According to Ritchey and Miraux (2026), the battery recycling industry in Europe lacks the required feedstock. At least 60% of Europe's black mass is being exported outside of the continent to be processed elsewhere. The authors in their report also added that a substantial quantity of black mass might be exported out under different customs codes, which makes it difficult to trace.

**Figure 17: Estimated Capital Expenditure Required to Scale EV Battery Recycling Infrastructure**




*Source: Authors' analysis based on Mandal et al. (2022).*

*Note: FY = financial year. FY26 refers to FY 2025–26; FY27–31 refers to FY 2026–27 to FY 2030–31; FY32–36 refers to FY 2031–32 to FY 2035–36; FY37–41 refers to FY 2036–37 to FY 2040–41.*

*The estimated capital expenditure is based on the hydrometallurgical route of recycling.*

# 6. Learnings From Regulations Across Major EV Markets

Battery circularity is an emerging opportunity for India as the volume of spent EV batteries grows over the coming years. In a way, now is the prep time for the country, and it is useful to take stock of how some of the mature EV markets around the globe are realising the battery-circular-economy agenda. One can learn from this peer review about the salient practices these countries have adopted at different stages of the circularity value chain, such as battery collection, traceability, second-life use, and mineral recovery and reuse.

The review of EV markets suggests that EV battery circularity regulation is evolving along five broad dimensions.

First, countries are strengthening producer responsibility and collection obligations to ensure that batteries are channelled into formal systems. Second, traceability mechanisms such as digital battery passports and lifecycle information systems are being introduced to enable easy and effective circularity. Third, some markets are moving towards mineral-specific recovery targets to make the best use of EoL batteries. Fourth, second-life use is increasingly being supported through effective battery characterisation, certification, and safety standards. Finally, regulatory frameworks are beginning to link recycling with industrial strategy, resource security, recycled-content demand, and controls over intermediate products.

These learnings can help improve the existing ecosystem in India. The country already has the regulatory foundation through the BWMR, 2022, which places EPR at the centre of the battery waste management strategy. The Critical Mineral Recycling Incentive Scheme and the proposed Battery Aadhaar framework further indicate that India is making efforts to develop support mechanisms for the battery circular economy (GoI, 2026; Ministry of Mines, 2025). Geographies such as the EU, China, California in the US, Japan, and South Korea have taken progressive steps to promote battery circularity. Table 3 provides a snapshot of the regulatory approaches that these geographies have adopted towards battery circularity.

**Table 3: Regulatory Approaches for EV Battery Circularity Across Major Electric Vehicle Markets**

| Market | Foundation | Traceability and Second Life | Recovery and Recycling Requirements | Key Learnings for India |
|---|---|---|---|---|
| **The EU** | Comprehensive lifecycle regulations covering EPR collection, recycling efficiency, recycled-content requirements, and information disclosure. | A digital battery passport is required for industrial and EV battery packs above 2 kWh; it supports product-level information and lifecycle traceability. | Material recovery targets include 90% recovery for cobalt, copper, lead, and nickel by 2027 and 95% by 2031; the lithium recovery target is 50% by 2027 and 80% by 2031. Minimum recycled-content requirements apply from 2031 and 2036. Regulation of black mass as hazardous waste stipulates tracking of intermediate recycling products and control of cross-border movement. | Introduce mineral-specific recovery targets and strengthen monitoring of intermediate products such as black mass. |

| Market | Foundation | Traceability and Second Life | Recovery and Recycling Requirements | Key Learnings for India |
|---|---|---|---|---|
| **China** | Producer-led recycling system with authorised collection networks and a whitelist of approved recyclers. | Standardised battery coding and national traceability platform to track batteries across the lifecycle.<br><br>Support for second-life battery applications. | Mineral-specific recovery targets require at least 90% recovery for lithium and 98% recovery for nickel, cobalt, manganese, copper, aluminium, and rare earth metals. | Develop authorised collection networks and systems of approved recyclers and introduce mineral-specific recovery targets and traceability to make the best use of resources. |
| **California (in the US)** | Battery-stewardship and traction-battery policy approaches emphasise producer responsibility, collection planning, and end-of-life accountability. | Reporting systems and stewardship plans strengthen lifecycle accountability, though there is no full battery-passport system. | Policy recognises reuse, refurbishment, repurposing, and recycling pathways for traction batteries. | BWMR-based EPR can be strengthened with producer-financed take-back systems, collection planning, and end-of-life accountability before large EV battery retirement volumes emerge. |
| **Japan** | Voluntary collection and recycling model led by producer responsibility organisations and industry–government collaboration. | Traceability is less centralised, but producer-led collection and international data-sharing efforts are emerging. | Recovery ambitions include 70% recovery for lithium and 95% for nickel and cobalt. Feedstock availability is constrained by exports of used EVs, while environmentally sound recycling remains costly. | Producer-led partnerships can be effective to support second life and recycling. |

| Market | Foundation | Traceability and Second Life | Recovery and Recycling Requirements | Key Learnings for India |
|---|---|---|---|---|
| **South Korea** | Strong public-sector role through used-battery collection centres and performance evaluation systems. | State-of-health testing and reuse grading help determine whether batteries should be sold, repurposed, or recycled. | Repurposing centres and storage protocols are encouraged to improve feedstock availability. | Developing state-of-the-art battery testing centres and standards is critical to enable proper battery characterisation to allow repurposing and recycling. |

*Source: Authors' analysis based on Chattopadhyaya (2026), European Commission (2025a, 2025b), International Energy Agency (2025a, 2025b, 2025c), and State Council of the People's Republic of China (2026).*

*Note: BWMR = Battery Waste Management Rules; EPR = extended producer responsibility; EU = European Union; EV = electric vehicle; kWh = kilowatt-hour; US = United States.*

The review of the battery circularity ecosystems in advanced EV markets highlights salient steps these jurisdictions have taken to enable effective use of used LiBs as a resource for the economy. The EU sets an example of legally binding recovery targets, recycled-content requirements, and product-level information through battery passports and controls on intermediate recycling products. China shows the importance of mineral-specific recovery targets, a list of authorised recyclers, lifecycle traceability, and measures to prevent leakage into the grey market when formal collection systems are not economically attractive. California demonstrates how producer stewardship and battery collection financing can be developed before large retirement volumes emerge. Japan and South Korea offer useful lessons on producer-led battery collection, testing, grading, and second-life applications.

India has taken several important measures similar to some of the good practices noted in the peer markets. Drawing on its own experience and that of other economies, it can gradually build on the existing system to nurture its battery circular economy with the objective of making the best use of used EV batteries as a strategic resource.

# 7. A Call to Action to Support India's EV Battery Circular Economy

This study recommends 10 key interventions to overcome some of the major market barriers and support the overall EV battery circularity ecosystem of the country.[26]

**i. Mandate sourcing of recycled critical and strategic minerals as part of the effort to create the national critical minerals stockpile.**

India's NCMM conceives seven broad interventions, one of which is "Trade and Markets". Among a range of action items, the intervention has advocated institutionalising the National Critical Mineral Stockpile Programme for stockpiling critical and strategic minerals to avoid disruptions in mineral supply for domestic utilisation. "Recycling of Critical Minerals" is one of the seven pillars of NCMM. The Mission should mandate that recycled critical and strategic minerals constitute a minimum share of the proposed mineral stockpile. This has strong merit since these recycled minerals are readily available in the domestic market. Also, this will help create a demand for recycled minerals in the country.

***Responsible stakeholder***: Ministry of Mines.

**ii. Revisit the existing provisions in BWMR to align timelines for EV battery collection targets with actual battery life and set mineral-specific recovery targets.**

Current EPR compliance provisions may induce "forced" early retirement of EV batteries as these are based on a conservative assumption of the mobility life of EV batteries. Also, this disincentivises the manufacture of better-quality batteries with longer lives, on the one hand, and better battery management that helps extend the useful life of batteries, on the other. Therefore, the given timelines for achieving battery collection targets need to be revisited based on the effective longevity currently recorded for EV batteries in the Indian market in each vehicle category.

Moreover, unlike the EU and China, which have introduced mineral-specific recovery requirements, India's BWMR, 2022 falls short of specifying recovery targets for the battery minerals. Such target setting will likely push recyclers to go for recovery of minerals and not stop at black mass production. This step would also complement BWMR's existing minimum recycled-content provisions by ensuring that demand for secondary materials is supported by verified domestic mineral recovery. Currently, the Rules stipulate only an overall minimum recovery target for battery materials, expressed as the total weight of all recovered materials as a percentage of a battery's dry weight.[27]

***Responsible stakeholder:*** MoEFCC.

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[26] The draft guidelines for implementation of the Battery Pack Aadhaar system were released in January 2026. Battery Aadhaar is expected to be operationalised in the coming years.

[27] In the case of EV batteries, the targets for 2024–25, 2025–26, and from 2026–27 onwards are 70%, 80%, and 90%, respectively.

### iii. Develop and notify standards for battery characterisation, repurposing, and recycled mineral quality.

Currently, there is neither a notified standard to enable battery circularity nor any provision in the BWMR specifying technical requirements for evaluating batteries or verifying the quality and purity of recycled minerals. The existing Indian Standard (IS) 17855:2022, issued by BIS and harmonised with International Organization for Standardization (ISO) 12405-4:2018, focuses on test specifications for lithium-ion traction battery packs and systems used in EVs, covering performance, reliability, and electrical functionality. It does not directly address second-life battery applications or recycled-mineral quality certification. Necessary standards should be notified by the relevant line ministry to ensure enforceability.

Without standards, on the one hand, battery makers avoid consenting to repurposing or offering warranties for repurposed batteries. On the other hand, producers may find it difficult to ensure that recovered minerals meet the grade required for reuse in new EV battery cells.

***Responsible stakeholders:*** BIS, MeitY, and the Ministry of Mines.

### iv. Introduce buy-back or take-back programmes for spent EV batteries.

The current spent EV battery collection system in India remains fragmented, making it difficult to ensure that waste batteries are channelled to authorised recyclers. This is a major challenge for both the manufacturers (which have compliance requirements) and the EV users who do not know what to do with EVs or their batteries when the batteries are no longer fit for mobility use. EV makers can introduce take-back or buy-back mechanisms to collect retired EV batteries from their clients. Here, dealers and authorised service centres, being the interface between vehicle customers and makers, could play a pivotal role in sensitising and guiding the EV users to participate in the "return" programmes.

***Responsible stakeholders:*** EV owners, EV manufacturers, automobile dealers, service providers, and battery recyclers.

### v. Introduce standards to support ease of battery circularity at the design and manufacturing stage.

There is no standard supporting the principle of "Design for Repurposing and Recycling", which advocates considering ease of repurposing and/or recycling at the battery-pack design and manufacturing stages to enable the efficient, safe, and economical repurposing and/or recycling of used EV batteries. Necessary standards can be introduced to give effect to this principle.

***Responsible stakeholders:*** BIS, MeitY, and MoRTH.

### vi. Develop testing infrastructure for battery characterisation to support repurposing and recycling.

Characterisation and evaluation of battery health are important to determine whether the EV battery can be repurposed or should be sent directly for recycling. This would require state-of-the-art testing facilities across the country, especially in the major cities (EV adoption hubs), considering the volume of EV batteries in circulation. Budgets allocated in EV programmes should be utilised to fund development of the required infrastructure. PM E-DRIVE, the flagship central government scheme to support EV adoption, has a budgetary allocation of ₹780 crore for upgrading testing agencies.

***Responsible stakeholder***: MHI.

### vii. Monitor black mass movement and limit exports to ensure domestic mineral recovery.

For India, domestic utilisation of black mass for mineral recovery is of strategic importance. The standard operating procedure issued by the Central Pollution Control Board for utilisation of black mass from LiBs provides a useful basis: black mass may be treated as an intermediate product only if it is processed within the same premises where it is generated; otherwise, it should be treated as hazardous waste.

Stronger enforcement and monitoring are, therefore, needed to prevent unauthorised movement of black mass. This would increase the availability of black mass for domestic processing units for recovery of minerals of interest within the country. Even when the country does not have a sizeable LiB cell manufacturing capacity, recovery of minerals makes sense. Selling recovered minerals, instead of black mass, in the international market is a case of value-added export.

***Responsible stakeholder:*** Ministry of Commerce and Industry.

### viii. Build recycling capacity, collection, and transportation networks before retirement volumes grow dramatically.

The analysis indicates that sizeable quantities of recoverable minerals are expected to become available over the next decade. However, the required recycling capacity and investments should be planned well in advance before managing volumes of spent batteries becomes a serious challenge. Establishing collection and transportation networks, building recycling facilities, and stabilising process lines for mineral recovery are critical, and these take time to reach commercial scale. The findings from the study emphasise the need for a targeted approach towards used battery collection and handling, as some EV segments, like electric two-wheeled vehicles, have an outsized share in EoL battery volume. Recycling operations also take time to produce commercial-grade minerals.

***Responsible stakeholder:*** Battery recyclers.

### ix. Harmonise regulations for safe collection, storage, and transportation of used EV batteries.

As EV battery waste volumes increase, regulations for the safe collection, storage, and transportation of used LiBs will become increasingly important. These batteries can pose fire and other safety risks if they are damaged, improperly segregated, poorly stored, or mishandled during collection and transport.

Since fire-safety requirements are often governed at the state or urban local body level, varying regulations across states can create compliance uncertainty for industry. Harmonised regulations would help industry meet safety requirements more consistently, reduce fire risks, and improve compliance.

***Responsible stakeholders:*** Petroleum and Explosives Safety Organisation and state governments.

### x. Encourage long-term agreements between manufacturers and recyclers.

There is a lack of predictability for EV manufacturers, battery manufacturers, and recyclers regarding used battery sourcing, management, and price. Long-term contracts between EV or battery manufacturers and recyclers can improve the predictability of waste-battery volumes and prices. Drawing on international experience, EV and battery makers should explore developing industry-level alliances or creating common platforms to manage collection, second-life use, and recycling of waste batteries.

***Responsible stakeholders***: EV manufacturers and battery recyclers.

It is worth emphasising that allied actions towards addressing lacunae in the existing broader recycling ecosystem in the country, covering research and development of mineral recycling technologies,[28] skill development, industry policy, awareness generation, etc., would also benefit EV battery recycling.

Today's preparedness will determine whether EoL EV batteries will end up being exported (or, worse, in landfills) or become a useful resource for the economy as the EV population grows.

[28] Novel techniques include the application of polymer sorbents in mineral recovery, direct cathode recycling, etc. The Anusandhan National Research Foundation has reportedly selected a number of research proposals related to mineral recycling.

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# Appendices

## Appendix A: Barriers That Limit the Feasibility of Mainstreaming Battery Repurposing

In principle, the longer a battery is in use, the better it is from the environmental point of view and, to an extent, for business. Hence, it makes sense to repurpose an end-of-first-life battery before recycling it. However, doing this in a practical world is a different ball game because of the following serious challenges; some of them are intertwined.

### (i) Battery characterisation has reliability issues.

Characterisation of a battery, particularly based on its previous life, is critical to understand the opportunity to repurpose it. This means that effective traceability of battery-specific data, right from its manufacturing to usage, becomes important. Data management systems such as Battery Aadhaar (explained in a subsequent section), which is similar to the EU's Battery Passport, can support lifecycle data collection and sharing. However, creating such infrastructure requires active participation of stakeholders across the battery value chain and making the system operational at a system level can be both time-consuming and expensive. Reliable battery characterisation at scale appears to be a distant possibility.

### (ii) Securing a consistent supply of batteries ready for repurposing is difficult.

Considering the multiple use-cases for the second life of EV batteries, each requiring unique battery performance, grouping fit-for-purpose batteries is a complex and uphill task. Scaling this requires huge effort and may be practically infeasible. Coupled with difficulty in battery characterisation, achieving a supply line of ready-for-repurposing batteries becomes truly challenging.

### (iii) There are reliability and liability concerns.

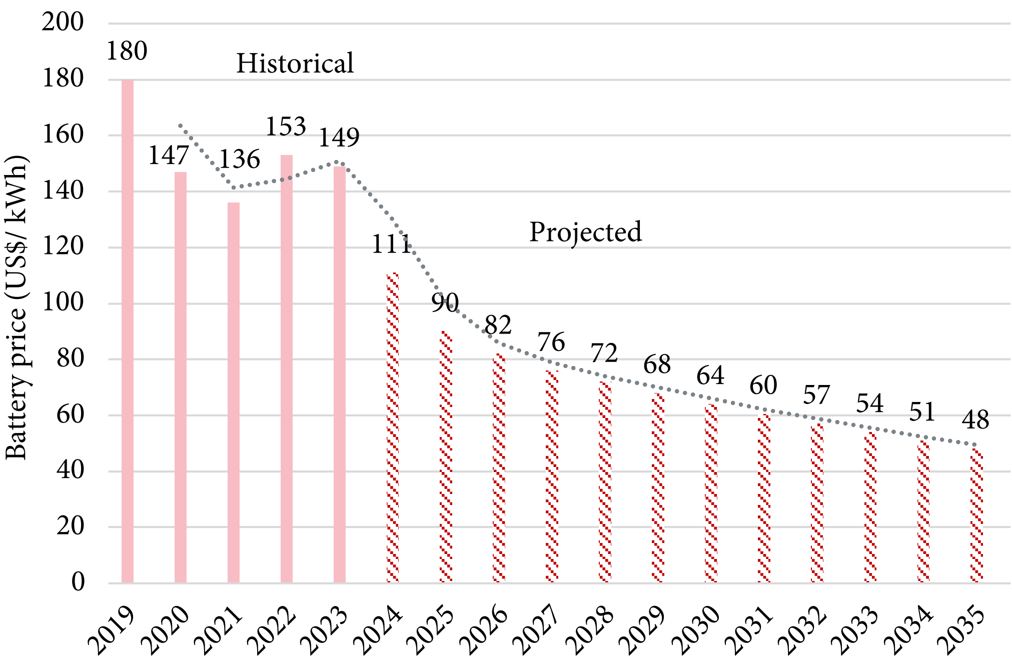
Second-life batteries display high variability in on-ground performance (due to the above issues), which potentially raises concerns about possible high failure rates. Warranties on repurposed batteries are not widely available and, when offered, are valid for only a short period. This does not encourage customers to opt for second-life batteries. This concern is also reflected in the documents issued by central government agencies for selection of battery energy storage system developers, where the selection criteria mandate the use of new battery packs or cells which indirectly prohibits application of used batteries or cells.

## (iv) Business viability of battery repurposing is highly uncertain.

Although battery repurposing does not require high CapEx, there are costs associated with the steps required to make end-of-first-life LiBs fit for a second life. Moreover, the process is tedious and the outcome, i.e., the volume of ready-to-deploy second-life LiBs, is uncertain and not proportionate to the quantity of feedstock (used EV batteries), as the conversion rate from first to extended life is low (due to some of the above-mentioned challenges).

Also, preferring battery repurposing over straightaway recycling is likely to be limited to large battery packs (in terms of capacity), particularly batteries with LFP chemistry.[29] Most importantly, the business model is heavily dependent on the pricing of the second-life batteries instead of their service quality. To be preferred over a new battery, the market price of a repurposed one has to be heavily discounted to make it attractive despite the lack or limited duration of a product warranty. Such a model works when the price of new LiBs remains at an elevated level. The declining price trajectory of virgin LiBs (refer to Figure A–1), which is expected to continue, does not augur well for the battery repurposing business.

**Figure A–1: Historical and Projected Lithium-Ion Battery Price (US Dollars per Kilowatt-Hour)**




*Source: Goldman Sachs (2024) and authors' calculations.*

*Note: kWh = kilowatt-hour. Actual values are up to 2023. Prices for the remaining period have been projected.*

[29] LFP batteries typically have a longer useful life (i.e., greater number of charge–discharge cycles), which makes them suitable for second-life applications. Due to the lack of precious critical minerals, other than lithium, in their composition, recyclers do not find LFP batteries very attractive for recycling.

Apart from the above challenges, the lack of standards for second-life batteries in India creates apprehension about their reliability and thus limits their acceptance in the market.

## Appendix B: Mineral Intensity Factors by Battery Chemistry

**Table A–1: Mineral Content of Battery Chemistries Used in the Analysis, Kilograms per Kilowatt-hour**

| Battery chemistry | Lithium | Nickel | Cobalt | Manganese | Copper | Phosphorus | Graphite |
|---|---|---|---|---|---|---|---|
| LFP | 0.1 | 0 | 0 | 0 | 0.43 | 0.5 | 1.1 |
| NMC | 0.13 | 0.57 | 0.24 | 0.23 | 0.79 | 0 | 1.08 |
| NCA | 0.1 | 0.67 | 0.13 | 0 | 0.76 | 0 | 1.08 |

*Source: Verma et al. (2025).*

*Note: kg = kilogram; kWh = kilowatt-hour; LFP = lithium iron phosphate; NCA = nickel cobalt aluminium; NMC = nickel manganese cobalt.*

## Appendix C: Representative Battery Pack Sizes by Vehicle Segment

**Table A–2: Representative Battery Pack Sizes and Annual Change by Vehicle Segments**

| EV segment | Battery pack size (kWh) | Y-o-Y change in battery pack size (%) |
|---|---|---|
| Two-wheeled vehicles | 2.5 | 1 |
| Passenger e-rickshaws | 4 | 0 |
| Three-wheeled vehicles | 7.5 | 2 |
| Passenger cars | 30 | 3 |
| Minitrucks | 18 | 3 |
| Standard-size public buses | 220 | 3 |
| Midi-size public buses | 182 | 3 |
| Medium- and heavy-duty trucks | 304.8 | 3 |

*Source: Authors' compilation based on publicly available original equipment manufacturer model specifications.*

*Note: EV = electric vehicle; kWh = kilowatt-hour; Y-o-Y = year-on-year.*

# Appendix D: Battery Chemistry Shares by Segment and Period

**Table A–3: Battery Chemistry Shares Across Vehicle Segments and Time Periods**

| EV segment | Up to 2025 (%) | | | 2026–2030 (%) | | | 2031–2038 (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | NCA | NMC | LFP | Others | NMC | LFP | Others | NMC | LFP |
| Two-wheeled vehicles | 5 | 50 | 45 | 5 | 50 | 45 | 10 | 40 | 50 |
| Passenger e-rickshaws | 0 | 0 | 100 | 0 | 0 | 100 | 0 | 0 | 100 |
| Three-wheeled vehicles | 0 | 45 | 55 | 0 | 45 | 55 | 5 | 30 | 65 |
| Passenger cars | 5 | 25 | 70 | 13 | 20 | 67 | 20 | 15 | 65 |
| Minitrucks | 0 | 30 | 70 | 5 | 25 | 70 | 10 | 25 | 65 |
| Standard-size buses | 0 | 30 | 70 | 0 | 30 | 70 | 5 | 30 | 65 |
| Midi-size buses | 0 | 30 | 70 | 0 | 30 | 70 | 5 | 30 | 65 |
| Medium- and heavy-duty trucks | 0 | 30 | 70 | 0 | 30 | 70 | 5 | 30 | 65 |

*Source: Goel et al. (2024) and authors' assumptions based on sector research.*

*Note: EV = electric vehicle; LFP = lithium iron phosphate; NCA = nickel cobalt aluminium; NMC = nickel manganese cobalt.*

# Appendix E: Vehicle-Specific Minimum Mobility Life Assumptions

**Table A–4: Minimum Mobility Life Assumptions by Vehicle Segment**

| EV segment | Minimum Mobility Life (years) |
|---|---|
| Two-wheeled vehicles | 4 |
| Passenger e-rickshaws | 3 |
| Three-wheeled vehicles | 3 |
| Passenger cars | 8 |
| Minitrucks | 7 |
| Standard-size public buses | 10 |
| Midi-size public buses | 10 |
| Medium- and heavy-duty trucks | 8 |

*Source: Ministry of Environment, Forest and Climate Change (2022) and authors' assumptions based on sector research.*

*Note: EV = electric vehicle.*

# Appendix F: Annual Minimum Battery Collection Targets

**Table A–5: Annual Minimum Waste-Battery Collection Targets Used in the Analysis**

| EV segment | 2015 (%) | 2016 (%) | 2017 (%) | 2018 (%) | 2019 (%) | 2020 (%) | 2021 (%) | 2022 (%) | 2023 (%) | 2024 (%) | 2025 (%) | 2026 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Two-wheeled vehicles | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Passenger e-rickshaws | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 20 | 70 | 70 |
| Three-wheeled vehicles | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 10 | 10 | 15 |
| Passenger cars | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 20 | 30 | 40 |
| Minitrucks | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 20 | 30 | 40 |
| Standard-size buses | 0 | 0 | 0 | 0 | 0 | 30 | 30 | 30 | 50 | 50 | 60 | 70 |
| Midi-size buses | 0 | 0 | 0 | 0 | 0 | 30 | 30 | 30 | 50 | 50 | 60 | 70 |
| Medium- and heavy-duty trucks | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 20 | 30 | 40 |

| EV segment | 2027 (%) | 2028 (%) | 2029 (%) | 2030 (%) | 2031 (%) | 2032 (%) | 2033 (%) | 2034 (%) | 2035 (%) | 2036 (%) | 2037 (%) | 2038 (%) | 2039 (%) | 2040 (%) | 2041 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Two-wheeled vehicles | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| Passenger e-rickshaws | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| Three-wheeled vehicles | 15 | 15 | 15 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| Passenger cars | 50 | 60 | 60 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| Minitrucks | 50 | 60 | 60 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| Standard-size buses | 75 | 80 | 90 | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 100 | 100 | 100 | 100 | 100 |
| Midi-size buses | 75 | 80 | 90 | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 100 | 100 | 100 | 100 | 100 |
| Medium- and heavy-duty trucks | 50 | 60 | 60 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |

*Source: Ministry of Environment, Forest and Climate Change (2022) and authors' assumptions based on sector research.*

*Note: EV = electric vehicle.*

# Appendix G: Possible Second-Life Duration by Vehicle Segment

**Table A–6: Second-Life Duration by Vehicle Segment**

| EV segment | Second-life (years) |
|---|---|
| Two-wheeled vehicles | 0 |
| Passenger e-rickshaws | 0 |
| Three-wheeled vehicles | 3 |
| Passenger cars | 5 |
| Minitrucks | 5 |
| Standard-size public buses | 6 |
| Midi-size public buses | 6 |
| Medium- and heavy-duty trucks | 5 |

*Source: Transport & Environment (2024) and McNamara et al. (2025) and authors' assumptions based on sector research.*

*Note: EV = electric vehicle.*

# Appendix H: Share of End-of-Life Batteries Considered for Repurposing

**Table A–7: Share of End-of-Life Batteries Considered for Repurposing**

| EV segment | 2015 (%) | 2016 (%) | 2017 (%) | 2018 (%) | 2019 (%) | 2020 (%) | 2021 (%) | 2022 (%) | 2023 (%) | 2024 (%) | 2025 (%) | 2026 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Two-wheeled vehicles | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Passenger e-rickshaws | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Three-wheeled vehicles | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Passenger cars | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| Minitrucks | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Standard-size buses | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 20 |
| Midi-size buses | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 20 |
| Medium- and heavy-duty trucks | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| EV segment | 2027 (%) | 2028 (%) | 2029 (%) | 2030 (%) | 2031 (%) | 2032 (%) | 2033 (%) | 2034 (%) | 2035 (%) | 2036 (%) | 2037 (%) | 2038 (%) | 2039 (%) | 2040 (%) | 2041 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Two-wheeled vehicles | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Passenger e-rickshaws | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Three-wheeled vehicles | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 5 | 5 | 5 | 5 | 10 | 10 | 10 | 10 |
| Passenger cars | 5 | 5 | 5 | 5 | 5 | 10 | 10 | 10 | 10 | 10 | 10 | 15 | 15 | 15 | 15 |
| Minitrucks | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 5 | 5 | 5 | 5 | 10 | 10 | 10 | 10 |
| Standard-size buses | 20 | 20 | 20 | 20 | 20 | 40 | 40 | 40 | 40 | 40 | 40 | 60 | 60 | 60 | 60 |
| Midi-size buses | 20 | 20 | 20 | 20 | 20 | 40 | 40 | 40 | 40 | 40 | 40 | 60 | 60 | 60 | 60 |
| Medium- and heavy-duty trucks | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 5 | 5 | 5 | 5 | 10 | 10 | 10 | 10 |

*Source: Authors' analysis.*

*Note: EV = electric vehicle.*

## Appendix I: Battery Chemistry-Specific Energy Density

**Table A–8: Energy Density Ranges by Battery Chemistry**

| Chemistry | LFP | NMC | NCA |
|---|---|---|---|
| Typical Energy Density Range (kWh/kg) | 0.10–0.16 | 0.18–0.26 | 0.20–0.28 |

*Source: Verma et al. (2025).*

*Note: kg = kilogram; kWh = kilowatt-hour; LFP = lithium iron phosphate; NCA = nickel cobalt aluminium; NMC = nickel manganese cobalt.*

## Appendix J: Mineral Recovery Rates in Hydrometallurgy and Selling Price

**Table A–9: Mineral Recovery Rates in Hydrometallurgy and Selling Price**

| Mineral | Hydrometallurgy (%) | Selling Price (₹/kg) |
|---|---|---|
| Lithium | 90 | 8,468.66 |
| Nickel | 99 | 1,501.94 |
| Cobalt | 99 | 2,691.85 |
| Manganese | 95 | 180.70 |
| Copper | 99 | 777.59 |

*Source: Verma et al. (2025) and International Monetary Fund (n.d.).*

*Note: kg = kilogram.*

## Appendix K: Shares of Recycling Processes

**Table A–10: Shares of Recycling Processes Used in Mineral Recovery Estimates**

| Financial years | 2020–2031 (%) | 2032–2036 (%) | 2037–2041 (%) |
|---|---|---|---|
| Pyrolysis–hydrometallurgy | 0 | 0 | 0 |
| Hydrometallurgy (black mass) | 100 | 95 | 90 |
| Direct recycling | 0 | 5 | 10 |

*Source: Authors' assumptions based on sector research.*

# Appendix L: Recycling Capacity and Investment Assumptions

**Table A–11: Assumptions Used to Estimate Recycling Capacity and Investment**

| | |
|---|---|
| Plant Capacity (kg) | 1,00,00,000 |
| Total CapEx | ₹1,66,00,00,000 |

*Source: Mandal et al. (2022).*

*Note: CapEx = capital expenditure; kg = kilogram.*

# Appendix M: Growth and Penetration Rate Assumptions by Segment

**Table A–12: Growth Rates and Penetration by Vehicle Segment**

| Parameter | Value (%) | Source |
|---|---|---|
| Two-wheeled vehicle growth rate | 7 | Kearney, 2025. |
| Electric two-wheeled vehicle penetration rate by 2035 | 50 | KPMG, 2025. |
| Three-wheeled vehicle growth rate | 8 | Bonafide Research, 2025. |
| Electric three-wheeled vehicle penetration rate by 2035 | 80 | KPMG, 2025. |
| Passenger cars growth rate | 6 | IMARC, 2025. |
| Electric passenger car penetration rate by 2035 | 30 | KPMG, 2025. |
| Trucks growth rate | 5 | Autobei Consulting Group, 2024. |

# Appendix N: Actual EV Sales by Segment, Financial Year 2014–15 to 2025–26

**Table A–13: Actual Electric Vehicle Sales by Segment**

| EV segment | FY 2014–15 | FY 2015–16 | FY 2016–17 | FY 2017–18 | FY 2018–19 | FY 2019–20 | FY 2020–21 | FY 2021–22 | FY 2022–23 | FY 2023–24 | FY 2024–25 | FY 2025–26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Two-wheeled vehicle** | 1,512 | 1,417 | 1,331 | 1,979 | 28,001 | 26,839 | 44,834 | 2,52,783 | 7,28,223 | 9,48,534 | 11,50,765 | 14,02,479 |
| **Passenger e-rickshaws** | 0 | 1,311 | 5,163 | 8,974 | 11,228 | 13,664 | 7,922 | 15,938 | 34,938 | 49,026 | 47,439 | 47,777 |
| **Three-wheeled vehicle** | 38 | 629 | 1,472 | 2,244 | 4,046 | 7,240 | 12,738 | 25,899 | 55,402 | 1,42,375 | 2,24,233 | 3,52,246 |
| **Passenger cars** | 665 | 852 | 858 | 1,249 | 1,846 | 2,371 | 5,157 | 18,598 | 47,401 | 91,014 | 1,08,367 | 2,00,168 |
| **Minitrucks** | 60 | 55 | 328 | 924 | 512 | 53 | 32 | 1,022 | 453 | 4,641 | 5,153 | 13,767 |
| **Standard-size public buses** | 1 | 2 | 2 | 8 | 28 | 168 | 166 | 454 | 893 | 2,108 | 1,987 | 5,881 |
| **Midi-size public buses** | 1 | 2 | 3 | 12 | 38 | 318 | 203 | 733 | 1,113 | 1,408 | 1,327 | 5,882 |
| **Medium- and heavy-duty trucks** | 14 | 9 | 11 | 1 | 2 | 3 | 0 | 0 | 183 | 237 | 201 | 826 |
| **Total** | **2,291** | **4,277** | **9,168** | **15,391** | **45,701** | **50,656** | **71,052** | **3,15,427** | **8,68,606** | **12,39,343** | **15,39,472** | **20,29,026** |

*Source: Authors' analysis based on Vahan dashboard data.*

*Note: EV = electric vehicle; FY = financial year.*

# Appendix O: Projected Electric Vehicle Sales by Segment, Financial Year 2026–27 to Financial Year 2037–38

## Table A–14: Projected EV Sales by Segment

| EV segment | FY 2026–27 | FY 2027–28 | FY 2028–29 | FY 2029–30 | FY 2030–31 | FY 2031–32 | FY 2032–33 | FY 2033–34 | FY 2034–35 | FY 2035–36 | FY 2036–37 | FY 2037–38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Two-wheeled vehicle** | 19,72,017 | 27,53,811 | 38,12,147 | 52,20,253 | 70,54,638 | 93,85,416 | 1,22,63,454 | 1,57,07,326 | 1,96,94,833 | 2,49,58,704 | 3,16,29,460 | 4,00,83,121 |
| **Passenger e-rickshaws** | 51,590 | 55,723 | 60,180 | 64,993 | 70,194 | 75,809 | 81,873 | 88,424 | 95,497 | 1,03,137 | 1,11,388 | 1,20,299 |
| **Three-wheeled vehicle** | 4,26,929 | 5,12,375 | 6,08,826 | 7,16,326 | 8,34,755 | 9,63,900 | 11,03,526 | 12,53,448 | 14,13,595 | 15,99,913 | 18,10,788 | 20,49,457 |
| **Passenger cars** | 2,75,817 | 3,78,808 | 5,18,078 | 7,04,796 | 9,52,449 | 12,76,583 | 16,94,014 | 22,21,341 | 28,72,766 | 37,41,037 | 48,71,735 | 63,44,178 |
| **Minitrucks** | 22,132 | 35,378 | 56,078 | 87,810 | 1,35,131 | 2,03,066 | 2,95,821 | 4,14,828 | 5,57,011 | 7,64,330 | 10,48,813 | 13,26,818 |
| **Standard-size public buses** | 1,407 | 1,743 | 2,160 | 2,677 | 3,317 | 3,613 | 3,935 | 4,286 | 4,668 | 5,084 | 5,537 | 6,031 |
| **Midi-size public buses** | 1,407 | 1,743 | 2,160 | 2,677 | 2,644 | 2,966 | 3,327 | 3,732 | 4,187 | 4,696 | 5,268 | 5,909 |
| **Medium- and heavy-duty trucks** | 455 | 545 | 677 | 613 | 673 | 722 | 737 | 783 | 823 | 860 | 906 | 951 |
| **Total** | **27,51,754** | **37,40,126** | **50,60,306** | **68,00,144** | **90,53,801** | **1,19,12,074** | **1,54,46,687** | **1,96,94,167** | **2,46,43,380** | **3,11,77,762** | **3,94,83,896** | **4,99,36,764** |

*Source: Authors' analysis.*

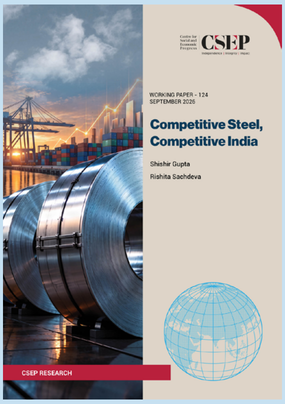
*Note: EV = electric vehicle; FY = financial year.*

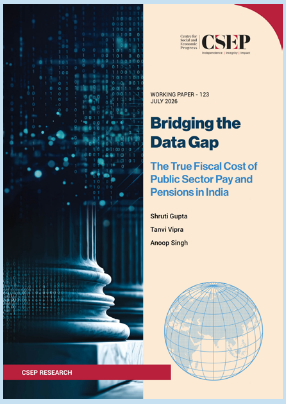
# About the authors

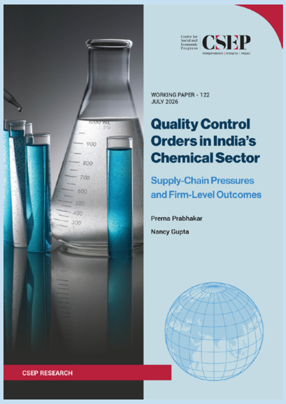
**Shyamasis Das** is a Fellow at CSEP, with over 16 years of experience working at the intersections of energy and utility, mobility, batteries and minerals, circularity, climate change, and policy. He has led several data-driven studies on India's EV transition and its links with emissions, electricity, sustainability, and public finance, and has developed transition roadmaps and implementation guidance for India and other developing countries, including Vietnam. He serves on several committees and task forces, including the Material Recycling Association of India's task force on Critical Minerals Recycling and the Ministry of Finance's Technical Committee on India's Climate Finance Taxonomy.

**Kartik Nair,** former Research Associate at CSEP, is a sustainability and policy professional working at the intersection of electric mobility, battery recycling, circular economy, and clean energy transitions. He has experience in policy research and developing strategies to strengthen India's electric vehicle and battery ecosystem. His work has focused on battery mineral recovery, recycling infrastructure, recycled-content targets, and reducing critical mineral import dependence. He has contributed to research and policy projects at institutions such as ICRIER and has also worked with government stakeholders on electric mobility policy.

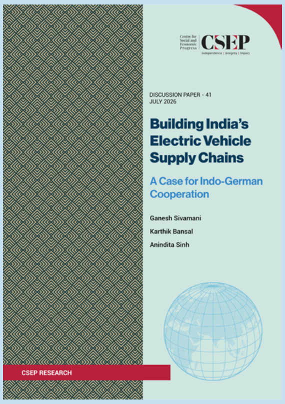
# Other publications

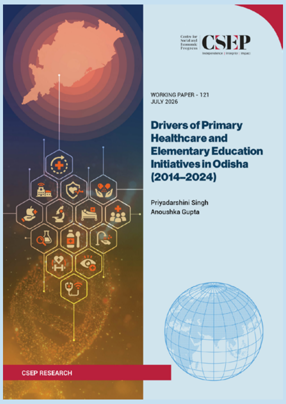


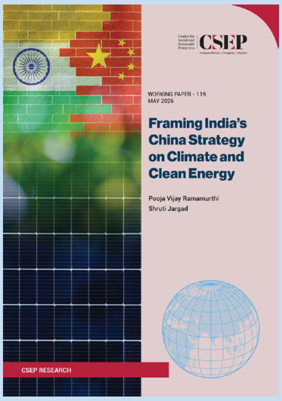



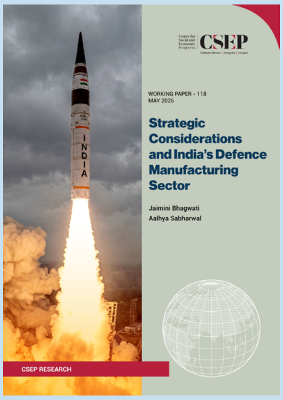




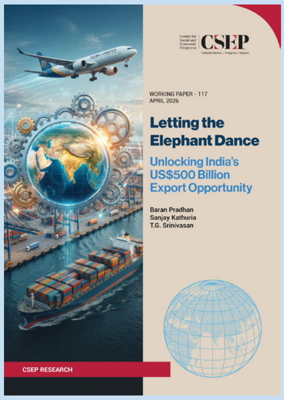



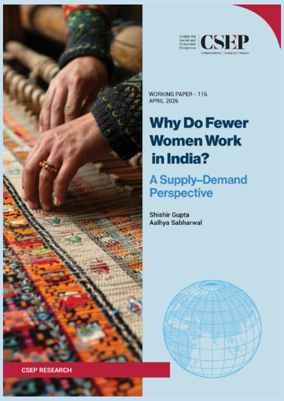


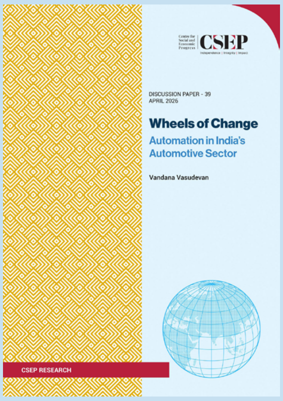



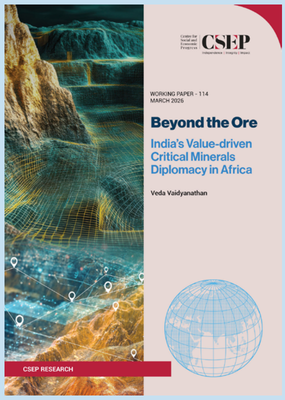






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