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CONFERENCE PROCEEDINGS

Enabling EV Battery Reuse and Recycling in India

A SUMMARY OF EXPERT PERSPECTIVES ON POLICIES AND REGULATIONS REQUIRED FOR ENABLING EV BATTERY REUSE AND RECYCLING IN INDIA

3 February, 2023 | New Delhi | Dr. Parveen Kumar, Pawan Mulukutla, and Madhav Pai

1. BACKGROUND

WRI India in collaboration with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) India, hosted a focus group discussion titled "Policy and Regulations for Enabling EV Battery Reuse and Recycling in India." The discussions examined the policies and regulations needed to enable the reuse and recycling of retired electric vehicle (EV) batteries. The focus group discussion was part of the "Forum for Decarbonizing Transport" under the NDC Transport Initiative for Asia (NDC-TIA) project. The panel consisted of experts (see Appendix A for the list of participants) who highlighted action points to address the current gaps in policy and regulatory frameworks and recommended possible solutions to streamline End of Life (EoL) battery management.

The closed-door focused discussions on recycling and reuse were conducted over two sessions. The participants included reuse and recycling industry representatives, policy researchers, and related stakeholders (see Appendix A). The deliberations revolved around the challenges and gaps in the Battery Waste Management Rules 2022 (BWMR 2022), safety concerns regarding lithium-ion batteries (LIBs), battery data management, and the need for reuse and recycling market development.
The topics of discussion included the following:

- The importance of reuse and recycling in the supply chain management of LIB raw materials for achieving self-sustainability.
- Gaps in standards, regulations, assessment mechanisms, testing, and certification in the reuse and recycling ecosystem.

CONTENTS

- Analysis of BWMR 2022 and the challenges to effective implementation of Extended Producer Responsibility (EPR).
- Challenges to reuse and recycling due to the heterogeneity of battery designs and chemistries.
- The role of the government and industry players in forging effective collaborations among stakeholders to ensure secure data sharing and battery management.
- Research and development (R&D) requirements for improved efficiency and material purity during recycling.
- The scope for regulations on EV battery durability requirements, considering the uncertainty around the remaining useful life (RUL).
- Ways to facilitate actions for creating a secure marketplace for repurposed batteries.

2.INTRODUCTION

Currently, EVs account for 35 percent of the LIB market share, which is likely to increase to approximately 90 percent by 2030 (Gulia 2022). The increased demand will be adversely impacted by the limited geographical spread of critical materials (supply vulnerability), their projected shortage (material criticality), and changes in the prices of critical raw materials due to geopolitical developments (price volatility) and may cause various environmental impacts due to increased mining as well as improper management of retired EV batteries.

Currently, the majority of EVs are powered by LIBs, and India relies completely on the import of lithium-ion cells. To reduce import dependence, the government has approved a production-linked incentive (PLI) scheme for the manufacture of advanced chemistry cells (ACCs) in India. Further, the use of retired EV batteries for second-life applications, such as behind-the-meter (BTM), front-of-the-meter (FTM), telecommunications and data center backup services, renewable-energy-powered EV charging stations, and low-power EV applications will help reduce the demand for new batteries. Finally, the EoL recycling of batteries would help India deal with end-to-end manufacturing issues such as raw material constraints, waste generation, environmental pollution, and high costs. Recycled critical raw materials will not only improve material efficiency but can also bring tremendous value to a wide range of stakeholders across the automotive and energy sectors.

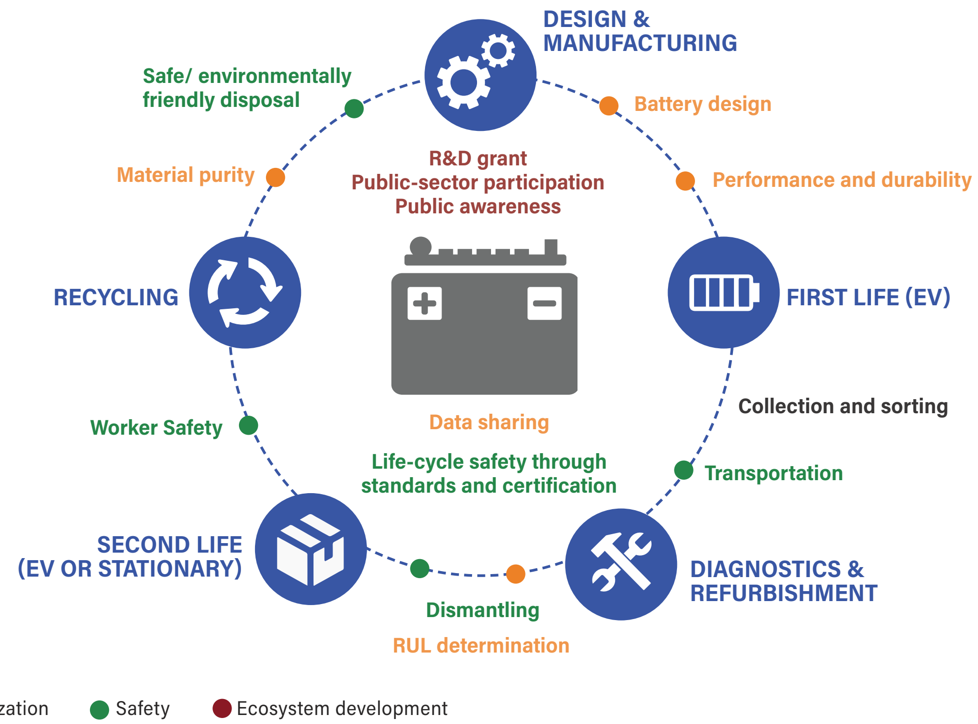
To establish a circular economy for EV batteries, we need an enabling policy and a regulatory framework, along with effective collaborations among stakeholders to establish a robust reuse and recycling ecosystem. However, India lacks stringent measures such as LIB-specific policies, standards, regulations, and guidelines that can enable robust implementation of battery reuse and recycling on the ground. With an EV surge clearly in sight, it is time for stakeholders in the sector to come together to design a holistic framework to ensure that EV batteries are used to their full potential through second-life applications and recycling.

3. CHALLENGES IN THE BATTERY REUSE AND RECYCLING ECOSYSTEM

Reuse and recycling are critical aspects of the creation of a circular economy. However, there are challenges to achieving full-scale reuse and recycling in the ecosystem. We compared global policies and regulations with India's policy landscape, and the identified gaps and challenges are mapped in Figure 1. The gaps and challenges identified in India are as follows:

- **The unorganized sector:** In India, the electric two-wheeler (e-2W) and electric three-wheeler (e-3W) segments are shifting from lead-acid batteries (LABs) to LIBs. The recycling of LABs is dominated by the unorganized sector, where the tracking of batteries and safety concerns for workers and the environment are huge challenges. To ensure safety and address other challenges, the battery reuse and recycling industry requires a robust formal sector.
- **Gaps in data, asset management, and tracking:** To achieve a circular economy, EoL batteries need to be tracked, and the tracking data need to be managed securely. In the case of LIBs, technical data, battery health, and performance need to be tracked as well. Creating a robust data management tool to trace the entire lifecycle of batteries of varying size and chemistry is a big challenge.
- **Safety challenges:** LIBs are high-power batteries with high residual power, necessitating careful handling throughout their life. From transportation and storage to dismantling and disposal, the battery needs to be carefully monitored, and safety precautions should be taken.
    - **Transportation and storage:** We have observed cases of EV battery fires during transportation. Due to their high residual power, they undergo thermal runaway in some extreme conditions, which leads to fire and the release of hazardous gases. Therefore, serious attention needs to be paid to the safety aspects of transportation and storage of these batteries.
    - **Worker and environmental safety:** The working conditions for the LAB and LIB recycling industries are different. As new players enter the system and the technology transition from LAB to LIB accelerates, the industry needs to ensure workers' safety in the recycling process and in the post-recycling handling of recycled waste material.
- **RUL determination:** RUL is an important criterion for deciding whether to recycle or reuse. Currently, there is no clarity about an effective RUL determination process, which is necessary to rationalize the decision-making process governing reuse or recycling.
- **Segregation:** LIBs come in varying sizes and chemistries. The segregation of batteries based on their size, chemistry, and State of Health (SoH) is important for decision-making regarding their reuse and recycling. Segregation of these batteries needs a standardized mechanism, the lack of which may create inefficiencies in the whole reuse/recycle ecosystem.

FIGURE 1. Challenge and gap mapping in the circular economy



Notes: EV = electric vehicle; RUL = remaining useful life.
Sources: Compiled by WRI India.

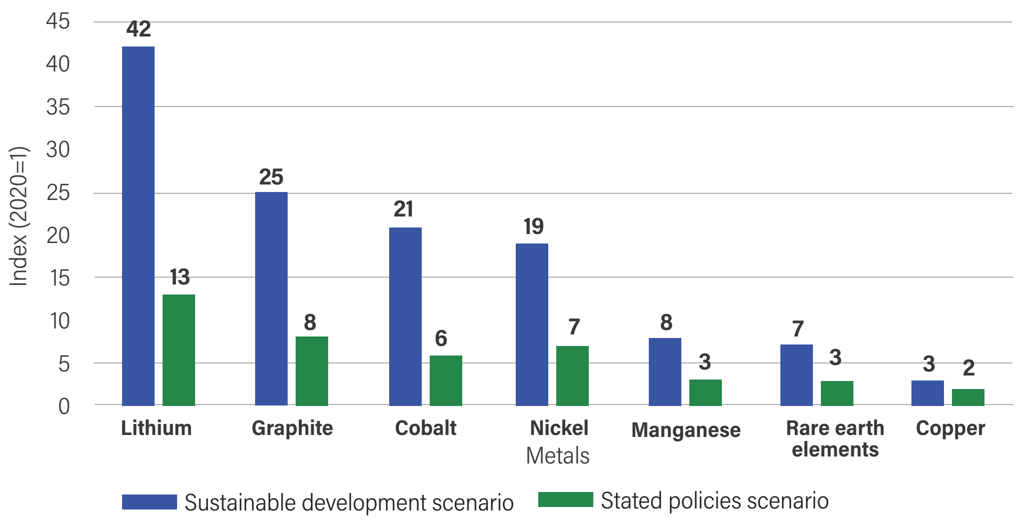
4. MARKET ANALYSIS OF REUSE AND RECYCLING OF EV BATTERIES

Currently, LIBs account for 51 percent of the total battery market (Gattu 2022). The global demand of 700 GWh in 2022 is expected to rise to 4.7 TWh by 2030 (Hanicke et al. 2023). During the same period, India's demand of 3.9 GWh in 2022 is expected to rise to 116 GWh (Gulia et al. 2022). The EV application share, which is currently around 35 percent in India, is expected to reach 90 percent by 2030 (Gulia et al. 2022).

4.1. Raw material: Demand and supply

According to an International Energy Agency (IEA) report titled "The Role of Critical Minerals in Clean Energy Transitions 2022," the demand for the seven minerals essential for low-carbon technologies is expected to increase significantly. Figure 2 shows the projected increase in demand for these minerals in both the sustainable development scenario and the stated policies scenario.

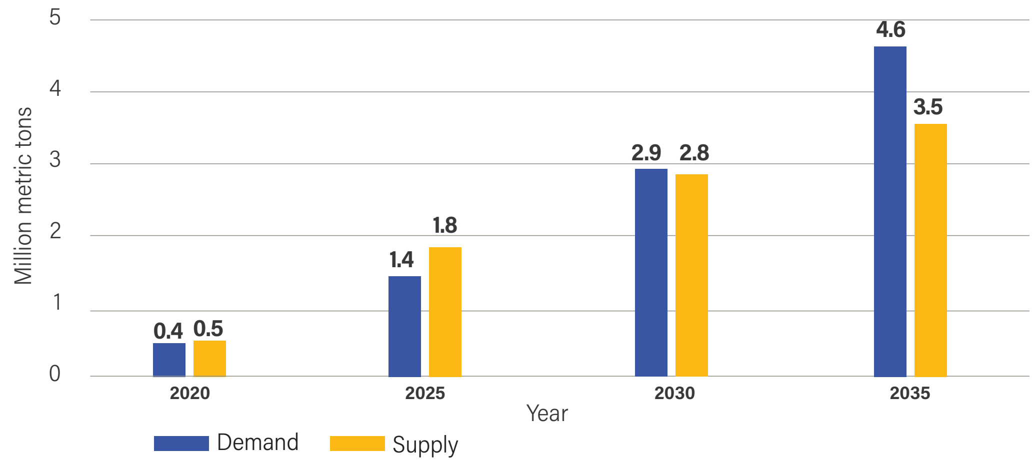
FIGURE 2. **Growth in metal demand from 2020 to 2040**



Sources: IEA 2021.

Here, we see the demand for lithium increasing 13–42 times by 2040 from the 2020 level. In the same period, the demand for cobalt is likely to rise 6–21 times and that for nickel 7–19 times (IEA 2021). This increased demand may create a gap in the supply or availability of the critical materials. According to analysis by S&P Global Market Intelligence and the Boston Consulting Group (BCG), we may face a lithium supply gap of 1.1 million metric tons by 2035 (Wurzbacher et al. 2022) (see Figure 3).

FIGURE 3. **Supply and demand of lithium globally**



Sources: Wurzbacher et al. 2022.

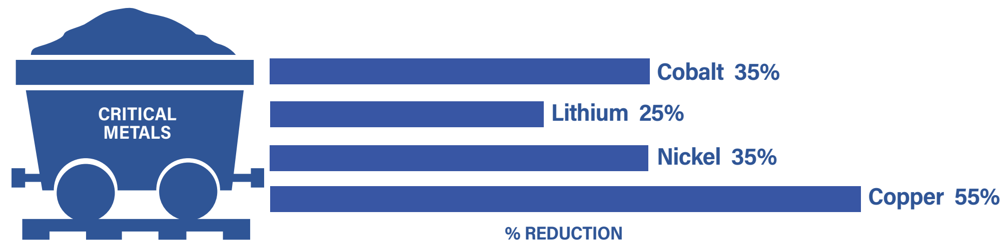
4.2. Reuse and recycling potential

There is a huge potential for battery reuse in India as it aims to become carbon neutral by 2070. As conventional energy use transitions to renewable energy, batteries at the end of their EV application can be used for stationary energy storage.

According to National Institution for Transforming India (NITI) Aayog estimates, new batteries would create a recycling volume of 128 GWh by 2030, of which around 46 percent will come from EVs. To treat this volume, India's lithium battery recycling capacity would have to increase about 60 times over the next eight years, from the current level of 2 GWh (Times of India 2023).

Reuse will extend the usage of retired EV batteries in other applications, and recycling will ensure the local availability of the battery-critical materials and reduce the pressure on raw material mining (see Figure 4). This will help reduce the environmental and carbon footprint as well as greenhouse gas (GHG) emissions.

FIGURE 4. **Reduction in critical metal mining due to recycling by 2040**



Sources: Dominish et al. 2021.

4.3. Status of policies and regulations

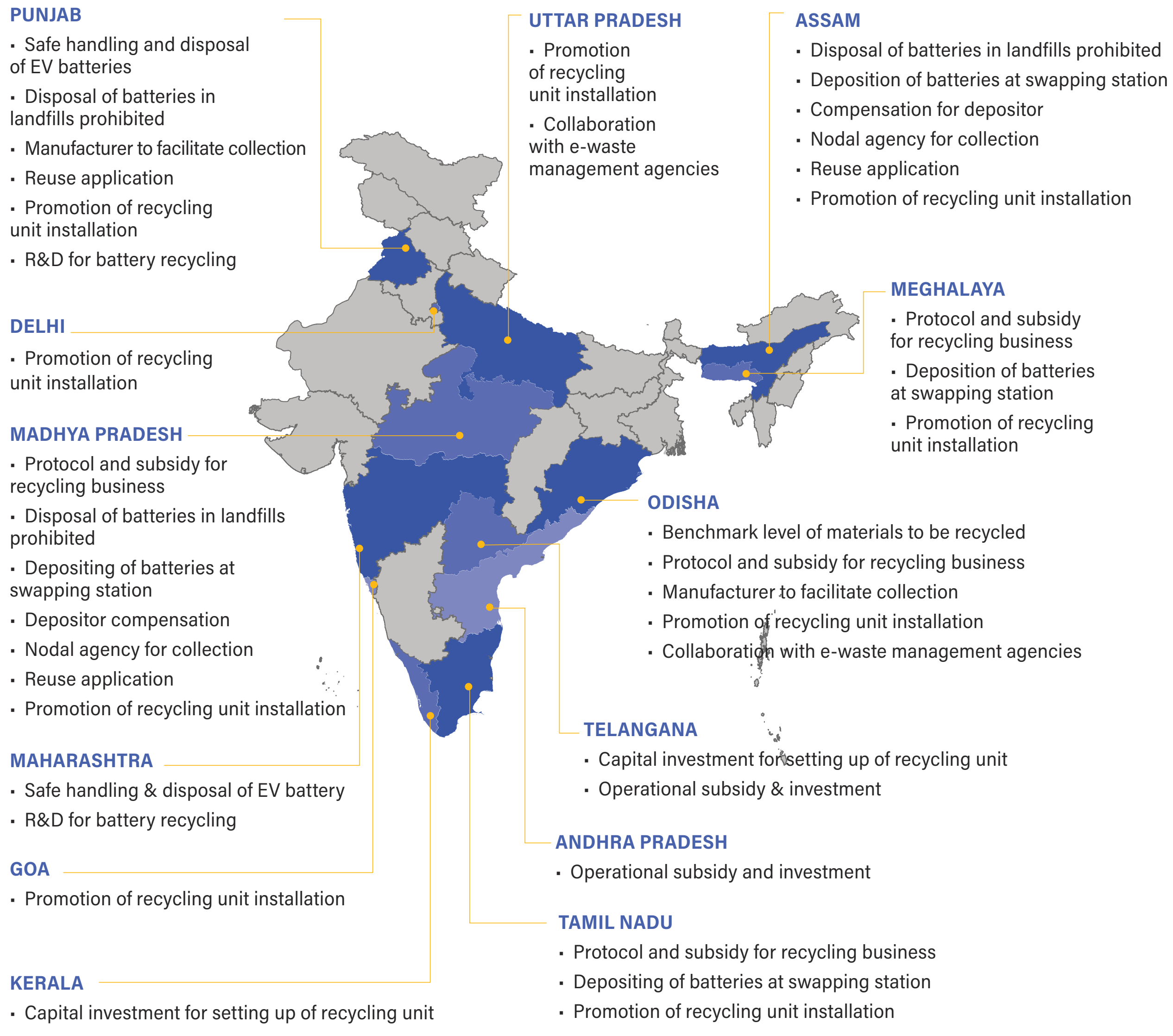
There is a critical need for robust policies and regulations for the full-scale adoption of reuse and recycling. China, the European Union (EU), United States, India, and other countries encourage reuse and recycling through their policies and regulations (see Figure 5). For example, the EU's new battery policy mandates a battery passport system for batteries above 2 kWh. With battery passports, the entire life cycle of the battery can be traced, and the current status and change in ownership due to the reuse applications of each battery can be known. Similarly, for EoL management, China has adopted the EPR system, making it the producer's responsibility to collect the battery from the consumer and take responsibility for reuse and recycling.

FIGURE 5. Global policy and regulation mapping for reuse and recycle of LIBs

Notes: LIBs = lithium-ion batteries.
Sources: Developed by WRI India.

For EoL management of EV batteries in India, the government has notified BWMR 2022 at the national level. BWMR 2022 has a provision for EPR usage to track and trace retired EV batteries. Another major step is the Draft Battery Swapping Policy, which has a provision for Unique Identification Numbers (UIN) to facilitate life cycle management of EV batteries, including technical data requirements at different stages of their life. In addition to the initiatives at the national level, several states have announced incentives and measures to ensure EoL management of EV batteries in their respective state EV policies (see Figure 6).

FIGURE 6. EoL EV battery reuse and recycling frameworks adopted in state EV policies



DISCLAIMER: This map is for illustrative purposes and does not imply the expression of any opinion on the part of WRI India concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.
Notes: EV = electric vehicle. *Sources:* Compiled by WRI India.

4.4. Market landscape of LIB reuse

Reuse of LIB is not merely a concept; companies worldwide are engaged in reuse activities relating to the power grid, small urban mobility applications, and so on. Globally, second-life batteries are expected to store more than 200 GWh by 2030, with a global value of more than US$30 billion (Shahjalal et al. 2022). Currently, in India, Audi has partnered with Nunam technology for its batteries to be reused in e-rickshaws. Similarly, Mercedes-Benz Energy has tied up with Lohum for the use of LIBs in stationary and non-auto mobility applications. Table 1 lists some emerging collaborations in the reuse sector.

TABLE 1 | Global application of LIB reuse

JOINT VENTURES	DESCRIPTION	LOCATION
BMW, Vattenfall, Bosch	2,600 battery modules from 100 EVs, providing 2 MW output and 2.8 MWh of capacity	Germany
Renault, Connected Energy Ltd.	'E-STOR': providing on-grid energy storage that prevents power grid overload and balances supply and demand	United Kingdom
Mitsubishi,PSA EDF, Forsee Power	Bidirectional battery energy consumption optimization from retired batteries	France
General Motors, ABB	5 Chevrolet Volt LIBs, 74 kW solar array and two 2kW wind turbines to power a General Motors office building site	United States
Mercedes Benz Energy, Lohum	Lohum will offtake at least 50MWh across multiple second-use battery modules every year from Mercedes Benz Energy (MBE) globally	India
Audi AG, Nunam	Audi AG and the Audi Environmental Foundation to roll out electric rickshaws powered by used Audi e-tron batteries	India

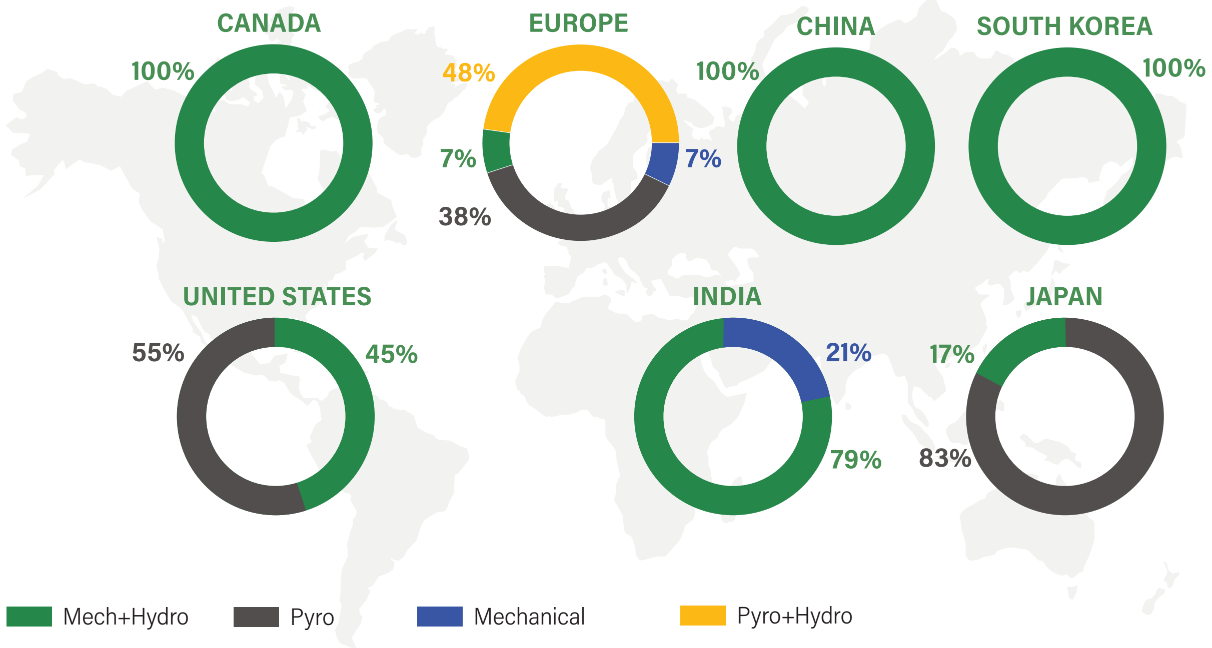
Notes: BMW = Bayerische Motoren Werke AG; EDF = Électricité de France; EV = electric vehicle; kW = kilowatt; LIB = lithium-ion battery; MMC = Mitsubishi Motors Corporation; MW = megawatt; MWh = megawatt-hour; PSA = Peugeot Société Anonyme.

Sources: Živčák 2021.

4.5. Market landscape of LIB recycling

Nearly two-thirds of the world's LIB recycling capacity (207,500 metric tons) is located in East Asia. Europe is second, with seven battery recycling facilities having a total capacity of 92,000 metric tons. North America has four recycling facilities with a total capacity of 20,500 metric tons, almost equally divided between Canada and the United States (Baum et al. 2022). Figure 7 shows the technologies adopted for battery recycling and their shares in different regions of the world in 2020.

FIGURE 7. Global battery recycling technology trends in 2020



Source: Gattu et al. 2022.

India has some players who compete in the global market, such as Attero, with a current LIB recycling capacity of 4,500 metric tons/year (Mehta 2022). ACE and Gravita India plan to develop a capacity of more than 10,000 metric tons/year each.

There appears to be a correlation between recycling capacity and the development of policies and regulations in Europe and China. Development of timely policies, regulations, and implementation strategies have helped countries build their recycling industry.

5. FOCUS GROUP DISCUSSION OUTCOMES

This section highlights the key discussion points from the two sessions of the focus group discussion.

SESSION 1: Policy and Regulatory Framework for an Efficient Battery Recycling Ecosystem

Key discussion points

- Gaps in policy and regulations for EV battery recycling
- Challenges in collection and sorting of EoL LIBs
- Safety concerns in storage, transportation, and handling
- Mechanisms for data collection, sharing, and security
- Feasibility of design for recycling
- Enabling actions to improve recycling efficiency and utilization of recovered raw materials
- Challenges for recyclers in transitioning from LAB to LIB recycling

SESSION 2: Policy and Regulatory Framework to Develop Retired EV Battery Reuse Ecosystem

Key discussion points

- Reuse potential of small and big battery packs
- Need for setting assessment criteria to estimate the RUL of batteries
- Requirement of performance and safety standards/testing and certification of repurposed batteries
- Bulk consumer/user responsibilities
- The role of the government in creating an early market for refurbished batteries

5.1. Key lessons and entry points for action

Effective tracking and tracing of EV batteries

Reuse: BWMR 2022 is a good start as it establishes and defines reuse as an activity in the circular value chain in India. Tracking battery health can further help reuse players take ownership of and liability forbattery assets in exchange for an EPR certificate. More clarity is needed on the allowed activities (e.g., remanufacture, refurbishing, reuse as it is, or repair and reuse) and the assessment framework for better decision-making and reuse safety prospects. The Draft Battery Swapping Policy has already proposed some enabling actions that will help the reuse industry. However, for the effective implementation of EPR and management of batteries in the reuse and recycling phases, we need more regulatory support and guidelines to ascertain stakeholder responsibilities. EPR can be implemented in a phased manner, with the initial compliance requirement being placed on EV manufacturers with a certain minimum annual turnover. Gradually, after gaining valuable experience, EPR can be extended to include small and unorganized players. Original equipment manufacturers (OEMs) can be encouraged to form consortia or partnerships with smaller market players.

Entry points for action: Assessment and decision-making criteria for the retirement of batteries at different stages of life need to be defined and agreed upon clearly. The post-retirement applications allowed for EV batteries need to be clarified. Guidelines for the effective implementation of EPR at different stages of battery life are also required.

Recycling: BWMR 2022 will evolve with time, and setting targets and defining efficiency parameters will further help achieve the objective of recycling. More clarity on the identity of LIB scrap, the expected end product, and details of the intermediary process will help implement the provisions of BWMR 2022 dealing with the percentage of recycled material to be included in the new products. Scannable batteries, which can provide information about battery health in the first and second life, will facilitate efficient decision-making related to refurbishing and recycling. An efficient mechanism for tracing batteries at different life stages will also ensure the presence of formal players in the refurbishing and recycling ecosystem.

Entry points for action: There is a need for clarity on the outputs of the recycling process, so that battery manufacturers can use recovered raw materials efficiently. Strict implementation of EPR is important, which can be facilitated by making EPR transactions a seamless process. The unorganized sector needs to be controlled by syncing the battery's technical and health data with EPR certifications.

Tackling the heterogeneity of battery design and technology

Reuse: The cost of repurposing against potential revenue generation in second-life applications is the only critical factor that determines its commercial success. If OEMs consider reuse a design requirement, the odds against true circularity can reduce. Heterogeneity of design may be due to proprietary reasons, but if all designs can collectively treat dismantling as an end use, reuse will be encouraged. Segregation and tracking of batteries are significant challenges, but batteries of different chemistries that are aligned parallelly to make battery packs can be a potential solution to this challenge.

Entry points for action: Heterogeneity in battery chemistry and design are pervasive challenges in achieving an efficient reuse ecosystem by making the automation of the entire process difficult. To tackle this, the provision of battery segregation at the source should be implemented. This market can thrive if battery OEMs collaborate with the relevant stakeholders to design reuse-and-recycling-friendly battery packs without compromising on their performance and safety.

Recycling: Currently, not many EV battery packs can be made available for recycling. The current recycling industry gets retired LIBs from e-waste sourced from laptops, mobiles, and so on, and India exports most of the recovered black mass. It will take nearly three to four years for the Indian industry to start getting sufficient retired EV batteries for recycling on an industrial scale. This time can be utilized to fill the gaps through robust ecosystem development. In the coming years, as capacity develops, EoL batteries need to be segregated at the source level to ensure the recovery of pure cathode-grade material for the efficient use of recycled material in the new batteries provisioned in BWMR 2022.

Entry points for action: India is at a nascent stage of EV adoption. Understandably, with the low quantity of EoL batteries and the heterogeneity of chemistry and design, the entire process of recycling and reuse becomes inefficient. With time, as the shares of different battery chemistries increase, the process will become more efficient. For this to happen, technical data on batteries must be available so that they can be efficiently segregated at the source.

The role of guidelines and stakeholder collaborations

Reuse: The industry needs a robust framework for a circular economy of batteries that considers the environmental impact, customer safety, and national climate goals. We need guidelines to establish and encourage transparency among stakeholders with respect to lifecycle data while ensuring good quality at the cell and pack levels. The industry needs to work together for safety across the value chain because it is a collaborative responsibility beyond certificates and standards. The implementation of BWMR 2022 can be eased with the help of a single window clearance system, and EPR trading needs to be user-friendly. Safety guidelines should be formulated for handling EV batteries effectively at their different stages of life. The standards should be issued with a validity period (to avoid multiple changes), after which they can either be reviewed or extended. The industry requires firm guidelines for ensuring safety during reuse, which should be drafted and included in the BWMR. The method of SoH assessment must evolve from the industry. SoH assessment guidelines can help structure the ecosystem and enable stakeholder alignment for the assessment. The quality of cells/battery packs and usage profiles will not only affect first-life applications, but will also impact the longevity of second-life applications. AIS-156 now has a provision for monitoring e-3W batteries. OEMs should work together with the reuse industry players because e-2W and e-3W batteries will retire sooner than other EV batteries. Because these two EV modes are available in huge quantities, the collection and sharing of battery-related data is a critical component in the creation of a robust reuse ecosystem.

Entry points for action: Guidelines should be framed for encouraging best practices and handling retired EV batteries during the reuse phase and at the end of their second life. Safety standards at different stages of battery life need to be clearly laid down, and all standards should be accompanied by a validity period. More importantly, the implementation of all these standards and regulations, especially EPR trading, needs to be easy. Collaboration and transparency among stakeholders are important to maintain safety in battery reuse.

Recycling: LIBs are dangerous goods, and lithium-ion waste is hazardous. As LIBs contain fluorine and other heavy metals, safety concerns in the working ecosystem should be addressed through regulation or guidelines. Currently, a detailed framework for the handling, storage, and transport of lithium-ion waste is not available. Not only India, but countries across the world are struggling to develop such frameworks. In recycling, the major challenge is converting R&D to an industrial-scale process. Here, government R&D institutions can collaborate to scale up efficient recycling processes or technologies. China, the EU, and the United States provide subsidies to develop the battery recycling ecosystem and support R&D for industrial-scale processes. India also needs to develop a mechanism for academia–industry collaboration to support the R&D requirements of the recycling industry. Government support is crucial to improve recycling efficiency. The transportation of retired EV batteries is the biggest challenge, and to mitigate this, battery packs can be transported with sand barrels and fire extinguishers for as long as safety concerns persist.

Entry points for action: The recycling market is evolving, and the processes and safety protocols related to the storage and transportation of retired EV batteries need to be tackled urgently. As the recycling industry is part of a hazardous ecosystem, it needs guidelines related to workers' safety. The industry will also benefit from collaborations with research institutions that can help in scaling efficient processes and technologies. The government can provide support for R&D to industry-level scaling of the processes and technologies.

Assessment, testing, and certification ecosystem

Reuse: The criteria for deciding when to move the EV battery from its first-life to its second-life applications are a critical element of the process. For the SoH evaluation, the ratio of the remaining capacity to the original capacity can be considered. The decision related to the second-life application can be made based on the battery's SoH status and remaining capacity. This will enable industry players in the reuse business to take better decisions related to RUL for the second-life applications. Other stakeholders can participate in the shared risk model to monetize the batteries and reduce the total cost of ownership (TCO). In this way, the market will be able to move past low-value batteries and determine the price tag of batteries based on their remaining capacity. The Central Electricity Regulatory Commission (CERC) already has standards for grid applications. Other agencies should also set similar standards for their applications. Before entering the market, vehicles should be certified by the Automotive Research Association of India (ARAI) or International Centre for Automotive Technology (ICAT), which includes testing of batteries as well. Refurbished batteries should go through the same stress tests. Currently, the ARAI does not have adequate infrastructure for catering to the future demand for refurbished batteries, and more capacity is needed to handle this market requirement. More such agencies are required, and they need to follow a single checklist. Batteries entering their second life would have to satisfy the set criteria, after which the agencies can certify them for further use. Alongside standards, an implementation framework and incentives through a green credit scheme are also necessary; these will help manufacturers take ownership of the entire supply chain.

Entry points for action: The RUL assessment is an important aspect of decision-making regarding the second-life applications of batteries. Reuse facilitators and other stakeholders can explore a risk-sharing model to reduce the cost per kilowatt-hour of second-life applications. Some guidelines are already in place for batteries in different applications. These can be explored for refurbished batteries as well. Testing and certification agencies such as ARAI should set up more decentralized testing laboratories to meet the expected future demand. A compendium of laws and certifying agencies should be prepared for streamlining refurbished battery adoption.

Recycling: Currently, batteries in the LIB recycling ecosystem, which are low-powered batteries (lithium cobalt oxide [LCO] battery and other polymer batteries), come primarily from portable electronics e-waste. As the EV market grows, future retired batteries will increasingly come from EVs, which use high-powered LIBs (nickel manganese cobalt oxide [NMC] and lithium iron phosphate [LFP]). As we transition from low- to high-powered batteries, recyclers will need to develop capacity in line with the expected market demand. In the process, existing LAB recyclers unaware of the safety concerns associated with LIB recycling may also participate, which can raise safety concerns because LIBs contain hazardous metals. A skill development program for the reuse and recycling sector will help ensure workplace safety. Stringent regulations and certification systems are needed to ensure safety across the ecosystem.

Entry points for action: As the recycling industry transitions from low-powered batteries to high-powered LIBs, it needs to institute stringent regulations and certification systems to ensure safety across the ecosystem. Robust testing and certification agencies with decentralized facilities can help make the ecosystem more inclusive and accessible.

Support for market development

Reuse: There is significant scope for power distribution companies (i.e., discoms) to use repurposed batteries for energy storage. Because the management cost of refurbished batteries is likely to be high due to the overall operational requirements (e.g., high auxiliary energy requirements for air conditioning), government support will help the initial adoption. An understanding of the remaining life of EV batteries and the monetary value of batteries with different chemistries will be important to gain insights into the economic rate of return for the reuse industry.

Entry points for action: For reuse to be viable, the monetary value of the refurbished batteries must be higher than the refurbishing costs. Standardization during battery manufacturing could increase reuse potential. Initial support for the adoption of refurbished batteries would help bulk users (e.g., users of grid applications) as the auxiliary expenditure increases.

Recycling: Currently, the bulk of battery waste is handled by the unorganized sector. To manage waste safely and efficiently, the development of a robust organized sector in the recycling industry is critical. The government can play an important role in developing the required systems and standards. To achieve economies of scale, the downstream process should be centralized. The upstream process can be centralized depending on the industrial activity, that is, whether it is recycling, reusing, or doing both. Instead of thinking of recycling as a cost-centric activity, it should be considered a revenue generator and industry creator. A push to transition from the unorganized sector to the organized sector would be a significant step forward, and traceability of materials would further accelerate its success. A mechanism should be developed to pull unorganized players into the organized sector, and incentives can play a key role in this effort. Customer awareness about the incentives they gain when exchanging batteries for EoL recycling would also contribute to the success of the formal sector. The battery recycling industry can be transformed into a potential revenue generator with support from the Ministry of New and Renewable Energy (MNRE) and Ministry of Heavy Industries (MHI). Because the battery reuse and recycling industry is at a nascent stage, support mechanisms from the government that would operate in parallel to the existing schemes can be explored.

Entry points for action: Several initiatives are required to prevent consumers from transacting with the unorganized sector. An efficient tracking mechanism as well as a transparent mechanism for incentive-linked exchange of batteries can play an important role in ensuring that retired EV batteries are recycled in the formal sector. The involvement of the MHI and other government ministries would help fast-track the development of the reuse and recycling industry.

6. NEXT STEPS

The following are the key recommendations by experts to build a robust reuse and recycling ecosystem for EV batteries:

- Guidelines should be developed for the effective implementation of EPR at different stages of battery life.
- OEMs in the industry should also work toward reuse-and-recycling-friendly battery design and technical data collection for sharing among stakeholders.
- Guidelines should be created for best practices to ensure efficiency and safety at reuse and recycling facilities.
- Retirement criteria and post-retirement usability criteria should be determined for batteries in all applications.
- A framework should be created for collaboration between research institutions and industry to fast-track the scaling of efficient processes and technologies.
- Safety standards need to be established and implemented for transportation, storage, and workers' safety in the reuse and recycling industry.
- Capacity building in the reuse and recycling industry is urgently required to handle the future demand for managing high-power LIBs retired from EVs.
- More agencies should be established for safety assessment, testing, and certification of batteries.

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ABBREVIATIONS

ACC: Advanced Chemistry Cell

ARAI: Automotive Research Association of India

BWMR: Battery Waste Management Rules

BCG: Boston Consulting Group

CERC: Central Electricity Regulatory Commission

CO2: Carbon dioxide

e-2W: Electric two-wheeler

e-3W: Electric three-wheeler

EoL: End of Life

EPR: Extended Producer Responsibility

EV: electric vehicle

g/KM: Gram per kilometer

GWh: Gigawatt-hour

kWh: Kilowatt-hour

LIB: Lithium-ion battery

LAB: Lead-acid battery

LCO: Lithium cobalt oxide

LFP: Lithium iron phosphate

MHI: Ministry of Heavy Industries

NMC: Nickel manganese cobalt oxide

OEM: Original equipment manufacturer

PLI: Production-linked incentive

R&D: Research and development

RUL: Remaining useful life

SoH: State of Health

S&P: Standard & Poor's

TCO: Total cost of ownership

TWh: Terawatt-hour

UIN: Unique Identification Number

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ABOUT WRI INDIA

World Resources Institute India is a research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Liveable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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