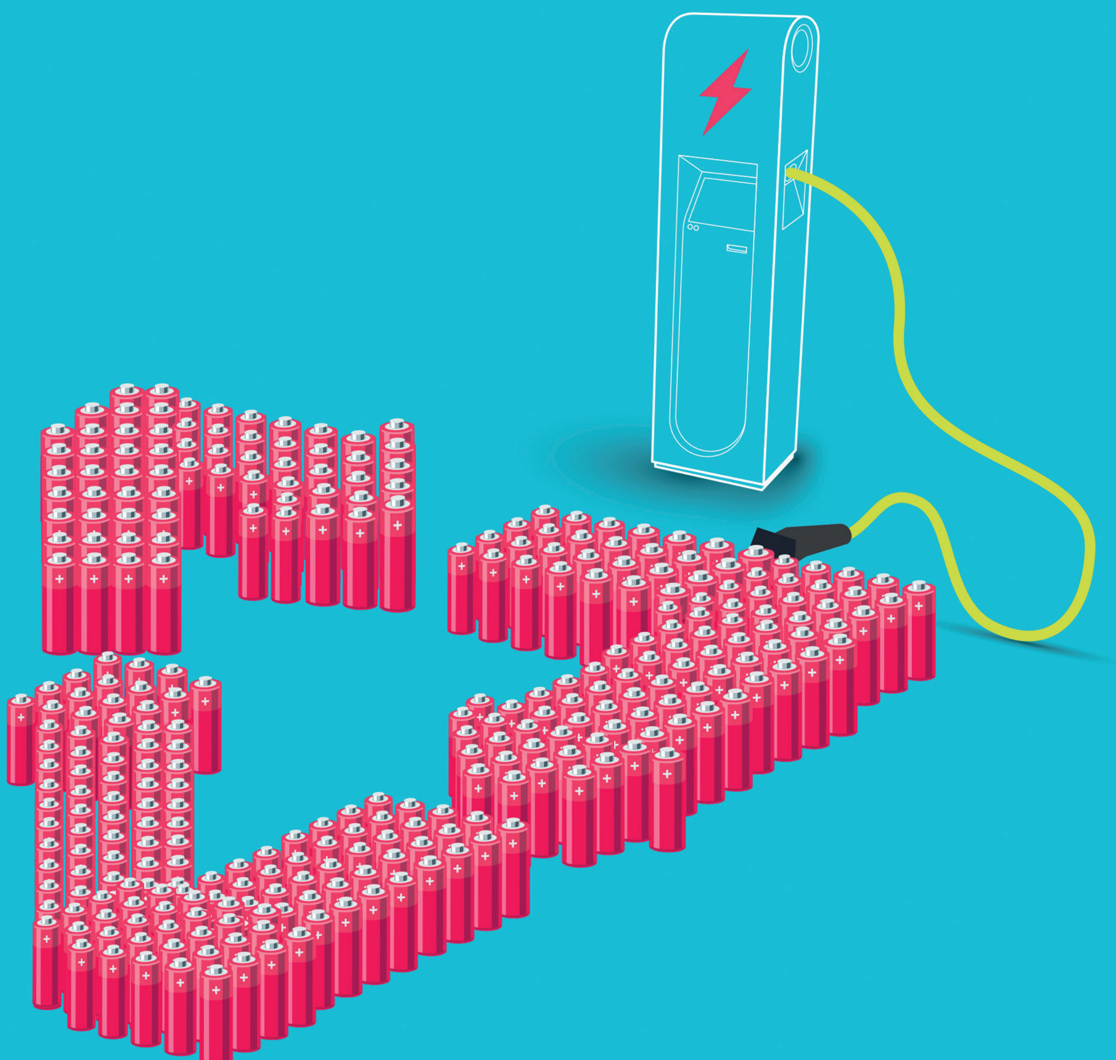
POLICY BRIEF

RECYCLING EV BATTERY MATERIAL

Towards material security and sustainability



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Spotlight on electric vehicle battery recycling

India's ambition to scale up the electric vehicle (EV) programme and build local manufacturing face the challenge of securing adequate supply and access to raw material for battery cell production. Without a strategy to secure adequate supply of critical battery materials, this can limit growth of local manufacturing of EVs and batteries. Currently, the dependence on import for Lithium-ion batteries and cells is significant as the local cell manufacturing is extremely limited. This makes India's ambition and India's electric vehicle industry highly vulnerable to uncertainties and risks in the global supply chain.

Currently, most of the Li-ion cell requirements are met from import especially from China. Narrow base of local manufacturing, limited access to raw material, lack of local mining and refining have made dependence on import inevitable at these early stages of growth. Yet India is at the cusp of change. There is growing interest to reduce import dependence and build self-reliance to enable the economy to retain most of the value chain within India and ensure larger economic benefits and jobs.

The current policies are designed to build and promote domestic industry. The Rs 10,000 crore demand creation scheme Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME II) scheme requires the EV equipment manufacturers (OEMs) to demonstrate that at least 50 per cent of the components in their vehicles are manufactured in India and are locally sourced. The Automotive Research Association of India (ARAI) tests this localization percentage before the EV is certified for sales. There has been some concerns around the fact that the industry has not done enough to achieve this target. The FAME allocation however has been doubled in the 2023-24 national budget and the timeframe extended by another year to enable the market for EVs and EV batteries to have an opportunity to grow and mature. The next phase of FAME III is also on the anvil.

On the other hand there is a Rs 18,000 crore supply support program called Production-Linked Incentives (PLI) to support and build local manufacturing. The PLI scheme, which is directed at Advanced Chemistry Cell (ACC) manufacturers, has already selected three companies for the purpose. It is also evident that a few OEMs, traditional battery players, and start-ups are venturing into cell and battery manufacturing.

These policy initiatives are expected to increase domestic availability of batteries, reduce imports and battery costs. But India needs good access to key raw materials including lithium, nickel, cobalt and manganese among others that are expected to account for 51 per cent of the cell cost. Their local reserves are limited.

To achieve material security there is also considerable thrust to expand mining exploration in India and overseas. While there is optimism around lithium find in Jammu and Kashmir, India's joint venture company - Khanij Bidesh India Ltd is buying mining assets overseas including lithium and cobalt. An expert committee set up by the Centre has also identified 30 minerals as critical to India, including lithium, to boost investment in mining.

Yet another strategy is the investments under the global partnership called Minerals Security Partnership (MSP), a US-led alliance of developed countries, that India has joined as the only developing country. This critical mineral club is expected to catalyse investment from the government and private sector in the critical mineral supply and value chain.

Towards recycling of battery material: As the desperation to secure access to material grows globally, yet another dimension of improving access and enabling material security is recycling of battery material. Global studies have shown that this has enormous potential as the material once locked inside the battery can have infinite life if it can be extracted and separated properly and recycled.

It is this strategy that this policy brief aims to focus on to understand the opportunity in this strategy and how this can be developed in India as a viable model for material security and environmental sustainability.

At this stage when the volume of EVs is still small, generation of end of life vehicles is very limited in India and globally. At a global scale it has been estimated by the International Council on Clean Transportation (ICCT) that 1.2 million batteries from light- and heavy-duty battery operated and hybrids are expected to reach their end of life in 2030 globally, increasing to 14 million in 2040, and 50 million in 2050. Reusing 50 per cent of these end-of-life vehicle batteries and efficient recycling of them can reduce the combined annual demand in new lithium, cobalt, nickel, and manganese mining by 3 per cent in 2030, 11 per cent in 2040, and 28 per cent in 2050.[1]

In India a 2022 report of Niti Aayog and Green Growth Equity Fund Technical Cooperation Facility, on Advanced Chemistry Cell Battery Reuse and Recycling

Market in India,[2] has estimated cumulative stock of lithium ion batteries in 2021 at about 22.4 GWh – out of this the share of stationary application is 40 per cent with an estimated 9 GWh of deployments, share of transport application is 9 per cent with 2.1 GWh of deployments and consumer electronics is at 49 per cent with 11.3 GWh of deployment. But the share of transport is expected to grow. In 2022 alone, the share of transport was 38 per cent of the total estimated annual demand for lithium ion batteries. [3]

As the cumulative demand for lithium ion batteries grows the quantum of end of life vehicles will also grow. The Niti Aayog report estimates that the cumulative potential of lithium-ion batteries in India during 2022-30 will be around 600 GWh across all segments in the base case, and the recycling volume coming from these batteries will be 128 GWh by 2030. Out of this, almost 59 GWh or 46 per cent will be from the electric vehicles segment alone. [4]

This builds a case for a strong strategy to create infrastructure, systems and enterprise around battery reuse and recycling. In fact, there is a strong consideration to provide budgetary support for setting up recycling facilities. There is a proposal to allocate Rs 3,500 crore for the scheme for a period of around three years.

Battery recycling has the co-benefit of enhancing material access and security as well as minimising environmental hazards from indifferent disposal of batteries. There have been several pieces of legislation since 2010 that include E-Waste (Management and Handling) Rules 2011, the E-waste (Management and Handling) Rules 2016 and the E-Waste (Management) Amendment Rules 2018 and finally E-Waste (Management and Handling) Rules 2022. These provide the overall framework for the electronic waste management. But it is only the Battery-Waste (Management and Handling) Rules 2022 that addresses the lithium ion batteries from electric vehicles.

Even though there is still considerable scope of improving these rules for more effective recycling, it is necessary to take steps toward setting up of the infrastructure and systems for implementation during this latency period for large volumes of end of life batteries to flow into the market.

The battery recycling market will be driven by the dominant cell chemistries in the market. Nickel, cobalt, lithium, copper and graphite are critical items for cell manufacturing. Cell chemistries will play a decisive role in sustainable lithium ion battery recycling. In India currently, lithium nickel manganese cobalt oxide (NMC) and lithium iron phosphate (LFP) chemistries dominate in the transport sector. Nickel and cobalt are high value metals. In the long run prices of these materials will vary especially lithium prices as that may reduce substantially.

A good recycling programme and a robust battery tracking system can also be leveraged to reduce the overall carbon footprint of the batteries and improve sustainability. Several methods and recycling technologies exist that need to inform the pathway for implementation in states. Recyclers are making several technology choices.

The emerging recycling industry would need to address both second life of batteries and recycling of end of life batteries. Second use will require assessment of degradation, scope of other applications, dis-assembly for applications and so forth. Second use helps to prolong the use of the existing batteries before they are recycled. This brings in more efficiency in the resource cycle.

This conversation around the implementation of battery recycling programmes in states has become necessary. While adequate steps will have to be taken to implement the Battery Waste Management Rules 2022 in states, several EV policies of the state governments have also provided for recycling of EV batteries. But not many have yet focussed on the strategies for implementation.

It is therefore necessary to understand the adequacy of the current EV recycling regulations at the national level, preparedness at the state level for implementation and also the role of the EV manufacturing industry in the recycling strategy.

While developing recycling strategy it may be noted that the global supply chain risks are expected to stay and given the geo-politics, may even worsen in the coming years. EV battery materials are sourced from some of the most politically unstable economies in the world, a fact that brings to light the intensity of supply chain risk and the need for alternatives. Among battery metals lithium is sourced from South America and Australia, while Nickel is sourced from Indonesia and Russia and Cobalt from the Democratic Republic of Congo in Africa.

India does not have much known reserves of raw materials like lithium and cobalt and not enough nickel and graphite to hedge against uncertainties in the battery supply chain. Nor does it have the refining capacity to produce battery grade materials to manufacture them. India will therefore be dependent on other nations in the absence of a robust policy and manufacturing eco-system and will be merely exchanging one type of energy security for another but with similar vulnerabilities.

The EV battery supply chain risks appear much more pronounced since 2022 after the Russian invasion of Ukraine tightened the supply of nickel, a key ingredient in the making of li-ion cell cathodes. This conflict has had economic consequences on battery component prices and will consequently impact the price of electric vehicles causing a potential delay in price parity that is important for EV adoption. Globally, the price pressure on critical battery raw materials could expand and battery input costs will likely increase by over USD7,000 for several popular models, according to global information services and consultancy firm S&P Global. This highlights the sector's vulnerability to geo-political events.

India, therefore, should push for recycling as an alternative source of battery raw materials as it has the potential to subsidize input costs for battery material sourced from the mines. In addition, access to battery material for manufacturing can trigger deep localisation in the supply chain and lead to fresh investments in the indigenous supply chain and larger economic benefits for industry.

Spent lithium ion batteries contain a significant amount of valuable metals, some with an even higher grade than the metal grade in natural ores. They usually contain 5–20 per cent cobalt (Co), 5–10 per cent nickel (Ni), 5–7 per cent lithium (Li), 5–10 per cent other metals (copper (Cu), aluminum (Al), iron (Fe), etc.), 15 per cent organic compounds, and 7 per cent plastic, although their compositions differ depending on the choice of chemistry according to the vehicle application it is meant to serve.

It is imperative therefore that India builds a concrete plan to address uncertainties in battery material sourcing with an alternative plan to offset potential tightening of the supply chain. The uncertainty in the battery metals market is not new. With battery metals, as with other metals in the mining industry, availability and price is a cyclical phenomenon. Large gaps in supply and demand can push up prices. Even before the Ukraine crisis started, battery metals experienced a fair amount of volatility driven by global electric vehicle demand. Prices of EV battery cathode metals nickel, cobalt and lithium prices increased by 37 per cent[5], 41 per cent[6] and 48 per cent[7], between February 2021 and February 2022.

India needs alternative sources of raw materials and those input feeds could be domestic, originating from recycled batteries. The question now is how can we bring back spent batteries into the mainstream?

From this perspective, the Centre for Science and Environment has carried out this rapid review of the existing policies and regulations related to EV battery recycling to identify the gaps in the current approaches and the steps forward. This review has also involved extensive engagement with the recycling industry to assess the strategy needed.

For EV battery recycling industry to grow it is necessary that the EV industry and market grows rapidly to create volumes.

Key highlights

India has taken the regulatory step towards laying down the foundation for recycling of EV batteries especially lithium ion chemistries in 2022. At the same time several state governments have provided for EV battery recycling in their respective EV policies.

The Battery Waste Management Rules 2022 have taken on board some critical aspects of battery management and recycling that if implemented well can build a robust recycling programme needed to enhance material security. Some of the key elements of this regulation are as follows.

- **Applies to all stakeholders** including every manufacturer, producer, collection centre, importer, re-conditioner, re-furbisher, dismantler, assembler, dealer, recycler, auctioneer, among others.

- **The Rules have set a target for 90 per cent recovery of the material** – 70 per cent **recovery by** 2024-25, 80 per cent by 2026, and 90 per cent recovery by 2026-27 onwards.

- **Mandatory collection targets:** As per the rules, an electric two-wheeler manufacturer has to meet a mandatory collection target of 70 per cent of batteries placed in the market in 2022-23 and has a seven-year compliance time frame starting 2026-27. From 2033-34 onwards to 2039-40, 80 per cent and above is needed. For electric three-wheeler manufacturers, it is 70 per cent of the vehicles placed in 2021-22 onwards. And for electric four-wheelers the compliance cycle is 70 per cent from 2029-30 till 2035-36.

- **Mandatory phase in targets have been set for using recycled material in new battery products to finally achieve 20 per cent by 2030-31.**

- **Introduced Extended Producer Responsibility (EPR) and defined the role of the producer.** This provides for transactable EPR certificates for producers for environmentally sound management of waste batteries based on the weight of battery processed, percentage fulfilment of material recovery targets for the specified year and geographical source of battery.

- **The EPR registration system is managed online on a centralised portal** controlled by the central and state pollution control boards.

- **Introduced Environmental Compensation (EC) based on polluters pay principle and for non-compliance with the provision of the rules.**

- **Regulating hazardous substances:** In manufacturing of electrical and electronic equipment. The Rules limit use of Lead, Mercury, Cadmium, to a residual level of a maximum concentration value of 0.1 per cent to 0.01 per cent.

- **Manufacturers need to file an annual record of their sales and buyback** and ensure the batteries collected are transported safely to the authorised/ registered recyclers.

What is missing in the current rules?

While the new rules promise to trigger a circular economy, the policy needs to be further modified to address a few critical gaps and to enable more efficient and effective recycling and material recovery and promote a circular economy. If implemented properly, this can become a platform to expand inputs to feedstock for cell manufacturing in the future. This will enhance material supply security and offer cost benefits.

Some of the key gaps in the current rules are as follows:

- **Rules do not address the labelling requirements of lithium ion batteries** – Prior knowledge of the battery chemistries that can vary widely and what has gone inside is critical for the recyclers for efficient disassembly, separation and recovery.

- **Rules need to promote eco-design for recycling and remanufacturing.** It should be possible to foresee at the design stage the implication of the assembly for recycling and employ corrective methods accordingly.

- **Rules need to provide for tracking of battery material used on the batteries.** This traceability is critical to reduce the carbon and environmental footprint of the batteries.

- **Need to establish regulatory standards for testing and classifying used batteries that have a second life** and could still be used in other applications such as in households or as energy backup[8].

- **Provide incentives for recycling capacity and facilities.** Recycling plants are capital intensive and will be operating at low capacity as the volume of end-of-life batteries are still very low at this early stages of the EV programme.

The economics of recycling are at odds: Lithium ion battery recycling units are highly capital intensive. Evidence shows that a lithium ion battery recycling unit with annual capacity of 18000 metric tonnes (MT) requires an investment of INR 220-370 crores while a 18000 MT lead acid plant costs Rs 4 crore[9]. Operating costs of a lithium ion battery recycling unit is about 17 times more. Also transportation of spent battery feedstock adds about 35-50 per cent to the purchase cost. Every batch of processed black mass and extracted salts need to be sampled at every stage and sampling equipment is expensive. The cost recovery is a challenge as the capacity utilisation of the plants take time.

The Indian battery recycling industry is expected to be in a position to expand into large recycling capacities by 2027-2030 timeframe. Business diversification becomes important mainly because of the upfront capital costs in setting up systems. Since most plants are starting out as pilots, the costs have to be managed at every stage.

Aligning recycling technology with the evolving battery chemistries: The battery recycling industry needs to be continuously aligned with the evolving cell technologies in the EV industry. A continuous shift in battery technologies could lead to stranded assets. While a case for standardised battery technology can be made to facilitate profitability for recyclers, it may also stifle innovation in upstream technologies. Therefore, efforts can be made for expanding recycling coverage in terms of types of batteries recycled and range of material to be recovered in order to augment capacity.

Need robust oversight and transparency for the recycling processes throughout the value chain. Several recyclers send material downstream for processing to vendors. The vendors and their processes need to be audited and qualified for EV battery material processing. Recycling plants will need to follow ESG norms even as recycling businesses work on maximising throughput, maximising the value of recovered materials and minimising cost and waste. Recyclers CSE spoke with have claimed to have productivity rates of 99 per cent with recovered materials.

Residual Value of Batteries: For reuse cases, a thorough analysis is needed on devising an accurate methodology for determining the residual value of an EV battery. The residual value is the price at which the battery goes for re-sale and depends entirely on the depreciation mechanism attributed to it.

Financing challenges: Even though EVs have such valuable metals embedded in them, they are facing issues with loan financing and insurance assessments because of a perceived deficit in resale value. Second life applications and recycling of batteries could change that with the help of a buy back scheme that could benefit other applications with lower performance requirements. Depending on the material content, lithium ion battery recycling could be a profitable operation

Address uncertainty in the recycling market: Recycling industry points out that due to slow growth in EV demand, absence of battery traceability mechanism (unique identification number or UIN) for battery placed in the market; Inadequate battery collection and logistics, dominance of unorganised supply chain have brought in a lot of demand uncertainty in the recycling market. This raises the input cost for the organized sector. Constant technology evolution is yet another challenge for standardization and recycling processes.

Tap the global learning curve to design policies, regulations, and strategies: Globally, countries are taking initiatives to strengthen the recycling industry and market. In China, battery recycling is heavily incentivised through financial and regulatory frameworks. California in the US is bringing about policy reforms for end-of-life reuse and recycling of batteries. The European Commission has introduced new reforms that seek a carbon footprint declaration for batteries sold in Europe starting 2024 through a digital tool called 'battery passport'. The China regulations are encouraging standardisation of battery design, production and verification to improve the assembly and dismantling of used batteries. This also makes a provision for repairing and repackaging for second life utilisation. Global research efforts are aiming to improve the process to make recycled lithium economically attractive. Countries are working towards Environmental, Social and Governance (ESG) and EPR commitments. The US states including California, New York and Minnesota, have banned landfilling of lithium-ion batteries to influence the recycling market. Japan has established a Producer Responsibility Organisation for collection of used batteries. There are many such efforts that provide the learning curve to build the recycling industry in India.

Way forward

This review reveals that there is an urgent requirement to promote closed-loop recycling, whereby spent batteries are collected and recycled directly, thus reducing energy use and waste by eliminating the mining process.

Revise the Battery Waste Management Rules 2022 to make battery labelling mandatory and transparent to provide all the critical information needed on battery composition, state of health, battery performance etc for efficient refurbishing and recycling. Develop proper guidelines for capturing the information and for making the information easily accessible to the recyclers.

Central Pollution Control Board and the State Pollution Control Boards need to establish effective and robust system for implementation of all rules related to the extended producer responsibility (EPR), environment compensation charge, targets and mandate for recycling and use of recycled material etc. It is necessary to pay attention and strictly regulate the issuance of EPR certificates.

Promote standardisation of lithium ion batteries to support efficient recycling: For the establishment of recycling centres, standardisation of the battery chemistry is needed, as well as standardised battery forms based on the application, to streamline the dismantling process. This need not compromise upstream innovations. Incentivise battery reuse and associated technologies and registration of producers for tracking of batteries in circulation and ensure they are recycled after their second use along with a repository for battery end-of-life configurations.

The Rules need to encourage responsible battery disposal through OEM service centres which could act as collection centres. It may also be possible to encourage development of national level not-for-profit battery collection schemes to formalise the channels for EV battery collection and proper disposal. It could be a common pool concept or a separate collection agency to streamline collection of batteries and recycling in formal smelters.

Introduce mechanism to track battery information like the battery passport initiative in the European Union. It will allow buyers to make more informed decisions about the batteries they purchase and make it easier to reuse and recycle. Tracking and studying of battery information will also improve safety, as it will include information on the battery's performance and any safety issues that have been identified.

Standardize state-of-health metrics to inform decisions on second-life applications. Globally this is being perceived as a good practice. [10]

Support R&D on recycling technologies and processes: Support research to develop of commercially viable recycling processes with a high recovery rate. Battery manufacturers can forge recycling partnerships as they deploy batteries in EVs to streamline operational processes for collection, testing and recycling.

Evaluate and promote a more efficient recycling process for maximum recovery of a wider range of materials. It is necessary to increase the recovery rates. This should be verifiable and measurable. While waste management rules have mandated targeted recovery of material, more element specific targets may maximise recovery of all battery materials.

Need favourable price differential for recycled material vis a vis virgin material: This is possible if the socio economic costs of mineral extraction can be internalised in the pricing of material. Recycled material should always be more competitive.

Strengthen safety standards for reuse and recycling that can also be crucial for reducing risks. Batteries contain hazardous materials that can harm the environment and human health if not handled carefully. For instance, all lithium-based batteries are safer at a lower charge, and this is why it is mandated that shipments of Li-ion should be transported at 30 per cent state-of-charge.

Encourage design for recycling practices in close collaboration with the battery manufacturers: This can institutionalise recovery rates from recycling processes in Battery Waste Management Rules; higher for matured technologies while working towards improved recovery from the newer upcoming technologies.

Incentives for manufacturers to meet recycling regulations: This can be in the form of green taxes etc to enforce EPR. This will help in attaining a higher recycling rate. The industry also requires to build a waste management budget and allocate funds for managing end of life batteries.

Globally, regulators are aiming to strengthen standards for battery durability, and safety to support and optimize reuse and recycling processes[11]. Mandatory battery durability requirements can incentivize the production of long-lasting batteries and support second-life usage.

Need more explicit environment guidelines and standards for the states to establish appropriate systems and infrastructure to minimise environmental impacts and promote seamless battery recycling. Disposal of batteries in landfill should be prohibited and made illegal and an effective mechanism be developed for batteries for proper disposal through recyclers.

Integrate informal sector with formal recyclers: It is possible to adopt innovative models for integration of informal systems with the formal recycling facilities for collection and transport. Currently, the formal sector making investments into recycling technologies find the competition from the informal sector and poor logistics of battery collection a challenge. This needs integration

Build consumer awareness regarding safe disposal of EV batteries. The Deposit Refund System mentioned in the rules can provide incentives to customers to return batteries thereby ensuring collection of batteries by the manufacturers.

Regulatory framework for recycling of EV batteries in India: Hits and misses

Even though several pieces of legislation have been issued from time to time to regulate electronic waste in India the recently released Battery Waste Management Rules 2022 by the The Ministry of Environment, Forest and Climate Change (MoEFCC) brings the electric vehicle batteries especially the lithium ion chemistries within the orbit of management and recycling.

These rules have replaced the E-waste (Management) Rules, 2016 and are effective from 1st April, 2023. The Battery Management Rules have a wider scope. This is technology agnostic and is directed at a wide range of stakeholders involved in manufacturing, import, processing, sale and purchase and end use of batteries or its components.

This has strong bearing on the recycling systems, infrastructures and business models for EV battery recycling in cities and states. As the city governments and the concerned departments including urban local bodies and state pollution control boards are beginning to implement these rules, it is necessary to understand what is required and identify the gaps that still need to be addressed for a robust programme.

Electric vehicle policies of several state governments have also provided for recycling of EV batteries. For example, Delhi's EV policy promotes reuse of EV batteries through private sector participation involving EV and battery manufactures and encourages establishment of recycling businesses. Punjab EV policy encourages automakers and private players to issue schemes to promote buyback of used battery packs. It also outlines the provisions for the creation of an e-marketplace to encourage resale of used batteries, establishment of recycling units, in addition to certain incentives to promote resale.

Similarly, Telangana EV policy intends to facilitate reuse of EV batteries in stationary energy storage applications and encourages collaborations between battery manufacturers, EV manufacturers, energy storage operators and recyclers. It is also one of the few states that provides incentives to battery recycling businesses for the mining of battery materials on par with EV and EV component manufacturing. As per the Uttar Pradesh EV policy large anchor and service units will be provided capital interest subsidy for setting up recycling centres. It will provide capital interest subsidy at 50 per cent per annum up to Rs 1 crore per year for 5 years on loans taken for procuring equipment and machinery for battery recycling. Madhya Pradesh EV policy enables energy operators and battery swapping operators to operate as end-of-life battery recycling agencies, where EV owners can deposit used vehicle batteries for a nominal remuneration. Batteries can then be sent for assessment for use as for instance, 'power banks' to store renewable energy.

The state action will have to be enabled and supported to implement the Battery Waste management Rules 2022. While the key elements of the rules and the requirements have been outlined in ANNEX 1, it is necessary to highlight and draw attention to some of the key elements that are expected to transform EV battery waste management. This needs guided implementation.

The scope of application: The new rules will be applicable to "every manufacturer, producer, collection centre, importer, re-conditioner, re-furbisher, dismantler, assembler, dealer, recycler, auctioneer, vehicle service centre, consumer and bulk consumers involved in manufacture, processing, sale, purchase, collection, storage, re-processing and use of batteries or components there of including their components, consumables and spare parts which make the product operational." The Rules deem battery waste hazardous and prohibits open burning and disposal of battery waste in landfills.

Collection of used batteries against new batteries sold, and issuance of purchase invoices (when used batteries are collected): The Rules have asked manufacturers to set up collection centres by themselves or jointly with a third party operator at various places for collecting used batteries from consumers and dealers. They will also have to make arrangements for safe transportation of old batteries from the collection centres to the authorised/registered recyclers.

Furthermore, manufacturers will also need to file an annual record of their sales and buyback to the State Pollution Control Boards by December 31 of every year. Establishing collection centres, at different venues for the collection of used batteries from dealers and consumers is necessary. They need to ensure safe collection and transportation of batteries to authorised/ registered recyclers.

Mandatory collection targets: An electric two-wheeler manufacturer has to meet a mandatory collection target of 70 per cent of batteries placed in the market in 2022-23 and has a seven-year compliance time frame starting 2026-27. From 2033-34 onwards to 2039-40, in a 7 year cycle, it will be 80 per cent and above.

For electric three-wheeler manufacturers, the meter starts earlier in 2021-22, according to their introduction into the market and their compliance cycle starts in 2024-25. It starts from 70 per cent of the vehicles placed in 2021-22 onwards.

Electric four-wheelers have a longer compliance cycle at 14 years. The compliance cycle is 70 per cent from 2029-30 till 2035-36 which is a 7 year cycle.

The Rules have set a target for 90 per cent recovery of the material – 70 per cent recovery by 2024-25, 80 per cent by 2026, and 90 per cent recovery by 2026-27 onwards. (see Table 1: Recovery target for battery material).

Mandatory collection targets: As per the rules, an electric two-wheeler manufacturer has to meet a mandatory collection target of 70 per cent of batteries placed in the market in 2022-23 and has a seven-year compliance time frame starting 2026-27. From 2033-34 onwards to 2039-40, 80 per cent and above is needed. For electric three-wheeler manufacturers, it is 70 per cent of the vehicles placed in 2021-22 onwards. And for electric four-wheelers the compliance cycle is 70 per cent from 2029-30 till 2035-36.

Targets of using recycled material in new products: The rules have set specific targets for using recycled materials in new cells. The producer is expected to include 5 per cent of recycled material in the total dry weight of a cell by 2027-28, expanding to 10, 15 and 20 per cent by 2030-31. In case of imported cells, the producer has to meet the obligation by getting the same amount of recycled materials utilised by other businesses or by exporting a similar amount of materials. The minimum use material target differs by sector with automotive and industrial sectors having the highest percentage of obligation at 35 per cent and closer deadline at 2024-25. (see Table 2: Recycled Material Target)

Table 1: Recovery target for battery material

Type of batteries	Recovery target for the year %		
	2024-25	2025-26	2026-2027 and onwards
Portable	70	80	90
Automotive	55	60	60
Industrial	55	60	60
Electric vehicles	70	80	90

Table 2: Recycled Material Target

Type of batteries	Recycled material mandate (%)			
	2027-28	2028-29	2029-2030	2030-2031
Portable	5	10	15	20
Electric vehicles	5	10	15	20
	2024-25	2025-26	2026-27	2027-28
Automotive	35	35	40	40
Industrial	35	35	40	40

Source: Battery Waste Management Rules 2022

Table 3: Targets for automotive batteries for market introduction

<table>
<tr><th>Compliance cycle</th><th>Year</th><th>Mandatory waste battery collection target and 100% of refurbishing/recycling of the collection target (weight)</th><th>Mandatory waste battery collection target and 100% of refurbishing/recycling of the collection target for every 5-year cycle (weight)</th></tr>
<tr><td rowspan="5">2022-23 till 2026-27 (5 year cycle)</td><td>2022-23</td><td>Minimum 30% of the quantity of batteries placed in the market in 2018-19</td><td rowspan="6">Collection of 100% of waste batteries and of 100% of refurbishment/recycling shall be mandatory by end of 5 year compliance cycle (and of 5th year) against the batteries placed in the market during the 5 year compliance cycle

There may be a carry forward of up to 10% of the average quantity of batteries placed in the market per year during the 5 year cycle to the next compliance cycle</td></tr>
<tr><td>2023-24</td><td>Minimum 50% of the quantity of batteries placed in the market in 2019-20</td></tr>
<tr><td>2024-25</td><td>Minimum 70% of the quantity of batteries placed in the market in 2020-21</td></tr>
<tr><td>2025-26</td><td>Minimum 90% of the quantity of batteries placed in the market in 2021-22</td></tr>
<tr><td>2026-27</td><td>Minimum 90% of the quantity of batteries placed in the market in 2022-23</td></tr>
<tr><td>2033-34 till 2039-40 (7 year cycle) and onwards</td><td>2027-28 and onwards</td><td>Minimum 80% of the quantity of batteries placed in the market in the preceding FY (2028-29)</td></tr>
</table>

There are mandates for specific quantum of recycled content in new automotive batteries, thus ensuring uptake of the recycling supply chain. The system deploys a second line of deterrence in which names of defaulting entities will be made public on the CPCB website. (see Table 3: Targets for automotive batteries for market introduction).

Extended producer Responsibility (EPR) and role of the producer: The Rules have provided for Extended Producer Responsibility (EPR) for the batteries to ensure the attainment of the recycling/refurbishing obligations. It is based on the concept of 'polluters pay' principle. The producers (including importers) of batteries are responsible for collection and recycling/refurbishment of waste batteries and use of recovered materials from waste into new batteries.

The Rules look to ensure safe and formalised recycling of batteries that are in use, with a focus on tracking batteries that have completed their useful life through online records and data management. The proposed rules will seek accountability to make sure that the batteries are recycled through formal channels. This requires transactable EPR certificates for producers for environmentally sound management of waste batteries.

The rules mandate manufacturers to ensure collection, disposal and recycling of the batteries. The manufacturer in this case can obtain EPR from Recyclers using the Central Pollution Control Board (CPCB) portal. The portal is a centralised system which enables the producer to engage a third party or recycler to collect and dispose waste and this exchange is regulated by exchange of EPR certificate between the producer and the recycler.

The parameters for the certificate include the weight of battery processed, percentage fulfilment of material recovery targets for the specified year and geographical source of battery. The current version of the battery waste rules covers electric vehicle batteries, as well as portable, automotive and industrial batteries.

EPR certificates are generated for recyclers and refurbishers based on quantities assigned. Recyclers/refurbishers can sell the assigned EPR certificates to producers in exchange of waste batteries through the portal. Surplus certificates in one category can only be used for offsetting carry forward and sale for the same category.

The factors taken into account for certificate generation include:
- Weight of batteries processed
- Percentage fulfilment of material recovery targets for the year
- Geographical source of batteries

The EPR registration system is managed online on a centralised portal controlled by the central and state pollution control boards. The registration process is expected to capture granular information regarding quantity, weight of batteries along with dry weight of battery materials. The Battery Waste Management Rules 2022 also suggests a deposit refund system or buy-back option for the producer to meet their EPR obligations. The producer is also expected to include 5 per cent of recovered material in the total dry weight of a battery by 2027-28, expanding to 20 per cent by 2030-31. The EPR certificate enables transactions and can be used by the recyclers/refurbishers to purchase waste batteries from producers.

Environmental Compensation (EC): The Rules have introduced the Environment Compensation Charge for non-compliance. The Central Pollution Control Board is required to lay down guidelines for imposition and collection of environmental compensation on the producer in case of non-fulfilment of obligations set out in the rules and transaction or use of false EPR certificate. Penalties would be applicable even for recyclers. Imposition and collection of EC from producers, refurbishers/ recyclers of waste batteries in case of non-fulfilment of EPR obligations.

With regard to collection and return of unfulfilled EPR obligations, these will be carried forward up to three years. In case the shortfall is addressed with these three years, the EC levied shall be returned in the following manner:

- Within 1 year of levying – 75 percent
- Within 2 years of levying – 60 percent
- Within 3 year of levying – 40 percent
- Within 4 year of levying – 0 percent

- **Regulating hazardous substances:** In manufacturing of electrical and electronic equipment. the Rules state that Lead, Mercury, Cadmium, Hexavalent Chromium, polybrominated biphenyls and polybrominated diphenyl ethers cannot be beyond a maximum concentration value of 0.1 per cent by weight in homogeneous materials for lead, mercury, hexavalent chromium, polybrominated biphenyls and polybrominated diphenyl ethers and 0.01 per cent by weight in homogeneous materials for cadmium. The Central Pollution Control Board is required to monitor and verify the compliance. If non-compliant, the producer needs to take corrective measures and withdraw or recall the product from the market.

Currently, the labels have to indicate limits on the use of heavy metals only — cadmium, mercury and lead — and also have a picture of a crossed-out bin to indicate that the batteries cannot be binned and have to be handed out to a registered battery collector. With traditional batteries that were based on lead-acid and nickel cadmium chemistries, this is a useful practice which informs the

Table 4: Environmental hazards of lithium ion batteries

Component	Materials	Hazardous
Cathode	$LiNiO_2$, $LiMn_2O_4$, $LiCoO_2$, $LiFePO_4$, $LiNi_xCo_yMn_{1-x-y}O_2$	Heavy metals such as Ni and Co pose a threat to the environment and to human health
Electrolyte	$LiClO_4$, $LiPF_6$, $LiBF_4$, DMSO, PC, and DEC	Corrosive, produces hazardous gas such as HF, chlorine (Cl_2), carbon dioxide (CO_2), and carbon monoxide (CO) when burned
Binder	Polyvinylidene fluoride (PVDF), polytetrafluoroethylene (PTFE)	Produces Hydrogen Fluoride when heated

Source: Science Direct[12]

recycling community about the need to plan for their management. It also ensures that the producer maintains limits on the quantum of heavy metals used. (See Table 4: Environmental hazards of Lithium ion batteries).

Refurbishing: The Rules have taken on board the hierarchical strategy for batteries that includes refurbishing or second use of batteries before end of life recycling of batteries. It is legally possible to re-use and repurpose batteries before recycling. Re-furbishers will also have similar responsibilities of registration, collection and transportation. On obtaining refurbishing certificates purchased from the registered re-furbishers, the extended producer responsibility of the producers can be "deferred by the duration as laid down by the Central Pollution Control Board for the corresponding quantity of e-waste and will be added to the extended producer responsibility of the producer upon expiry of the extended life of the refurbished product". To incentivise refurbishing, 75 per cent of the deferred quantity will be added to the extended producer responsibility of the producer for recycling upon expiry of the extended life of the refurbished product.

The recycling rules need a rejig to address gaps

While the new rules promise to trigger a circular economy, the policy needs to be further modified to address a few critical gaps and to enable more efficient and effective recycling. There is a need for a cradle-to-cradle trajectory for the electric vehicles and their batteries.

Battery Waste Management Rules 2022 do not address the labelling requirements of lithium ion batteries: The current requirements are only focussed on heavy metals and do not address issues with lithium-ion battery chemistries. Information about lithium chemistries used in the cells printed on the battery label can enable more efficient and easier recycling processes. Different materials require different kinds of treatment at the recycling stage. Lack of

CALIFORNIA: EV BATTERY LABELLING RULES

Appendix A-7 - Adopt Section 1962.6, title 13, California Code of Regulations, April 2022: labelling requirements.[13]

Key features of the rules

This section shall apply to 2026 and subsequent model year zero emission vehicles, plug-in hybrid electric vehicles, hybrid electric vehicles, and 48-volt hybrid electric vehicles certified for sale in California.

This applies to "traction battery" used to supply power to propel the vehicle.
All applicable vehicles shall be equipped with permanent labels. Manufacturer to provide Information on:

- Chemistry identifier designating the battery chemistry, cathode type, anode type, manufacturer, and date of manufacture in accordance with the current version of SAE J2984 "Chemical Identification of Transportation Batteries for Recycling" SEP 2021, (SAE J2984).
- For chemistries not included in SAE J2984, need approval of an alternative identifier from the Executive Officer.
- Nominal system voltage and cell voltage, based on life cycle testing standard SAE J2288 "Life Cycle Testing of Electric Vehicle Battery Modules", November 2020 (SAE J2288).
- Count of individual cells in the labelled unit;
- Rated capacity of the unit as measured under life cycle testing standard SAE J2288.
- A digital identifier, linked to a data repository website as specified.
- A manufacturer may utilize a common digital identifier, linked to a data repository website
- The label shall be attached to the exterior of the battery
- For batteries that are designed such that portions of the battery pack may be separately removed for service or repair, a label shall be attached to each portion (e.g., on each module for a pack with separately replaceable modules).
- The manufacturer
- Label Format is specified.
- The digital identifier on the label shall meet the MicroQR code requirements of ISO 18004:2015, "Information technology — Automatic identification and data capture techniques — QR Code bar code symbology specification", adopted February 2015
- Data Repository Website Requirements -- Vehicle manufacturers shall make available information related to the vehicle's traction battery
- Information on websites to provide information related to the vehicle's traction battery.
- All information required to be printed on the physical label.
- Manufacturers are required to list each unique date of manufacture, hazardous substances, product safety information or recall information, as applicable, and safe disposal information.
- Website access and maintenance.
- Use common, readily available software and provide hyperlinks to any plug-ins, viewers, or browsers needed to access or use the website;
- To be available at all times, except during times required for routine or emergency maintenance, and routine maintenance
- Ensure all information is up to date and accurate;
- All information required by this section must be maintained on the website required by this subsection for a minimum of 20 years after the vehicle is delivered for sale. After that the information must be retained and made available upon request
- Enforcement of Label and Data Repository Website. Executive Officer to approve the labels as per the rules. If the Executive Officer finds any manufacturer using labels that are different from those approved will require corrective action or recall of vehicles under California Code of Regulations (13, section 2109).
- The Executive Officer may audit a vehicle manufacturer's data repository website to verify.

information about chemistries would require the recycler to deploy additional resources to investigate the materials present in the spent battery feedstock before they can be processed.

The recycling framework needs to address the complex material composition of halogenic compounds such as fluorine, the battery's high energy content, requirements of high recycling rates as well as economics of the industry. This results in comparatively long and complex process chains in comparison to those used in earlier batteries (See Table 6: Opportunity mapping for various technical recycling processes).

Globally, good practices are emerging around labelling of the EV batteries. This learning curve needs to be tapped. California has come up with very comprehensive rules on EV battery labelling (see box: California: EV battery labelling rules). In the European Union, the regulation seek a carbon footprint declaration for batteries sold in Europe starting in 2024 through a digital tool called "battery passport". This is required for transparency and traceability along the full lifecycle of all batteries above 2 kWh via labelling and a digital identity. This mandates information related to the battery composition, capacity, durability, and environmental performance of the battery.

Promote eco-design for recycling and remanufacturing: Global experience shows that end-of-life management needs to be addressed at the product design stage. It is necessary to foresee dismantling and component separation requirements at this stage. This can help to replace or minimise use of components that make dismantling of batteries harder. This can also help to reduce waste generation. Cell chemistry is evolving continuously and may present challenges. For instance, literature shows that easy separation of parts make recycling economically viable and more attention to separable cooling system, reversible joining (nuts and bolts instead of welds), and avoidance of adhesive compounds to hold cells in place can contribute towards easy dismantling.[14] Different configurations for the installation of the battery pack are used. Standardisation of pack assembly can also enable robotic disassembly for lithium-ion batteries, and increase safe and efficient recycling. Removing and disassembling lithium-ion batteries is more expensive and time consuming than lead-acid batteries.

The Battery Waste Management Rules 2022 is intended to promote materials feed by building a stream of recycled battery materials for the new production cycle. To enable efficiency with dismantling and recycling, batteries need to be designed to be recycling friendly. The design objective in itself should lead to efficient and effective recycling processes.

If larger sustainability standards were built into battery waste management, the potential forex strengthening rules for design, production and disposal of batteries in India could improve multi-fold. It will be more holistic in practice and govern the entire product life cycle, from the design phase to end-of-life.

Incentivise recycling capacity in the country and streamline collection of batteries, even though EV policies at the state level mention government intent to encourage battery recycling activities. The 2022 Niti Aayog report has further stated that there is no explicit mention of incentives. Policy requires more explicit, detailed and separate focus to issue licences for handling only Lithium ion batteries, separate from electronic waste, and as such there is no reduced minimum requirement for entry into the recycling of LIBs.[15]

Address battery material tracking and carbon footprint: The new rules also miss out on using labels as an opportunity to reflect the battery's carbon footprint. This would make their environmental impact more transparent, especially if it covers the entire life of the battery as well as the percentage of recycled battery materials such as cobalt, lithium and nickel. Such a practice could have multipronged benefits. Using carbon footprint as a parameter for producer responsibility could trigger research and development activities upstream with lower footprint materials, possibly sourced from within the country.

Lithium-ion batteries have a very high carbon footprint as they have materials sourced from various parts of the world (South America and Australia for lithium, Congo for cobalt and Indonesia for nickel). Sourcing information can also ensure identification and avoidance of a supply chain with socio economic impacts. About 15 per cent of cobalt sourced from Congo comes from artisanal mines that often use under-aged labour. There is a need to make their environmental impact more transparent, especially if it covers the entire life of the cell as well as the percentage of recycled materials such as cobalt, lithium and nickel.

With such tracking regulation in place, battery manufacturers will have to conduct due diligence exercises to ensure compliance. However, such regulations could add to the cost of batteries. Versions of similar regulations have already initiated efforts globally for developing cobalt-free batteries with lithium iron phosphate and lithium titanate chemistries, according to the Cobalt Institute, a United Kingdom-based trade association of cobalt producers and recyclers.

Using carbon footprint as a parameter for producer responsibility could trigger research and development activities upstream with lower footprint materials, possibly sourced from within the country. If larger sustainability standards were built into battery waste management, the potential for strengthening rules for design, production and disposal of batteries in India could improve multifold. It will be more holistic in practice and govern the entire product life cycle, from the design phase to end-of-life.

Need regulatory standards for recycling: There is no provision for establishing any regulatory standards for testing and classifying used batteries that have a second life and could still be used in other applications such as in households or as energy backup. This has also been pointed out by the 2022 Niti Aayog report[16].

A system with loopholes, therefore, may perpetrate gaps and will fail to promote a circular economy. In addition it will disrupt the country's climate mitigation targets. However, if implemented right, it can become a platform to expand inputs to feedstock for cell manufacturing in the future. This will support future material supply security and offer cost benefits.

Understanding recycling of EV batteries

As cities/states are expected to set up and promote systems and infrastructure for recycling of EV batteries in line with the battery waste management rules, 2022, it is necessary to understand different aspects of recycling of EV batteries to guide action.

Lithium-ion batteries are the most common application in electric vehicles owing to their high energy density, high cycle life (number of charge-discharge cycles) and favourable discharge resistance. These fall in the category of secondary batteries that can be charged and discharged multiple times.

A typical lithium ion battery pack is made up of modules, which are combinations of cells. Each cell is composed of six key components: cathode, anode, electrolyte, current collectors and separator and casing. Although the casing, separators and electrolytes can be efficiently recycled, it is a substantial challenge to recover material from the electrodes containing the current collectors, anode, and cathode, which are the most economically valuable components. In comparison, the lead acid battery is simpler to dismantle. It is self-contained in one unit, not assembled into modules and packs, and it needs no disassembly prior to recycling.

Cathode is the positive electrode which is rich in Lithium. Electrons released by Lithium atoms travel from the positively charged cathode to the electron rich and negatively charged anode through the electrolyte medium. The metal is also used in the electrolyte in small concentrations to enable easier flow of ions. The electric motor powering the EV is connected as a load in the outer circuit.

The separator separates the positive and the negative electrode; it is made from a material capable of allowing ions and electrons to flow freely and prevents short circuiting that could be caused by direct contact between the anode and the cathode. (See box: How EV batteries work?)

Mechanics of recycling: At the cell level, there is no standard cell chemistry or form, nor is there a standard module or pack design. This means that there can be a variety of products on the market at the same time, which in turn complicates recycling. Key metals in lithium ion batteries include six primary metals: aluminium, nickel, copper, cobalt, iron, and lithium. The anode typically consists of copper foil covered by a fine layer of carbon while the cathode contains nickel, manganese, aluminium, cobalt, and lithium metals. Of these, cobalt and nickel are available in selected regions of the world.

To gain access to these metals, disassembling battery packs involves three steps. First, the batteries are discharged with a common salt solution, dismantled by removing the cells from the packs, followed by a thermal treatment process for the electrolyte, after which it goes through mechanical and chemical treatment to recover lithium and other components.

For end of life management, spent batteries are first tested for a second life and batteries that do not make the cut for a second use are sent for recycling. According to information available from Battery recycler and refurbisher Lohum, lithium ion battery recycling and extraction technology in India delivers 95 per cent[17] material yield, prevents up to 50 per cent CO2e (90 per cent via reuse), and consumes 500x less water than mining per ton. For reuse, it is necessary to determine the remaining useful life of the battery cells, understand accurate salvage prices of the metals contained within the battery and decide optimal second-life applications to maximise residual value.

Efficient lithium battery recycling: The complex nature of lithium ion batteries also points at the need for recycling friendly design of batteries. It is believed that about 80 per cent of a product's environmental impact is determined in the design stage when the choice of materials, construction and appearance are all finalized. Batteries should be easy to remove from products and easily disassembled into smaller parts. However, designing for circularity does not stop with products - it also involves designing business models that maximize the value of the raw materials used. This is how circular product flows can be aligned with conserving high-quality material contained in those products.

Battery packs are typically screwed, welded and have components glued together. The battery modules are often stuck together with adhesives. In practice, this does not make separation of hard-fused materials viable, thus making recycling the contents for the manufacture of new products much more complicated and expensive.

The solution to these challenges could be standardisation. Screw connections and conjunctions between modules for instance could be standardised in order to facilitate an automated disassembly of the cells. Materials could also be designed for easier end of life management. For example, water-based or alcohol soluble binder for electrode materials can reduce expensive, potentially toxic solvents during recycling. This would enable simple separation of the current collector from the active material without significant use of ancillary chemicals.

If cell design and chemistry were to be standardised, automotive cells will grow in volume share as more and more electric vehicles get sold and this will enable easier recycling streams of grade purity and value.

However, manufacturers have little economic incentive to modify existing protocols to incorporate recycling-friendly designs. But they could offer long term resource utilisation and environment benefits.

According to the Metal Recycling Association of India (MRAI), the recycling industry consumes less resources than mining, in terms of land, power consumed and logistics costs. It also has a much smaller carbon footprint, and less harmful by-products.

When metal is mined from ore, only 4-5 per cent[18] of it is useful metal while the rest has to be disposed of. In comparison, recycling and extraction requires less energy. Recycling uses 1/20th of the energy required for the same amount of metal as mining from ore.

How safe are lithium ion batteries

Lithium ion batteries are relatively less detrimental to the environment when compared to older batteries based on lead-acid or nickel-cadmium chemistries. The primary danger they pose is related to the high voltage electric charge that they can potentially contain, or the electrolyte which is flammable.

Regulation therefore needs to differentiate between high and low voltage batteries. The high voltage batteries used in vehicles and stationary and industrial energy storage applications are remarkably different from the lower voltage batteries used in consumer electronic devices. The difference in material content, manufacturing quality and safety hazards between the two needs to be defined better in order to regulate them differently.

That would ensure a difference in recycling, transport and storage aligned with public safety and can potentially reduce the cost of management compared to doing it together.

It is also important for a regulatory strategy that supports development of new recycling technologies. The government needs to support scientific work into new battery recycling technologies that have the potential to reduce or eliminate the negative cost of lithium-ion battery recycling.

It is imperative therefore for battery waste management policy to include binding legislation that will in turn influence cell design to enable improvements in recycling efficiency.

Recycling methods/ metal extraction processes

Lithium ion battery recycling is a challenging task due to the complex material composition of batteries and their electrical and chemical energy content that could pose health, safety, and environmental risks. The end of life of batteries works backwards from the building of the battery. The cells are assembled in modules which are then moulded in battery packs. Pulling it apart for end-of-life involves three steps.

First, the batteries are discharged with common a salt solution, dismantled by removing the cells from the packs, followed by a thermal treatment process for the electrolyte, after which it goes through mechanical and chemical treatment to recover lithium and other components. EV battery recycling research started around 2005[19] and over the years multiple EV battery recycling processes have developed which can be classified into two general process routes. The first set of processes combines pyrometallurgy with hydrometallurgy and the second set consists of mechanical treatment prior to metallurgy. In case of a pyrometallurgical treatment, a Cobalt, Copper, and Nickel-containing alloy or matte, a Manganese and Lithium containing slag, and fly ash are produced. Alloy/matte and slag can be treated by hydrometallurgy to recover the individual metals. The fly ash comprises elements such as fluorine that is usually disposed of in landfills.

In the second group of processes, lithium ion batteries are treated mechanically, often after thermal treatment. The mechanical process results in products that are ferrous and non-ferrous metal concentrates of copper as well as a fraction containing active electrode materials called black mass.

The black mass can be either treated with pyrometallurgy or directly with hydrometallurgy. Depending on the overall process design, the black mass requires thermal treatment prior to hydrometallurgy to remove the organic components and to concentrate the metal content. In hydrometallurgy, Cobalt, Lithium, Manganese, Nickel, and, if applicable, graphite can be recovered. (See Box: Recycling techniques)

RECYCLING TECHNIQUES

Pyrometallurgy: In battery mining, the metal extraction process remains crucial of all. Pyrometallurgy can also be termed as smelting, it is one of the crucial recycling processes that targets recovery of precious metals like cobalt, nickel, copper and manganese from the generated electronic waste. With this process, batteries are subjected to temperatures as high as 1100 degree Celsius to melt all elements to recover the precious metals. It is similar to mining metals from ore. The organic compound generated from the process gets oxidised and evaporates. The lithium and aluminium on other hand are generated as slag. The lithium and aluminium are further not extracted from here because the extraction process is cost intensive. In the recent past, this method has evolved as a preferred metal extraction process developed from used batteries.

Hydrometallurgy: Hydrometallurgy usually follows pyrometallurgy to extract metal alloys of aluminium, manganese, lithium etc. The process is also termed as leaching where metals are leached from the slag using acid base solution. The solutions differ according to the target metal to be extracted. The process generates fly ash and fluorine as slag. As of now, it is used in several large recycling plans in China, which is currently the largest EV market globally.

Biometallurgy: This process involves a biotechnological processes, which includes interaction between metals and microorganisms or metal bearing minerals[21].

Direct Recycling: This is a recycling process that regenerates degraded active particles of cathode in a lithium ion battery. Cathode is the most important component in a battery and is characterized by 4 to 5 types of active metals. The direct recycling process only consumes Lithium ion and keeps the cathode structure intact after mining it out from used batteries. It is a low cost alternative.

Globally China, South Korea and Japan are leaders in recycling Li-ion batteries. SungEel, South Korea's largest recycler, uses hydrometallurgy[20] to extract metals from li-ion batteries and has patented the process for the same. Anhua Taisen in China and Shenzhen Green eco-manufacturer (GEM) use hydrometallurgy for recycling li-ion batteries. Nippon recycling centre Corp in Japan uses a pyrometallurgical process to extract nickel and cobalt.

India needs lead time to build adequate infrastructure and capacity to recycle battery materials that are expected to grow over the next 10-15 years. According

Table 5: Li-ion battery recycling organisations in India

Organisation	Technology	Location	Capacity (MTA)
Tes- Amm	Mechanical & Hydro-metallurgy	Chennai	1200
Attero recycling	Electro & Hydro-metallurgy	Noida	5000
SungEEL HiMetal	Hydro-metallurgy	Anantpur, Andhra Pradesh	5000
E-Parisaraa	Mechanical	Bangalore	2000
EcoReco	Mechanical	Mumbai	1200
Eco Tantra	Mechanical	Pune	350
Eximo Recycling	Mechanical	Vadodara	1200
Surbine Recycling	Electro & Hydro-metallurgy	Jamnagar	1500
Lohum	Hydrometallurgy	Noida	10,000

Source: IESA Battery recycling whitepaper

Table 6 Opportunity mapping for various technical recycling processes

Recycling process	Strengths	Weakness	Opportunity	Threats
Pyrometallurgy	Simple and short procedure,	Lithium and manganese loss, high energy consumption, more waste gas and cost of waste gas treatment	Combine with hydrometallurgy for better results	Hazardous emission
Hydrometallurgy	Higher efficiency, better quality output can be recovered,	Complex procedure, there is need for pre-treatment, more wastewater, long process	No hazardous gas emission, no metal loss, all cathode metals can be recovered	High capital cost
Direct Recycling	Short recovery route, low energy consumption, environment friendly, high recovery rate	Incomplete recovery, high operational and equipment requirements	Reduce recovery costs, further optimise product performance	

to the available evidence, the current capacity stands at less than 30,000 tonnes (See Table 5 Li-ion battery recycling organisations in India). Formalization of the battery recycling market targets a larger competitive playing field for emerging businesses and pushes for the need for adopting safe recycling technologies. As per recent changes in the market, the Indian recycling market is leaning towards hydrometallurgy, given its success in Asian countries leading battery recycling. (see Table 6 Opportunity mapping for various technical recycling processes).

Innovate business models: The manufacturing, re-use, and recycling of batteries would lead to a circular economy where the manufacturers would either double up as recyclers or new entrants with the sole focus on recycling of batteries would enter the market. New business models providing better solutions are likely to emerge with time. One such model could be battery leasing wherein the battery is returned at the end of the lease period and the onus to repurpose and recycle lies with the manufacturer. Battery suppliers in India have already started selling with a buy-back option.

PRE-TREATMENT PROCESSES

In order to prevent short circuiting or spontaneous combustion, spent batteries are first discharged. A common method of discharging is to immerse the spent LIBs in a salt solution. Next, the spent LIBs are manually dismantled or components are separated mechanically. Manual dismantling involves separating the cathode, anode, and other components, as follows: The plastic shell of the battery is removed first; then liquid nitrogen is used to deactivate harmful substances.

The end of the battery shell is removed by a saw; the battery is then opened longitudinally and the outer shell is removed. Finally, the cathode, anode, and separator are collected and dried in an oven for 24 h at 60 °C. The obtained cathode and anode are further separated for the metal extraction process. The cathode material has Aluminum foil wrapped around it using the binder (polyvinylidene fluoride (PVDF) or polytetrafluoroethylene (PTFE)), making it difficult to separate. Several methods are used for separation, such as solvent dissolution method[22], sodium hydroxide (NaOH) dissolution method[23], ultrasonic-assisted separation[24], thermal treatment method[25], and mechanical method[26].

The **solvent dissolution method** is seen as recycling friendly as the organic solvent weakens the adhesion of the binder of cathode scraps to remove the cathode materials from the Aluminium foil. One of the most commonly used organic solvents is N-methyl pyrolidone (NMP). In another process, the anode and cathode are heated with an NMP solution below 100 °C. This method allows Lithium Cobalt Oxide ($LiCoO_2$) and graphite to be separated from the collector effectively, while Aluminum and Copper continue to be in metal form.

The only disadvantage with the solvent dissolution method is that the solvents used in the separation process prove to be expensive and have a certain degree of toxicity, thus posing a threat to the environment and human health.

In comparison, leaching the cathode with a Sodium Hydroxide (NaOH) solution can separate the Aluminium foil at room temperature by dissolving it. This method offers the advantage of being a simple operation with high separation efficiency. However, recovering Aluminium from the solvent is a challenge. In addition, the alkali wastewater (i.e., NaOH solution) is environmentally harmful.

Some recyclers use ultrasonic treatment along with mechanical agitation to strip cathode material from aluminium foil. This mechanism offers stripping efficiency of 99 per cent with NMP as the cleaning solution at 70 °C, 240 W ultrasonic power, and 90 min ultrasonic processing time. The cathode material thus separated has very few clumps, which facilitates subsequent leaching processes.

The thermal treatment method decomposes the binder reducing the adhesive force between the cathode material and the foil; the cathode materials can then be easily separated by sieving. It is reported that PVDF binder generally decomposes above 350 °C, while other compunds (e.g., acetylene black, conductive carbon, etc.) generally decompose above 600 °C.

Mechanical methods are recognized as effective pre-treatment processes to manage spent lithium batteries; these include sieving and crushing followed by magnetic separation. Crushed battery cells typically consist of three parts: an Aluminium-enriched fraction (> 2 mm), a Copper- and Aluminium-enriched fraction (0.25–2 mm), and a Cobalt and graphite enriched fraction (< 0.25 mm). The cathode materials obtained from the < 0.25 mm fraction retain their original crystalline structure and chemical state in LIBs. However, the surface of these powders is coated with a layer of hydrocarbons, leading to difficulty in the metal-leaching process that follows.

The main disadvantage with mechanical methods (See Table 5: Advantages and disadvantages of different pretreatment methods) is that the components of spent lithium ion batteries cannot be completely separated from each other; in addition, the decomposition of Lithium hexafluorophosphate (LiPF6), di-ethyl carbonate (DEC), and propylene carbonate (PC) during mechanical processes poses a threat to the environment.

Although many pretreatment methods have been developed by researchers, challenges still exist regarding pretreatment of spent lithium ion batteries (See Table 7: Advantages and disadvantages of different pretreatment methods).

Table 7: Advantages and disadvantages of different pre-treatment methods

Technology	Advantages	Disadvantages
Solvent dissolution	High separation efficiency	High cost of solvent, environmental hazards
NaOH dissolution	Simple operation, high separation efficiency	Difficulty in aluminum recovery, alkali wastewater emission
Ultrasonic-assisted separation	Simple operation, almost no exhaust emission	Noise pollution, high device investment
Thermal treatment	Simple operation, high throughput	High energy consumption, high device investment, poisonous gas emission
Mechanical methods	Simple and convenient operation	Poisonous gas emission, cannot separate all kind of components in spent LIBs completely

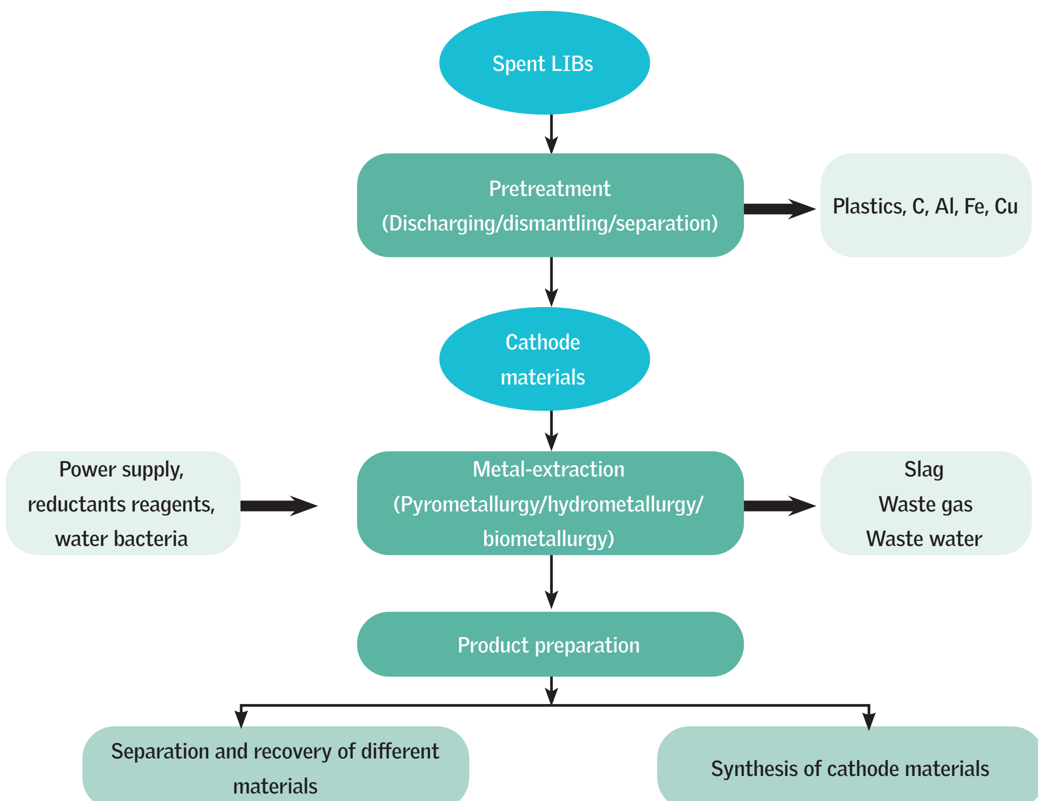
Recycling processes

Spent lithium ion batteries are first tested for a second life and batteries that do not make the cut for a second use are sent for recycling, which is a multi-stakeholder process. A number of recyclers in India are effectively pre-processors who can segregate the ferrous, nonferrous and black mass separately[27]. This involves discharging, module dismantling, incinerating and mechanical separation which results in a black mass.

The next level of recyclers process ferrous, non-ferrous and plastics components. With direct smelting, they get an alloy containing Cobalt and Nickel and a slag containing Lithium. Beyond the smelting recycler come the refiner and ultra-refiner. While the former can extract related salts, the latter can refine those salts and metals to cell grade powder and supply it directly to cathode manufacturers.

A review of existing literature shows the recovery of spent Lithium ion batteries is the main focus area with recycling valuable metals such as Cobalt, Lithium, and Nickel from cathode materials; the recovery of anode materials and electrolyte is rarely reported. State-of-the-art processes for metal recycling from spent Lithium ion batteries can be divided into three types, namely, pre-treatment, metal-extraction and product preparation processes. It is notable that the metal-extraction process plays an important role in the entire recovery process and involves one or both of the pyrometallurgical and the hydrometallurgical methods (see box on battery recycling methods).

Figure 1: Battery recycling



Source: https://www.sciencedirect.com/science/article/pii/S2095809917308226#b0050

Re-mining minerals from batteries

Like e-waste, vehicle batteries have historically been part of an informal sector in India. The informal sector employs thousands of households in urban areas to collect, sort, repair, refurbish, and dismantle disused electrical and electronic products. The popular recycling practice for middle-class urban households, particularly for waste paper, plastic, clothing, or metal, is to sell out to small-scale, informal sector buyers, and they further sort and sell these as an input material to artisanal or industrial processors.

Processes employed in managing e-waste will not work for lithium ion EV batteries. The informal sector resorts to manual sorting and extracting metals using methods such as open-air incineration and acid leaching, which are hazardous and exacerbate environmental pollution and health risks.

Conventional vehicles use batteries based on lead acid technologies that have relatively simpler chemistries and designs that make them simpler to recycle. In comparison, lithium ion batteries are much more complex to recycle because of the kind of chemistries used and their manufacturing process.

The hazardous nature of EV batteries warrants that they receive special attention. They have been known to cause fires, specifically in two wheelers, and have inspired the current safety regulations for EVs with the introduction of the AIS 156 covering L category vehicles (two- and three-wheelers and quadricycles).

Design of sustainable and environment friendly batteries for simpler waste management, recycling and disposal systems: It is believed that about 80 per cent of a product's environmental impact is determined in the design stage. At this stage, the choice of materials, construction and appearance are all finalized. Batteries should be easy to remove from products and easily disassembled into smaller parts. However, designing for circularity does not stop with products - it also involves designing business models that maximize the value of the raw materials used. This is how circular product flows can be aligned with conserving high-quality material contained in those products.

Recycling-friendly batteries have to be safe to handle and transport, simple to dismantle, cost-effective to manufacture and minimally harmful to the environment.

As mentioned earlier, recycling should start with a label. Lithium-ion batteries arriving at a recycling plant are typically without labels. Without information on content and design, it is not easy to disassemble or to sort the battery correctly. In such cases, batteries cannot be reused, recycled, refurbished or used for remanufacturing without undergoing an investigation and characterisation of what is contained within.

Battery packs are typically screwed, welded and have materials glued together. The battery modules are often stuck together with adhesives. In practice, this does not make separation of hard-fused materials viable, thus making recycling the contents for the manufacture of new products much more complicated and expensive.

A battery like this takes too long to extract, increases the risk of fire and creates challenging working conditions, as it has to be processed manually. Such design flaws could hinder recycling efficiency.

In comparison, lead acid batteries have relatively simple designs and chemistries that are easier to recycle. While the lead acid recycling process offers a benchmark for designing lithium ion battery disposal guidelines, multiple factors specific to lithium ion batteries can change the workflow.

First, collection of all e-waste continues to be a challenge. These batteries are part of e-waste that comprises mobile phones and laptops, articles that are either passed down to relatives or traded. As a result, quantum of batteries reaching recyclers through the formal sector is very low. Recycling processes are typically managed by scrap dealers in an informal sector. This involves backyard smelters that do not comply with pollution and environmental norms and therefore offer better value against used lead acid batteries. Therefore, authorised smelters do not receive enough batteries to justify economic viability of recycling operations.

In 2019, Toxic Links, Delhi based non-profit organisation, conducted a study and found that 90 per cent of lead acid batteries reach the informal recycling sector where they are recycled crudely and without any regulation, releasing toxins into the air, water and soil. The study was conducted across Rajasthan, Delhi, Jharkhand and Andhra Pradesh.

Therefore, for lithium ion batteries, it is important to build a waste management budget among producers. Some manufacturers allocate a budget for managing end of life batteries. But, it is a voluntary decision as budgets differ from manufacturer to manufacturer. It is imperative that a budget range is indicated for producers to follow for allocation and implementation.

Lithium ion batteries are much more complex than lead acid batteries which affects recyclability: An EV battery pack has multiple cells and each cell has six components: cathode, anode, electrolyte, separator, current collectors and casing. Although casing, electrolytes and separators can be efficiently recycled, it is a substantial challenge to recover material from the electrode unit containing the current collectors, anode, and cathode, which are the most economically valuable components in a cell.

In comparison, the lead acid battery is simpler to dismantle. It is self-contained in one unit, not assembled into modules and packs, it needs no disassembly prior to recycling. Each automotive battery weighs 12–21 kg of which lead is more than half the weight which make it economically worthwhile to recycle. The recycling process of a lead acid battery is a three step process: the case is crushed, allowing the sulphuric acid electrolyte to escape, and the lead electrodes are separated from the polypropylene casing and separated by virtue of their density. The lead is smelted and the polypropylene can be reused in new casings.

Employing the same process for lithium ion battery management is not possible, due to the more complex cell design and cell chemistry. That would not be the case, if the cell content and design were standardised. The lack of standardisation and the larger percentage of cells from small electronic devices means that initial recycling approaches will be more similar to solid municipal waste, producing lower purity tailing streams. If cell design and chemistry were to be standardised, automotive cells will grow in volume share as more and more electric vehicles get sold and this will enable easier recycling streams of higher purity and higher value.

With lithium ion batteries, the cathode and anode materials are typically coated on aluminium and copper foils, respectively. When recycled, the electrode (cathode and anode) materials and current collectors get mixed together, presenting challenges in separation. In addition, the process is not economically viable.

Recyclers use hydro and pyro metallurgical recovery of valuable metals in the lithium ion battery cell that offer the potential of reducing demand for mining and improving sustainability. Once recycled, battery component metals can be purified and reused in the production of new batteries. Over time this has the potential to reduce the mining requirement for raw materials by millions of tons. The ability to mine battery grade materials through recycling can enable countries such as India that do not have natural reserves of cobalt, lithium or nickel to mitigate supply chain risk. However, the process involves huge costs[28] and produces substantial amounts of environment unfriendly waste materials.

The additional cost of recycling to the battery's lifecycle poses the danger of shrinking demand for electric vehicles and, in turn, emission reduction efforts. The positive attributes of vehicle electrification will be undermined if one of the consequences of vehicle electrification is that millions of tons of used lithium-ion batteries end up in landfills or by the side of the road.

Therefore, any effort to mandate the recycling of lithium ion batteries will require a strategy that will avoid burdening end-consumers of EVs with the social and environmental cost of recycling. As part of the EPR strategy, EV manufacturers have to tie up with recyclers to create a disposal pipeline for their EV batteries. Contracts to buy the materials back from recyclers or open markets for these recycled metals would close the loop on the intended circular economy of EVs. Ideally, recycling-friendly batteries should be safe to handle and transport, simple to dismantle, cost-effective to manufacture and minimally harmful to the environment.

Recycling requires a mandate for labelling: To make that possible, the easiest way would be to provide the recyclers with information on the content and design of the batteries. Often lithium-ion batteries arrive at the recycling plant with little or no information on them. That makes disassembly very difficult. If the battery is not easy to dismantle, it is often impossible to sort the battery correctly. In such cases, these batteries cannot be reused, recycled, refurbished or used for remanufacturing without undergoing a complicated process of investigation and characterisation of what is contained within.

Most battery packs contain no information about the chemistry of the anode, cathode or electrolyte, meaning that cells from different packs need to be dealt with by the same process. To make that possible, the easiest way would be to provide the recycler with information on the content and design of the batteries. Most battery packs contain no information about the chemistry of the anode, cathode or electrolyte, meaning that cells from different packs need to be dealt with by the same process. The producer therefore needs to mandatorily provide a label with information about battery materials contained in those batteries to enable easier recycling.

It is therefore important for batteries to have a 'hazmat' or hazardous material label, as well as a compositional label for easy identification. Improved battery labelling would enable different battery chemistries to be separated before processing and would prevent contamination between two chemistries (NMC and LFP).

The issues of labelling are beginning to be addressed globally, with the Society of Automobile Engineers (SAE International)[29] recently recommending a labelling scheme, and the Chinese government also considering mandating labelling of lithium ion batteries.

One of the main issues is the way in which the cells, modules and packs are assembled. The cells are often hermetically[1] sealed and the modules and packs are often glued together with adhesives. While this provides rigidity, its end of life treatment has to include molecular organic solvents. This precludes disassembly as a viable recycling method due to the time and solvent requirements. The assembly of packs and modules is probably the largest barrier to disassembly and hence efficient cell dismantling and recycling.

While the disassembly approach is more successful at recovering more material, and in a purer state, this is naturally at the cost of the speed at which material can be processed – which is limited by the pack, module and cell opening. The structures are clearly established for safety and potentially cell longevity, but at the expense of recycling efficiency.

It's therefore necessary for battery waste management policy to include binding legislation that will in turn influence cell design to enable improvements in recycling efficiency.

Promoting the most efficient recycling process

The aim of any recycling process is to divide the constituents of a device into chemically pure, distinct phases. Separation of components in a mixture depends upon a difference in the properties of the components which can be utilised to bring about a separation. These differences include size, density, wettability, magnetism, redox behaviour, surface charge, solubility, appearance, phase change, adsorption and combustion. The ability to bring about a separation depends upon the relative affinity of the components to the property being distinguished.

For lead acid batteries, the separation is based on density and, given that lead and polypropylene have values of 11.3 and 0.9 g cm^{-3}, separation is simple. Carrying out the same exercise with lithium ion batteries is not possible due to the dissimilarities in density between the cathode materials and current collectors. Accordingly, separation is based on a variety of steps including redox, solubility, electrostatic and magnetic properties.

1 A hermetically sealed container or space is so tightly closed that no air can leave or enter it.

The materials used in a lithium ion battery make recycling inefficient. Certain active materials such as lithium iron phosphate (LFP) have a lower intrinsic material value compared to lithium nickel cobalt manganese oxide (NCM). The profitability of recycling such materials is therefore reduced.

One approach to address existing and new challenges is to standardise screw connections and conjunctions between modules or cells in order to facilitate an automated disassembly of the cells. Moreover, the approach includes the design of materials. For example, water-based or alcohol soluble binder for electrode materials can reduce expensive, potentially toxic solvents during recycling. This would enable simple separation of the current collector from the active material without significant use of ancillary chemicals[30].

Another possibility is direct recycling. In this process, active materials, mainly from the cathode, are reactivated after use by relithiation for direct assembly in new cells -- without a complete resynthesis of the materials having to take place.

Manufacturers have little economic incentive to modify existing protocols to incorporate recycling-friendly designs. But recycling could offer long term resource utilisation and environment benefits.

According to the Metal Recycling Association of India (MRAI), the recycling industry consumes less resources than mining, in terms of land, power consumed and logistics costs. It also has a much smaller carbon footprint, and less harmful by-products.

When metal is mined from ore, only 4-5 per cent[31] of it is useful metal while the rest has to be disposed. The energy requirement to produce the same amount of metal is huge. In comparison, recycling uses 1/20th of the energy for the same amount of metal.

Lithium ion batteries are relatively less detrimental to the environment when compared to older batteries based on lead-acid or nickel-cadmium chemistries. The primary danger they pose is related to the high voltage electric charge that they can potentially contain. A used lithium-ion automotive battery lying in a junkyard or by the side of a road poses a direct threat to human health and safety because of its high voltage electric current. ‘Stranded energy’ may seem like an insignificant impact of this mode of disposal, but it has real economic impacts in terms of opportunity cost.

Regulation therefore needs to differentiate between high and low voltage batteries. The high voltage batteries used in vehicles and stationary and industrial energy storage applications are remarkably different from the lower voltage batteries used in consumer electronic devices. The difference in material content, manufacturing quality and safety hazards between the two needs to be defined better in order to regulate them differently. That would ensure a difference in recycling, transport and storage aligned with public safety and can potentially reduce the cost of management compared to doing it together.

Integrate informal sector with formal recyclers: A vast majority (around 95 per cent) of Waste from Electrical and Electronic Equipment (WEEE or e-waste) in India is managed informally. Poor working conditions and crude techniques for dismantling and recycling within the informal sector have an adverse effect on the environment and the physical well-being of thousands of people. One approach to preventing more harmful effects from occurring is to integrate actors from the informal economy into formal e-waste value chains (e.g. by linking informal collectors to authorised recyclers).

Despite the challenges, the existing informal sector is highly effective in collecting electrical and electronic goods at the end of life. Due to its strong networks based on long-standing personal relationships, the extent of manual labour involved and its knowledge about local e-waste flows, the informal sector needs to be harnessed by producers to fulfil their obligations under the current policy regime. Hence, building a socially and environmentally acceptable e-waste management system in India requires extensive involvement of the informal sector. The EV battery recycling policy should therefore address the formal-informal partnerships and build tools for long-term cooperation.

WHAT CONSTITUTES AN EV BATTERY?

Battery cells come in different shapes and sizes, but most have six key components: cathode, anode, current collectors, electrolyte, separator and casing. Cathode is the positive electrode which is rich in Lithium. It is made up of a Lithium metal salt. Lithium ions travel from the positively charged cathode to the electron rich and negatively charged anode through the electrolyte medium. Lithium metal is also used in the electrolyte in small concentrations to enable easier flow of ions. This flow of ions from cathode to anode happens during charging. During the discharge process, electrons flow from anode to cathode through the outer circuit and Lithium ions flow from anode back to the cathode. The electric motor that powers the EV is connected as a load in the outer circuit.

The separator separates the positive electrode and negative electrode and prevents short circuiting that may be caused due to direct contact between the two electrodes.

At the cell level, there is no standard cell chemistry or form, nor is there a standard module or pack design. This means that there can be a variety of products on the market at the same time, which in turn complicates recycling.

These cells are combined together to create modules which are in turn packaged together into a specially designed housing with electrical connections and a battery management system to form the battery pack. An automotive battery pack could be both large and complex depending on its design. Pack design can be an important area of innovation to ensure dismantling and recycling friendly batteries.

In general, batteries can be classified into two categories:

- Primary batteries, commonly known as single-use batteries and are not rechargeable
- Secondary batteries can be charged and recharged

Lithium-ion batteries belong to the second category. Over the years, the demand for lithium-ion batteries has increased across various sectors, including telecommunications, mobile phones, and electric vehicles (EVs). Demand is attributed to the benefits these batteries have over other types because of the high energy density they offer making them apt for EVs. These batteries also have the capability to withstand a high number of regeneration cycles and temperatures, offering high voltage – upwards of 3.60 per cell -- and favourable discharge resistance.

EV Battery Materials

Key metals in lithium ion batteries include five primary metals: aluminium, copper, cobalt, iron, and lithium. The anode typically consists of copper foil covered by a fine layer of carbon while the cathode contains nickel, manganese, aluminium, cobalt, and lithium metals. Of these, cobalt and nickel are available in selected regions of the world.

The battery chemistries currently used to power EVs are Lithium Cobalt Oxide (LCO), Lithium Nickel Manganese Cobalt Oxide (NMC), Lithium Nickel Cobalt Aluminium (NCA), Lithium Iron Phosphate (LFP) and Lithium Manganese Oxide (LMO). LCOs are commonly used in portable electronic devices while NMC and LFP are the most common type used to power EVs. Since LFPs offer durability, higher safety features and wide temperature range of operation, they have been popular with bus battery applications.

The key battery components that have the biggest influence on recycling are the cathode, anode, electrolyte, and separator.

Cathode or the **Positive Electrode** consists of the active material, which is coated on the current collector foil usually made of Aluminum. In most cases, polyvinylidene fluoride (PVDF) is used as binder. The active material has to be able to deintercalate or move Lithium ions into or out of the cell during charge-discharge cycles. There are three different types of commonly used cathode active materials. (See Table: Properties of commercial available cathode active materials)

Table 8: Properties of commercial available cathode active materials

Cathode active material	Reversible Capacity [Ah/Kg]	Specific Energy [Wh/Kg]	Advantages	Disadvantages
LCO ($LiCoO_2$)	150	624	Specific energy	Safety, stability and costs
NMC ($LiNi_xMn_yCo_zO_2$)	160–200	592–740	Reversible capacity	Capacity fade
NCA ($LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$)	200	740	Stability	Safety, costs
LMO ($LiMn_2O_4$)	120	410	Costs	Stability
LFP ($LiFePO_4$)	160	544	Costs, safety	Specific energy

Source: https://www.mdpi.com/2075-4701/10/8/1107

For optimized specific and reversible capacity and a higher thermal stability in NMC cathodes, the ratio of metals used have evolved from a ratio of 1:1:1 to 8:1:1 which is a nickel rich composition and is used by manufacturers in high performance applications such as cars. In contrast, buses use LFP batteries and this is expected to account for the larger flow of volumes of used batteries into the recycling sector.

In the Anode or the Negative Electrode, the current collector foil consists of Copper and the active material is graphite in most cases. Typically, styrene–butadiene rubber (SBR) is used as binder in combination with the polymeric thickener carboxymethyl cellulose (CMC). Consumer applications use natural graphite because of the metal's reliability and affordability. For high-energy or high-power applications, artificial graphite is used and some manufacturers combine the two to leverage both their benefits. A limited but increasing number of cell producers include small fractions of about 5 per cent silicon (Si) or Silicon dioxide (SiO_2) to increase cell energy in their anode active material. Further, in some high-power applications, lithium titanate (LTO) is used as anode active material with Aluminum current collector foil instead of Copper.

Electrolytes consist of the conducting salt, solvents, and additives in order to provide high and stable conductivity at a defined safety level. The conducting salt in most batteries are Lithium perchlorate ($LiClO_4$), Lithium hexafluorophosphate ($LiPF_6$) and Lithium tetrafluoroborate ($LiBF_4$). $LiPF_6$ is, in fact, one of the most common solutes used in lithium ion batteries. Organic solvents that are used include dimethyl sulfoxide (DMSO), ethylene carbonate (EC), propylene carbonate (PC), diethyl carbonate (DEC) and ethyl methyl carbonate (EMC) and the solvent solutions are often mixtures of one or more of the reagents listed above, depending on the application the battery is used for.

Separators divide the space between the electrodes and the electrolyte and are only permeable for ions. They are usually a single or multiple layers of polyethylene (PE) or polypropylene (PP). There are four different separator types: microporous membranes, ceramic-coated separators, non-woven mats, and solid inorganic and polymeric electrolytes. Polyolefin-based membranes with ceramic coatings currently dominate the market for separators.

As battery technology improves, recycling plants of future lithium ion batteries require effective planning that incorporates knowledge about new developments in battery technology. Most of the development in NMC cathodes is focused on improving materials to generate higher capacity (spherical NMC particles with Nickel rich core) and stability (Manganese-rich shell). In addition, there is a growing interest in LFP chemistries due to their low raw material costs and intrinsic safety. The battery development community is working with Lithium and Manganese-rich oxides to leverage their high theoretical specific capacity and low costs.

With anode materials, the trend is moving towards expanding either the quantum of Silicon in the negative electrode to almost 40 per cent or use tin (Sn). Silicon, however, is not without its own issues. During charge and discharge cycles, silicon can undergo drastic expansion and contraction stressing the electrode, which could lead to a rupture. Battery developers have worked out risk mitigation strategies to address these features of silicon. Lithium metal is a promising anode active material, especially for solid-state batteries. With electrolytes, solid electrolytes that combine the functions of the separator and the electrolyte may gain importance in the longer term future.

Economics of recycling

Lithium ion battery recycling is a capital intensive process. The CSE review finds that difference between capital expenditure required to set up a traditional lead acid battery recycling plant and a lithium ion one is in the order of over 50 times.

Studies show a lithium ion battery recycling unit with annual capacity of 18000 metric tonnes (MT) requires an investment of INR 220-370 crores while similar capacity lead acid plant costs Rs 4 crore[32]. At the unit level, while lead acid battery recycling costs Rs 7/kg, lithium ion recycling costs between Rs 100-150/kg. Operating costs of a lithium ion battery recycling unit is about 17 times as compared to lead acid battery recycling, according to industry insiders.

A lithium ion battery recycling plant with an annual capacity of 10,000 tons requires an investment of about Rs 15-20 crores for hydrometallurgy processes and Rs 250-300 crores for pyrometallurgy (see Table 9: Difference in cost of setting up a recycling plant). The high energy consumption (in the region of about 1000 kWh) in a lithium battery facility captures a substantial percentage of cost of setting up a lithium battery recycling plant.

Apart from the equipment costs, transportation of feedstock is also an area that requires intervention, as it adds about 35-50 per cent to purchase cost of about Rs 200/kg. For example, transporting used EV batteries over long distances to recycling centers would typically be done by truck. Lithium batteries must be packaged and shipped according to the hazardous material regulations. This requirement increases transport costs to more than 50 times[33] time than that of regular cargo if all rules are followed.

Capacity utilisation of the hydrometallurgical power plant or pyrometallurgical plant starts at 50 per cent utilisation and takes about 3-5 years to reach 70-80-90 per cent. The annual cost involved in the operation of the plant (OPEX) is estimated at around USD 5.25 million[34].

The cost of recycling a lithium-ion battery in India ranges between Rs 100-120/kWh, according to a SIAM estimate. To put this in perspective, a Chinese battery pack for an e-rickshaw of 3.9 kWh costs Rs 65,000 and weighs about 25 kg.[35]

Table 9: Difference in cost of setting up a recycling plant

Capital cost	Amount
Lithium ion (18000 MTA annual capacity)	Rs 220-370 crores
Lead acid (18000 MTA annual capacity)	Rs 4 crores
Operating cost	Amount
Cost of li-ion recycling	Rs 100-150/kg
Cost of lead acid battery recycling	Rs 7/kg

Source: ICRIER

A typical lead acid battery recycling unit in India has annual capacity of 1000 to 18000 MT while lithium ion battery recycler capacity is about 1800 MT (See Table 7: Difference in cost of setting up a recycling plant).

Considering the difference in capital cost required to set up a traditional lead acid battery recycling plant and a lithium ion one, the lithium ion battery recycling industry requires policy support with implementation tools and access to capital.

For a cost effective operation, therefore lithium ion facilities require scale. Since the sector is still in a nascent stage, end of life batteries will take from 7-10 years to arrive in the end of life battery market. The dearth of used EV battery volumes in India could have been a deterrent for investment in the sector to build capacity, but that is now mitigated by easy access to imported end of life EV batteries.

The high energy consumption (in the region of about 1000 kWh) in a lithium battery recycling facility captures a substantial percentage of cost of setting it up. Apart from access to capital, the most evident reason for slow emergence of EV battery recycling industry is lack of scale in waste generation. EV sales are still picking up and there are not as many batteries to recycle. Clearly, the lithium-ion battery recycling industry requires policy support with implementation tools and access to capital.

In this respect, EV battery ecosystem could take lessons from the lead acid battery resale market to become viable. One of the biggest challenges to be addressed is collection of the batteries. Once the supply-demand dynamics are worked out, the economics can change depending on the contract.

Options that can be explored include i) recycler/refurbisher could get material for free or pay for it; ii) they could get into a tolling contract in which the automaker pays the recycler by the metric ton of batteries or material that they process and return.

Table 10: Cost Estimate EV Battery Recycling Plant with 5,000 MT capacity

Hydrometallurgical Process
List of capital equipment - approx cost – USD 5.0m
Installation and construction cost - USD 1m
Technology acquiring cost - USD 2 m (indigenous technology)
R&D and testing laboratory set up cost - USD 0.5m
Sampling costs
Land
Other Associated cost fixed in nature

Source: Exigo Recycling Pvt Ltd

It is necessary to implement such contracts in conjunction with open battery passports to make end of life management a smoother process. Ideally, recycling-friendly batteries should be safe to handle and transport, simple to dismantle, cost-effective to manufacture and minimally harmful to the environment.

The Indian battery recycling industry is expected to be in a position to expand into large recycling capacities by 2027-2030 timeframe. Business diversification becomes meaningful mainly because of the upfront capital costs in setting up systems.

An ultra-refiner of battery grade materials, for instance, would have capex requirement of about USD10-20 million. A battery recycling plant with annual capacity of 5000 metric tonnes will require about USD5 million for capital equipment, and the cost of acquiring recycling technology will be USD2 million or 40 per cent of the initial spend on equipment (See Table 10: Cost Estimate EV Battery Recycling Plant with 5,000 MT capacity).

India could instead develop indigenous technology that could be cost effective for Indian recyclers. For that, the Indian battery recycling policy needs to incentivise research and development of technology. A number of methods currently continue to be at laboratory scale. Industrial scale recycling is still rare. Considering the level of refinement required to achieve high grade powders that can be used to build LIBs and the lack of scale operations, equipment costs are still prohibitively expensive. Globally too, there are not many LIB recyclers.

Since most plants are starting out as pilots, the costs have to be managed at every stage. For instance, every batch of processed black mass and extracted salts need to be sampled at every stage and sampling equipment is expensive.

Aligning recycling technology with the evolving battery chemistries

On an average, recycling companies process about three types of lithium ion batteries[36] in India. This implies that the lithium ion recycling industry needs to be continuously aligned with the evolving battery technologies and a shift in battery technologies could lead to stranded assets. While a case for standardised battery technology can be made to facilitate profitability for recyclers, it would also stifle innovation in upstream technologies. Therefore, efforts can be made for expanding recycling coverage in terms of types of batteries recycled in order to augment capacity.

In the next 5-7 years in India, the volume requirement will be much lower, so plants with large capacity will not be viable. Indian refiners have an option to either work at scale gradually or diversify their customer base across industries such as ceramics, paints along with automotive as well as across geographies to become viable. This could be a business positive strategy for recycling companies especially since used battery volumes at the moment cannot sustain profitability.

The recycling process needs to be transparent throughout the value chain. Several recyclers send material downstream for processing to vendors. The vendors and their processes need to be audited and qualified for EV battery material processing. Recycling plants will need to follow Environmental, Social and Governance (ESG) norms even as recycling businesses work on maximising throughput, maximising the value of recovered materials and minimising cost and waste. Recyclers CSE spoke with have claimed to have productivity rates of 99 per cent with recovered materials.

Depending on the material content, lithium ion battery recycling could be a profitable operation: This is likely to happen if the battery contains ample quantum of cobalt and nickel. The price of cobalt has witnessed a massive growth[37] between December 2014 and October 2021 pushed mainly by demand in the electric vehicles. Cobalt is the costliest, with demand for cobalt rising at a rate of 3-4 per cent every year since 2010. After hitting near-decade highs in cobalt prices in early 2018 almost reaching USD100,000 per tonne, prices for cobalt used in the global electric battery supply chain slipped down by 45 per cent over the following 2 years because of surplus production and less than expected demand for EVs. But going forward use of cobalt is likely to decrease.

Nickel and lithium too experienced a similar trajectory in prices. The price of Lithium Carbonate, the material used in making EV battery cathodes peaked at

USD17,000 in 2018, while battery grade nickel witnessed a gradual rise since 2016 and was at USD 16,000 per tonne in 2019.[38]

However, recycling should be designed to extract and recover all the possible material and not be unduly focussed on a limited range of material.

The price variation of different metals impacts various chemistries of lithium-ion batteries: EV manufacturers usually use nickel-cobalt-aluminium (NCA) or nickel-manganese-cobalt (NMC) batteries on passenger vehicles because of their higher energy density, which is significant in determining the range of the vehicle, or how far an EV can drive on a single charge.

The cost of materials in an EV battery account for almost 50 per cent of its value. Now when recycled metals start to get introduced into the feedstock for batteries, the input feed is expected to be lower than that of metals sourced from mine output. But this will also require favourable taxation policy to promote recycled material.

Financing challenges: Even though EVs have such valuable metals embedded in them, ironically, they are facing issues with loan financing and insurance assessments because of a perceived deficit in resale value. Second life applications and recycling of batteries could change that reputation with the help of a buy back scheme that could benefit a vehicle with lower performance requirements.

Residual Value of Batteries

For reuse cases, a thorough analysis is needed on devising an accurate methodology for determining the residual value of an EV battery. The residual value is the price at which the battery goes for re-sale and depends entirely on the depreciation mechanism attributed to it. According to a 2017 report by Moody's Analytics[39], electric vehicles depreciate more or less the same as conventional vehicles in the first couple of years, and increase depreciation value in years three and four. The residual value of a vehicle (which includes the battery) is estimated by automakers and finance providers to write lease contracts, decide on insurance premium as well as vehicle loan products. At the institutional level, the residual value of an EV battery defines the basis on which they sign contracts with manufacturers to take charge of EOL batteries.

Efforts at evaluation of resale or residual value of EVs and consequently their batteries since they form about 40-50 per cent of the total cost of the vehicle is a move in the right direction. A consumer survey by Deloitte whose results were published in January 2023 reveals that 63 per cent[40] of respondents were concerned about the residual value of EVs.

Like a car, a battery is a depreciating asset. Its residual value can be estimated from its refurbishing value and/or its recovery value after recycling. Typically it is calculated on the basis of is the percentage of the original battery capacity that remains after a certain number of years of use.

Batteries are typically sold after refurbishment if they have 70-80 per cent of usable life left and if not, they are mined for battery metals that may then be used for fresh assembling of new batteries. The price of the battery components at the end of its lifetime defines its residual value.

Residual value is a very important consideration while calculating the Total Cost of Ownership (TCO) of a vehicle. The TCO examines all potential costs, including depreciation, financing, fuel costs, insurance, maintenance and repairs, and taxes and fees. This method provides a cost comparison between vehicles with various characteristics, including those with different drive systems or powertrains. TCO studies have found that depreciation is the largest cost component, especially in the first few years of the vehicle's life.[41]

Since most car buyers do not own the vehicle for the entire lifetime, depreciation becomes an important consideration in the new vehicle's TCO.

Depreciation is defined as the difference between the price of a new vehicle and its residual value after a given time. While new vehicle prices are easy to understand using manufacturer suggested retail price (MSRP) or dealer listing prices, residual values are slightly more complex and therefore less understood, especially for new technology vehicles. Therefore, it is important to understand how vehicles running on new technologies such as batteries and motors retain their value and how they compare with conventional vehicles running on ICE technologies. According to a 2017 report by Moody's Analytics, electric vehicles depreciate more or less the same as conventional vehicles in the first couple of years, and increase depreciation value in years three and four[42].

The residual value of a vehicle (which includes the battery) is estimated by automakers and finance providers to write lease contracts, decide on insurance premium as well as vehicle loan products.

At the institutional level, the residual value of an EV battery defines the basis on which they sign contracts with manufacturers to take charge of EOL batteries.

Typically, for the recycler, this would involve a forecast residual value at which the recycler agrees to purchase the battery of a vehicle at the end of its life as part of extended producer responsibility specifications. For this, the recycler and producer agree on a forecasted price value of metals contained in those batteries on the Shanghai Metals Exchange projected to a future date aligned with end of life of the battery. Since China is the largest EV battery material buyer currently, it has the biggest influence on the price of metals such as nickel, lithium and cobalt and therefore the use of SME data. The calculation could use data from other metals exchanges as well should they have larger say in defining the price.

Factors used in determining residual values include battery performance and driving range, as well as accessibility to charging, state of charge (SOC) and state of health (SOH) estimation.

SOH[43] is the ratio of the capacity discharged by the power battery at a certain rate from the fully charged state to the cut-off voltage and its corresponding nominal capacity under standard conditions, and it is the key to evaluate the health of the power battery. Other factors that may play a part in the depreciation calculation include market fluctuations, economic impacts, and incentives from the government at central, state and local levels at the federal, state, and local levels.

Residual values of EV batteries also have an application in the insurance sector. Currently, EV buyers pay very high premiums for EV insurance because the methodology of determining the residual value of an EV battery is not set in stone yet. Insurance companies attach a very high risk-factor to EVs because of the newness of the technology that is still not understood and consequently charge higher than justified insurance premiums. This leads to higher TCO of EVs and contributes to demand destruction. It is imperative to therefore understand and set standards about how an EV depreciates in the accounting books of manufacturers, owners, governments, insurers and recyclers.

Clearly the EV battery eco-system requires a financial system similar to the lead acid battery resale market to become viable. Battery recyclers can offer value to the vehicle owner and the fleet operator enabling the creation of a financial eco-system. Such a framework could be similar to the end of life system existing in the lead acid battery eco-system where a vehicle owner gets some value out of the spent battery and the collector sells it to the battery recycler who can recover value by extracting the heavy metal out of the old battery. Lead acid batteries are typically sold at an average price of Rs 90/kg. Lithium ion batteries could have a price fixed on their sale that could effectively make the LIB eco-system a financially viable option.

Lohum, a Noida based recycler, offers a buyback value of a third of the original value at Rs 5/Wh for commercial electric three wheeler lithium ion batteries at the end of a 1000-cycle life. This value could go up to 50 per cent of its original value depending on the usage profile of the battery.

One of the biggest challenges facing lithium ion battery recyclers has to do with collection. While the lead acid battery market has brokers collecting batteries and feeding them to recycling operations, lithium ion battery recycling falls under the large ambit of e-waste management which has multiple grey areas. Old mobile phones or laptops are often passed down to other people or traded. The source of collection for e-waste or e-battery, therefore, holds importance. Once a recycler has a source, the economics can change depending on the contract, whether it involves getting material for free or paying for it, or a tolling contract where an automaker pays the recycler by the metric ton of batteries or material that it processes and returns.

How lithium ion batteries are treated post collection is entirely dependent on its usage profile – information that should ideally be documented in a Battery Passport for future users, be it either buyers or repurposing companies. For instance, batteries that are often fast charged tend to degrade quickly. In India, where temperatures are high, the impact of fast charging will be higher than they would in colder countries. This is why experts recommend avoiding a fast charge on very hot days, even if the battery is equipped with a cooling system.

Every battery's management system maintains a charging zone when the battery stays protected. At the two ends of the spectrum when the battery is fully discharged or the battery is almost charged, at those points fast charging is not recommended. It is in the middle range where batteries can be fast charged. This is a major reason why battery swapping is recommended in the two and three wheeler category. With that, the battery can be slow charged and the vehicle driver does not have to wait for a slow charging event of 3-4 hours, and can opt to swap batteries.

In a Science Direct article[44] titled "Financial viability of electric vehicle lithium-ion battery recycling", the authors use a cost model to arrive at net recycling profit for different battery chemistries (i.e. $LiMn_2O_4$ (LMO), $LiFePO_4$ (LFP), $LiNiCoAlO_2$ (NCA) and $LiNiMnCoO_2$ (NMC)), recycling processes (pyrometallurgical, hydrometallurgical, direct) and recycling locations (South Korea, China, the US, Belgium, and the UK). This cost model takes into account the entire recycling chain, starting from battery collection, transportation, disassembly, recycling, and revenue generated from recovered cell and pack materials

The results of the study showed that in most cases, Lithium ion battery recycling remains uneconomical and profitability is achieved only under a very narrow set of conditions of chemistry, location, and process. This bears the risk of impeding the establishment of a large enough recycling sector capable of dealing with the predicted amount of end-of-life batteries. Moreover, the lack of recycling profitability might lead to an increased export of EVs or batteries to countries without strong hazardous waste legislation, either legally for second use or illegally.

If recycling remains unprofitable, battery waste volumes could build up, which, if uncontrolled, bear a significant environmental and safety risk, as toxic chemicals could leak into the environment and lead to landfill fires. Moreover, valuable materials that could be recovered and reused would simply be wasted.

One of the key activities in the development of new lithium ion batteries is a move towards developing batteries with very little or no cobalt. That, however, could land the industry with an unintended consequence. The metal is plays a significant role that makes recycling batteries economical, because other materials, especially lithium, are currently cheaper to mine than to recycle.

Collection is an expensive activity for recyclers. The recycler has to collect the spent batteries, which involves marketing and collection and transportation (cost item), recycle them (cost item) and sell the material collected (revenue item). As a best practice, recyclers must be encouraged to do thorough projections of their collections and sales and enter into long term contracts with manufacturers. For this and other logistical requirements, recycling industry needs to be supported and its challenges need to be addressed through policy with EPR budget guidelines.

It is also important for a regulatory strategy that supports development of new recycling technologies. The government needs to support scientific work into new battery recycling technologies that have the potential to reduce or eliminate the negative cost of lithium-ion battery recycling.

Lessons from global battery economies

Most of the lithium-ion batteries are manufactured China, Japan and South Korea. Consequently, most of the recycling facilities and regulatory framework are also coming up in these countries. For example, Foshan-based Guangdong Brunp- a subsidiary of CATL in China has a capacity of recycling 120,000 tonnes of batteries per year. This is the equivalent of what would be used in more than 200,000 cars. The firm claims it is able to recover most of the lithium, cobalt and nickel. In a country like China, battery recycling is heavily incentivised through financial and regulatory frameworks more with the strategic intention of using recycled raw material available within the country rather than importing freshly mined ore from outside the national borders.

California in the United States has established Car Battery Recycling Advisory Group in 2019 under the California Environment Protection Agency (CalEPA) to bring about policy reforms for end-of-life reuse and recycling of batteries. But, the battery recycling industry is still nascent in the country.

In December 2022, the European Commission has introduced new reforms aimed at building a circular economy for EV batteries. The reforms seek a carbon footprint declaration for batteries sold in Europe starting 2024 through a digital tool called 'battery passport'. The rules mandate all storage systems to contain a clearly visible QR code that offers all the information related to the battery, including composition, capacity, durability and also data associated with environmental performance of the battery. This is an important step, considering 17 per cent of the global battery demand by 2030 is believed to be originate in Europe.

However, unless the battery manufacturing economies of China, Japan and South Korea tighten environment norms, the global battery industry will likely default on its ESG and Extended Producer Responsibility commitments, while the demand-generating countries will be left asking for more information.

Global research efforts have focused on improving the process to make recycled lithium economically attractive. The vast majority of lithium-ion batteries are produced in China, Japan and South Korea; accordingly, recycling capabilities are growing fastest there. For example, Government policies are helping to encourage this: China already has financial and regulatory incentives for battery companies that source materials from recycling firms instead of importing freshly mined ones.

In December 2022, the European commission issued new regulatory reforms to build circular economy around EV batteries. This was tabled two years ago in December 2020, when the EU revised the 2006 Battery Directive with a new batteries' regulation called the Circular Economy Action Plan for mandatory collection and recycling of automotive EV batteries.

The regulation seeks a carbon footprint declaration for batteries sold in Europe starting in 2024 through a digital tool called "battery passport". It targets enhanced transparency and traceability along the full lifecycle of all batteries above 2 kWh via labelling and a digital identity. The rules mandate for all storage systems to contain a perfectly visible QR code that, through its reading, offers all the information related to the battery: composition, capacity, durability and also data associated with environmental performance of the battery.

The regulation aims to make all batteries in EU sustainable, circular and safe and to establish global standards for environmentally and socially responsible batteries.

Globally, demand for batteries is estimated to increase by 14 times by 2030 and 17 per cent of this demand could be from EU, according to a release on the European Parliament website.[45] Thus EU also targets to bring in Extended Producer Responsibility from 2025 to have higher collection targets. It suggests that 63 per cent of portable batteries can be collected for recycling by 2027 and 73 per cent by 2030.[46] Similarly for batteries from light transport modes, the target will be 51 per cent and 61 per cent for 2028 and 2031 respectively. This is a key achievement under the European Green deal and this plays a central role in advancing EU's climate neutrality by 2050.

Formation of California's Lithium-ion Car Battery Recycling Advisory Group: California in United States established Lithium-ion Car Battery Recycling Advisory Group in 2019 under the California Environment Protection Agency (CalEPA) to bring policy reforms for end-of-life reuse and recycling of batteries. The advisory group informs policy reforms and legislative changes to recover and recycle lithium-ion vehicle batteries sold with motor vehicles in California. Members of the group include the Department of Toxic Substances Control (DTSC), and the Department for Resources Recycling and Recovery (CalRecycle) and additional members from the environmental community, auto dismantlers, public and private representatives involved in the manufacturing, collection, processing and recycling of electric vehicle batteries, and other interested parties.

In May 2021, the group released a draft on barriers and opportunities in the reuse, recycle of the batteries and logistics involved. The major barriers highlighted in this draft are unregulated after markets, absence of producer responsibility, information on safe handling and dismantling, cost competitiveness of repurposed batteries, lack of standardization in terms of design and assembly of batteries, lack of stimulus (fiscal/ non-fiscal) from the government. The major opportunities highlighted are reduced environmental and social impact, economic opportunities and better resource utilization.

Recycling regulation in China mandates battery OEM to set up recycling supply chain: China introduced Interim Measures for the Management of Recycling and Utilisation of Power Batteries for New Energy Vehicles in August 2018[47]. According to this, the manufacturer has responsibility of the manufacturing process of batteries and its entire lifecycle, including its recycling and waste disposal.

To manage the in-use batteries, regulation in China mandates EV manufacturers to recover used batteries. It required them to set up recycling supply chain and service outlet to facilitate collection, storage and transfer of old batteries. This led to setting up of recycling centres and business.

The new EV manufacturers have to establish a recording system for tracing all the information on sold vehicles and their owners. To achieve this, the manufacturers have to work with scrap vehicle collection entities, to share relevant information that facilitates scrap collection procedures. They have to also establish power battery recycling channels and take charge of the used battery recycling process.

The regulation also encourages standardisation of battery design, production and verification to improve the assembly and dismantling of used batteries. In addition, this provides provision for repairing and repackaging for second life utilisation.

China's battery management rules holds battery manufacturers responsible for new EV production to improve standardisation. The regulation also holds battery manufacturers responsible for providing instructions to new EV manufacturers for storing and dismantling the batteries. If necessary, the battery manufacturers must also provide training sessions to the new energy vehicle manufacturers. The regulation strongly recommends battery manufacturers to cooperate with new electric vehicle manufacturers on establishing a coding system that allows for relevant information on the power battery to be traced.

Three US states, California, New York and Minnesota, have banned landfilling of lithium-ion batteries to influence the recycling market. This will influence a merging of market-based approach to reclaim minerals from used batteries. This is unlike the system in China and it helps unburden battery manufacturers to deal with used batteries.

Japan established Producer Responsibility Organisation for collection of used batteries: Japan, under its Act on the Promotion of Effective Utilization of Resources and the Treatment of Specified Resources, has created Japan Portable Rechargeable Battery Recycling Center (JBRC), a Producer Responsibility Organisation (PROs)[48] for collection of used batteries.

The law mandates retailers to register as cooperation shop with the JBRC to sell compact rechargeable batteries and products using compact rechargeable batteries in the market. This is an important step to regulate the otherwise informal second life market demand for batteries.

The process is simple, all registered shops must install collection boxes for waste generated from compact rechargeable batteries. As and when collection boxes collect rechargeable batteries of 7-8 kgs, these registered cooperative shops request JBRC to schedule pick up. Once collected, cooperation businesses for recycling sort the batteries by type and hand them over to delivery businesses for transport to recycling units. Once collected, cooperation businesses for recycling sort the batteries by type and hand them over to delivery businesses for transport to recycling units.

Japanese industry is an active participant in the country's recycling eco-system. In 2018, Nissan and Sumitomo Corporation created a joint venture called 4R Energy Corporation to establish Japan's first EV battery recycling facility. This corporation offers refurbished batteries at about 50 per cent cost of brand-new batteries. This provides batteries a second life and ensuring full utilization of the resource.

Another auto giant Toyota Motor have partnered with Jera, a joint fuel-procurement venture between Tokyo Electric Power and Chubu Electric Power, in a bid to transform old batteries used for electric vehicles and hybrid vehicles into power storage system for renewable energy.

A commendable proposal in the EU Battery Regulation is one of universal Battery Passport. These can be accessed by any stakeholder to understand the battery's supply chain, carbon footprint, State of Charge (SOC) and State of Health (SOH). It would help collect data for audits of the manufacturers' performance on the various regulations being set out by the government.

It would be beneficial for the Indian battery ecosystem to negotiate for open Battery Management Systems. If the different battery manufacturers lock access to their battery packs' datasets, it will become very difficult for the government to monitor and regulate the battery maintenance and recycling industry as all the EV batteries in India are likely to be manufactured by private companies

The way forward

This review brings out that there is an urgent requirement to promote closed-loop recycling, whereby spent batteries are collected and recycled directly, thus reducing energy use and waste by cutting down on mine output used in new cells.

Revise the Battery Waste Management Rules 2022 to make battery labelling mandatory and transparent to provide all the critical information needed on battery composition, state of health and battery performance for efficient reuse and recycling. Develop proper guidelines for capturing the information and for making the information easily accessible to the recyclers.

Central Pollution Control Board and the State Pollution Control Boards need to establish effective and robust system for implementation of all rules related to the extended producer responsibility (EPR), environment compensation charge, targets and mandate for recycling and use of recycled material etc. It is necessary to pay attention and strictly regulate the issuance of EPR certificates.

Promote standardisation of lithium ion batteries to support efficient recycling: For the establishment of recycling centres, standardisation of cell chemistry is needed, as well as assembly technology, standardised battery forms based on the application, to streamline the dismantling process. This need not compromise upstream innovation. Incentivise battery reuse and associated technologies and registration of producers for tracking of batteries in circulation and ensure they are recycled after their second use along with a repository for battery end-of-life configurations.

The Rules need to encourage responsible battery disposal through OEM service centres which could act as collection centres. Encourage development of national level not-for-profit battery collection schemes to formalise the channels for EV battery collection and proper disposal. It could be a common pool concept or a separate collection agency to streamline collection of batteries and recycling in formal smelters.

Introduce battery tracking like the battery passport initiatives in the European Union.

Standardize state-of-health metrics to inform decisions on second-life applications. Globally this is being perceived as a good practice. [49]

Support R&D on recycling technologies and processes: Support research to develop commercially viable recycling processes with a high recovery rate. Battery manufacturers can forge recycling partnerships as they deploy batteries in EVs to streamline operational processes for collection, testing and recycling.

Evaluate and promote a more efficient recycling process for maximum recovery of a wider range of materials. It is necessary to increase the recovery rates. This should be verifiable and measurable. While waste management rules have mandated targeted recovery of material, more element specific targets may maximise recovery of all battery materials.

Need favourable price differential for recycled material vis a vis virgin material: This is possible if the socio economic costs of mineral extraction can be internalised in the pricing of material. Recycled material should always be more competitive.

Strengthen safety standards for reuse and recycling that can also be crucial for reducing risks.

Encourage design for recycling practices in close collaboration with the battery manufacturers: This can institutionalise recovery rates from recycling processes in Battery Waste Management Rules; higher for matured technologies while working towards improved recovery from the newer upcoming technologies.

Incentives for manufacturers to meet recycling regulations: This can be in the form of green taxes etc to enforce EPR. This will help in attaining a higher recycling rate. The industry is also required to build a waste management budget and allocate funds for managing end of life batteries.

Globally, regulators are aiming to strengthen standards for battery durability, and safety to support and optimize reuse and recycling processes[50]. Mandatory battery durability requirements can incentivize the production of long-lasting batteries and support second-life usage.

Need more explicit environment guidelines and standards for the states to establish appropriate systems and infrastructure to minimise environmental impacts and promote seamless battery recycling. Disposal of batteries in landfills should be prohibited and made illegal and an effective mechanism be developed for proper disposal of batteries through recyclers.

Integrate informal sector with formal recyclers: It is possible to adopt innovative models for integration of informal systems with the formal recycling facilities for collection and transport. Currently, the formal sector making investments into recycling technologies find the competition from the informal sector and poor logistics of battery collection a challenge. This needs integration

Build consumer awareness regarding safe disposal of EV batteries. The Deposit Refund System mentioned in the rules can provide incentives to customers to return batteries thereby ensuring collection of batteries by the manufacturers.

ANNEXURES

ANNEXURE 1

Battery Waste Management Rules 2022 – Key elements and guidance for implementation

The Battery Waste Management Rules 2022 are aimed at efficient management of EV waste batteries with the deployment of a 'polluter pays principle'.

The 2022 BWMR mandates:

- Transactable EPR certificates for producers for environmentally sound management of waste batteries

- Introduces Environmental Compensation (EC) based on polluters pay principle

- Provides new definitions of EV battery cells and battery packs and stresses on the importance of labelling requirements

Classification of batteries

- Automotive batteries – used for stater, lighting and ignition in vehicles

- EV batteries – specifically designed to give motive power to hybrid and electric vehicles for road transport

- Portable batteries – any battery that is sealed, less than 5 kg and not made for industrial purposes, could be used in electric vehicles or as automotive batteries

- Industrial batteries – designed for industrial uses, excluding portable batteries, electric vehicle batteries and automotive batteries. These may include sealed batteries (excluding portable battery); unsealed batteries (excluding automotive batteries) energy storage system batteries like grid scale storage batteries and secondary storage batteries.
- The Rules introduce Extended Producer Responsibility (EPR) system to enable attainment of recycling and refurbishing obligations. Each producer is required to meet the collection and recycling or refurbishing target based on the number of batteries they released into the market.

- The producer has to register through an online centralised portal managed by the central and state pollution control boards and also file plans for fulfilling EPR obligations of waste batteries when filing annual returns. This would contain granular information regarding quantity, weight of batteries along with dry weight of battery materials.

- The Rules also suggest a deposit refund system or buy-back option for the producer to meet their EPR obligations.

- The producer is also expected to include 5 per cent of recycled material in the total dry weight of a battery by 2027-28, expanding to 10, 15 and 20 per cent by 2030-31. In case of imported batteries, the producer has to meet the obligation by getting the same amount of recycled materials utilised by other businesses or by exporting a similar amount of materials. The minimum use material target differs by sector with automotive and industrial sectors having the highest percentage of obligation at 35 per cent and closer deadline at 2024-25.

- **Recycled Material Target**

Type of batteries	Recycled material mandate (%)			
	2027-28	2028-29	2029-2030	2030-2031
Portable	5	10	15	20
Electric vehicles	5	10	15	20
	2024-25	2025-26	2026-27	2027-28
Automotive	35	35	40	40
Industrial	35	35	40	40

Source: Battery Waste Management Rules 2022

- The producer has to ensure that waste batteries are disposed off in an environment friendly manner by moving it to the collection/refurbishment/recycling entity. Used lithium batteries contain embedded electrochemical energy – a small amount of charge left over after they can no longer power devices – can cause explosions.

- Urban and rural local bodies engaged with public waste management have to hand over collected waste batteries to producer or agencies working on their behalf, or an entity engaged in refurbishment/recycling.

- Apart from producers, refurbishers and recyclers also have to register on the portal with recyclers expected to abide by minimum material recovery targets, starting from 70 per cent total material recycled by 2024-25, expanding to 90 per cent by 2026-27. The maximum recovery target is subject to the percentage of non-recoverable hazardous material content in the batteries.

Type of batteries	Recovery target for the year %		
	2024-25	2025-26	2026-2027 and onwards
Portable	70	80	90
Automotive	55	60	60
Industrial	55	60	60
Electric vehicles	70	80	90

- EPR certificates will be generated by CPCB through the centralised portal based on the recycled/refurbished quantities and assigned to recyclers/refurbishers. The recyclers/refurbishers can sell the assigned EPR certificates to producers in exchange for waste batteries. The certificates will be issued to them on the basis of weight of batteries processed, percentage fulfilment of material recovery targets

Different stages of EV battery waste management

Depending on the waste generation stage, different entities are involved and have to follow defined responsibilities and guidelines.

- The role of producer is to introduce batteries into the market and organise for collection recycling/refurbishment.

- The role of consumer is to be responsible for disposal of battery waste

- In the waste collection stage the role of Public Waste Management Authority (municipalities) involves handing over of waste batteries to producers or refurbishers/recyclers

- The role of collection, segregation and treatment entities is to hand over waste batteries to registered refurbishers/recyclers

- If the batteries have life left in them, in the refurbishment/recycling (second-life) stage, the role of refurbisher is to find innovative ways to reuse batteries in compliance with CPCB guidelines

- For batteries that do not have any life left in them, the role of recycler is to process waste batteries.

Role of Producers

Producers of batteries are expected to achieve the EPR targets and provide EPR plans to CPCB. Operation of schemes such as deposit refund model is allowed

Requirements	Registration
• Abide by EPR Extended producer responsibility (EPR) for the batteries that it introduces in the market to ensure the attainment of the recycling/refurbishing obligations • Meet EPR targets Meeting collection and recycling and/or refurbishing targets (EPR targets) as mentioned in Schedule II for batteries made available in the market (target times, EPR plan needs to be submitted and operation schemes and operational schemes of DRS like earlier • Ensure refurbishment/recycling Ensuring that all collected batteries enter a refurbishment and/or recycling facility and not landfilled or incinerated	• Registration through the one centralised portal as per Form 1(A) • Filing for renewal of EPR registration in Form 1(A) before 60 days of the expiry • Providing EPR plan in the Form 1(C) in current FY by 30th June for the EPR obligations of waste batteries of the current FY as per Schedule II • Submission of EPR plan in the Form 1(C) to CPCB for the batteries for FY 2022-23 as per Schedule II within three months of the publication of rules • Operation of schemes such as deposit refund system or buy back or any other model Returns • Filing of annual returns in Form 3 on waste batteries collected and recycled/refurbished towards fulfilling EPR obligations with the concerned CPCB, SPCB, PCC by 30th June of the next FY.

Role of Refurbisher

Refurbishers have to ensure that their facilities follow CPCB standards and manage the hazardous and other solid waste generated from facilities

Requirements	Registration
• Follow CPCB standards Ensure that the facility is in accordance with CPCB standards and that activities are carried out according to guidelines mentioned by CPCB. There will be guidelines from CPCB for the facilities built by the refurbishers • Manage hazardous waste Ensure that hazardous waste generated from any activity is managed as per the provisions under Hazardous and other wastes (Management and Transboundary movement) Rules 2016. They need to declare how they handle waste • Manage other solid waste Ensure other waste generated during handling and refurbishing is managed as per existing regulations such as Solid Waste Management Rules 2016 & Plastic Waste Management Rules 2016	• Registration with the concerned SPCB/PCC through the one centralised portal. They have to provide a lot more detail than what is being submitted now • Permitted facilities shall ensure that all refurbishment processes comply with CPCB guidelines in light of technical and scientific progress and emerging new technologies in waste management and with best available techniques Returns • Refurbishers shall furnish quarterly returns in Form 4 regarding the following information: A. Quantity of used batteries collected/received from various producers/ entities B. Refurbished quantities C. Quantity of hazardous and/or other waste including solid waste/ plastic waste generated after refurbishment and disposal of such quantity • Quarterly data from refurbishers will be made available on the portal developed by CPCB as also on the websites of the entities

Role of Recyclers

Recyclers follow similar guidelines; in addition they have to meet recovery targets for battery materials based on the battery type.

Requirements	Registration
• Follow CPCB standards Ensure that the facility is in accordance with CPCB standards and that activities are carried out according to guidelines mentioned by CPCB • Manage hazardous waste Ensure that hazardous waste generated from any activity is managed as per the provisions under Hazardous and other wastes (Management and Transboundary movement) Rules 2016. They need to declare how they handle waste • Manage other solid waste Ensure other waste generated during handling and refurbishing is managed as per existing regulations such as Solid Waste Management Rules 2016 & Plastic Waste Management Rules 2016	• Registration with the concerned SPCB/PCC through the one centralised portal Returns • Recyclers shall furnish quarterly returns in Form 4 regarding the following information: A. Quantity of used batteries collected/received from various producers/entities B. Recycled quantities C. Compliance of material wise recovery percentage as per recovery targets as per rule D. Quantity of hazardous and/or other waste including solid waste/ plastic waste generated after refurbishment and disposal of such quantity • Recovery targets for recovered materials. Among the four types of batteries, the target starts from 2024-2025 and moves from 70 and 55 per cent to 90 and 60 per cent

Guidelines for Material handling, Loading and Un-loading

1. PPE matrix must be followed.
2. All the operations and workmen must be trained to do this.
3. Trained and certified HOPT/BOPT/Forklift operator to handle the material for loading and unloading.
4. Proper stacking of material with a safe distance between each pallet.
5. In case of any kind of Cell and battery pack movement it must be kept on a pallet properly and it should be wrapped.
6. If required to place an air balloon to be there between each pallet or Pallets to be tied inside the container to avoid the collision.
7. Never stack the Battery pack over the battery pack or pallet.
8. A person must be trained to do manual material handling.
9. Evaluate weight, distance, and hazards before lifting the load.
10. Wear appropriate PPE such as hand gloves and safety shoes to prevent cuts, abrasions, or crush injuries.
11. Make sure the route is clear for the movement of material.
12. Loads that are too large or too heavy must be carried by two people or by mechanical means.

13. Whenever possible, use mechanical means for heavy material handling.
14. Before actually starting the lifting operation, try lifting as a test with less effort to check load and comfort.
15. Keep the load close to the body, while physically lifting the material.
16. While lifting, the feet should be hip-width apart for balance and to provide a stable base for the lift.
17. Bend your knees keeping your back straight to lift the load and the hands are as near to the waist as possible.
18. Keep your arms straight and within the limit formed by the legs.
19. Continue lifting smoothly and adjust the weight or body posture as necessary.
20. Don't use makeshift arrangements to lift material.
21. Don't drag chains, ropes or cables, etc. on the ground.
22. Don't manually lift more than 50 kg for men or 30 kg for women.
23. Don't try to lift or carry material too heavy or too large for an individual.
24. Don't hold the load with your fingertips, use the palm of your hand instead.
25. Don't carry loads that could obscure the view of the path.
26. Don't bend your back to lift loads.
27. Avoid jerky or twisting movements

Battery Pack Packaging Safety Guidelines

1. Make sure all the carton boxes should be in healthy condition.
2. On side of the carton boxes, the foam must be placed to fix the battery pack with the carton.
3. To seal the battery box taping should be done.
4. It must be ensured that battery box should not go outside the pallet.
5. Ensure that the battery is firm in the box and not moving.
6. Ensure that the foam is properly placed in each layer
7. Never keep the material more than 105 CM in height with pallet.
8. If required then we must place the protective pallet corner guard or board.
9. The pallet's material should be properly wrapped with bubble plastic.
10. Depending on the size of the battery/box, lay the box horizontally on the pallet - 6 boxes in this case.
11. Trained and certified HOPT/BOPT/Forklift operator to handle the material for loading and unloading.
12. Proper stacking of material with a safe distance between each pallet.

Transportation Safety Guidelines

1. The driver must be competent and trained.
2. All the Battery pack SOC must be 30 per cent.
3. Each pallet must be tie-up internally with hooks and straps.

4. A safe distance should be maintained.
5. Registration certificate of vehicle (RC Book).
6. Certificate of insurance validity.
7. P U C Validity.
8. Load chart displayed in cabin.
9. Reg. number displayed on both sides.
10. HMV Driving license number/validity.
11. Check the capacity of the vehicle and material weight.
12. Make sure all battery must be discharged up to 30 per cent SOC.
13. A fire extinguisher must be inside the truck cabin minimum capacity 2 to 5 KG DCP/CO2.
14. Condition of the enclosed container, it must be waterproof.
15. The operator's seat belt should be there.
16. Working of main brake/ parking brake.
17. Working of Main & Reverse horn.
18. Driver must be trained, on how to react in case of emergency.
19. Check cabin door/ window locks & glass condition.
20. The first aid box must be inside the cabin.
21. Battery condition & terminals must be covered.
22. Tyre condition& Fitment of wheel nut / Check condition of all four tire

Storage Guidelines

1. Cells and Battery packs must be stored in a separate and defined place.
2. Cells and packs must be stored at room temperature.
3. There will be no flammable material should be stored along with the Cells and Battery Pack.
4. Separate areas should be used for different items (for ease of identification).
5. Certain materials and substances should be segregated during storage; alternatively, purpose-built secure storage (e.g. gas-bottle cages) may be required.
6. Appropriate warning signs should be displayed where necessary (e.g. where flammable materials are stored).
7. Storage areas should not be used for work activities.
8. Each stack should be for one material only (not mixed).
9. A maximum stack height must be set (depending on the strength and stability of the material being stacked).
10. Stacks should be vertical (not leaning).
11. Pallets should be used to keep materials off the ground.
12. Sufficient space must be allowed between stacks for safe movement.
13. Stacks must be protected from being struck by vehicles.

Guidelines for truck drivers

1. When unloading, the driver should proceed to the designated area and remove tarps, straps, or other load securement devices. Secure this material so it is not an obstruction to the forklift operator during the unloading process.
2. The driver should secure the vehicle, apply brakes and turn off the engine, as appropriate, to prevent unsafe movement during the loading/ unloading operation.
3. The driver should proceed to a designated area (safe zone) located away from the truck and outside of the loading/unloading area. The driver should remain in that area during the operation.
4. No material should be loaded/unloaded, nor should any forklifts be operating in the area around the truck until the driver has completed all of the tasks above and moved to the designated safe zone.
5. The Vehicle must securely be parked and it should not be obstructed by a pathway.

Guidelines for Forklift

1. Operating a forklift should be limited to individuals who are trained and qualified to do so, including general forklift safety topics and equipment-specific training. Initial training should be completed before the authorization of the driver to operate the forklift. Refresher training should be completed every three years following any forklift-related accident, property damage, or near-miss incident.
2. Make sure that the load has not shifted, the banding is still in place, and the overall load is in good condition and not likely to move or fall during the unloading process.
3. No one, including other workers, should be on the opposite side of a truck from a forklift while it is moving material
4. EMPOWER your forklift driver to stop the loading/ unloading process if the location of the truck driver cannot be confirmed or someone else enters the loading/unloading zone. While loading/unloading of material is an everyday activity at most operations, safety cannot be taken for granted. It is the management's responsibility to ensure that proper training and safe loading/ unloading procedures are in place and enforced.
5. The operator must be wearing all required PPE during the loading and unloading of material.
6. The forklift must be in healthy condition (Refer to below Checkpoints)
    1. Check fluid levels (oil, water, and hydraulic fluid, for example)
    2. Check for leaks, cracks, and visible defects everywhere on the forklift
    3. Check mast chains visually; avoid the use of hands

4. Test mast chain tension by lifting the load backrest to eye level—the mast chains should be level and any tilting may signify stretching or broken rollers
5. Check tire condition, and pressure, and look for any cuts or gouges
6. Determine fork condition, remembering to check the top clip retaining pin and heel
7. Ensure load backrest extension functions properly
8. Check the functionality of finger guards
9. Ensure safety decals and nameplates are legible and match the forklift model
10. Check that the operators' manual and log book are present and legible
11. Ensure the operators' manual compartment is clean of debris
12. Test all functional safety devices, such as seat belts and horns
13. Check the brakes, steering controls, and other operational items for proper function

LOADING CHECKLIST

S. No.	Key Check points	Yes/No
1	Is the truck/trailer correctly positioned and level?	
2	Are wheel chocks in place?	
3	Is there any damage to the truck or trailer?	
4	Are the appropriate people and equipment available for loading/unloading?	
5	Does the product require special lifts or a crane to handle the load?	
6	Are load straps in good condition (not frayed, worn, or torn)?	
7	Has the driver been moved to the company safe zone?	
8	Are all helpers in sight of the forklift/crane operator?	
9	Are the load restraints suitable to secure the load?	
10	Does the total weight of the cargo exceed the truck's carrying capacity?	
11	Is the load well packed in the appropriate packaging?	
12	Is documentation completed for all cargo being dispatched?	
13	Has the driver double-checked all restraints for specific load requirements?	

UN-LOADING CHECKLIST

S. No.	Key Checkpoints	Yes/No
1	Is the truck/trailer correctly positioned and level?	
2	Are wheel chocks in place?	
3	Is there any damage to the truck or trailer?	
4	Are the appropriate people and equipment available for loading/unloading?	
5	Does the product require special lifts or a crane to handle the load?	
6	Are load straps in good condition (not frayed, worn, or torn)?	
7	Has any freight moved while in transit?	
8	Are all items effectively secured to a pallet, cradle, or flatbed trailer?	
9	Are top-loaded items stable?	
10	Could any freight move or become unstable when the load restraints are removed?	
11	Has the driver been moved to the company safe zone?	
12	Are all helpers in sight of the forklift/crane operator?	

EPR certificates and Environmental Compensation

EPR certificates are generated for recyclers and refurbishers based on quantities assigned and Environmental Compensation is imposed on non-fulfilment of EPR

Recyclers/refurbishers can sell the assigned EPR certificates to producers in exchange of waste batteries through the portal. Surplus certificates in one category can only be used for offsetting carry forward and sale for the same category.

The factors taken into account for certificate generation include:

- Weight of batteries processed
- Percentage fulfilment of material recovery targets for the year
- Geographical source of batteries

Formula for calculation of EPR certificates (for recyclers)

EPR certificate (kg) = % fulfilment of battery material recovery target for the year + quantity of batteries processed (kg) + geographical source of batteries

The geographical source involves a change in formula. Imported batteries follow a formula separate from that of Indian manufactured batteries.

There is an Environmental Compensation (EC) that applies to stakeholders and penalties would be applicable even for recyclers. Imposition and collection of EC from producers, refurbishers/recyclers of waste batteries in case of non-fulfilment of EPR obligations

With regard to collection and return of unfulfilled EPR obligations, these will be carried forward up to three years. In case the shortfall is addressed with these three years, the EC levied shall be returned in the following manner:

- Within 1 year of levying – 75 per cent
- Within 2 years of levying – 60 per cent
- Within 3 year of levying – 40 per cent
- Within 4 year of levying – 0 per cent

EPR targets for automotive batteries for market introduction

<table>
<tr><th>Compliance cycle</th><th>Year</th><th>Mandatory waste battery collection target and 100% of refurbishing/recycling of the collection target (weight)</th><th>Mandatory waste battery collection target and 100% of refurbishing/recycling of the collection target for every 5-year cycle (weight)</th></tr>
<tr><td rowspan="5">2022-23 till 2026-27 (5 year cycle)</td><td>2022-23</td><td>Minimum 30% of the quantity of batteries placed in the market in 2018-19</td><td rowspan="6">Collection of 100% of waste batteries and of 100% of refurbishment/recycling shall be mandatory by end of 5 year compliance cycle (and of 5th year) against the batteries placed in the market during the 5 year compliance cycle

There may be a carry forward of up to 10% of the average quantity of batteries placed in the market per year during the 5 year cycle to the next compliance cycle</td></tr>
<tr><td>2023-24</td><td>Minimum 50% of the quantity of batteries placed in the market in 2019-20</td></tr>
<tr><td>2024-25</td><td>Minimum 70% of the quantity of batteries placed in the market in 2020-21</td></tr>
<tr><td>2025-26</td><td>Minimum 90% of the quantity of batteries placed in the market in 2021-22</td></tr>
<tr><td>2026-27</td><td>Minimum 90% of the quantity of batteries placed in the market in 2022-23</td></tr>
<tr><td>2033-34 till 2039-40 (7 year cycle) and onwards</td><td>2027-28 and onwards</td><td>Minimum 80% of the quantity of batteries placed in the market in the preceding FY (2028-29)</td></tr>
</table>

To get into a circular economy, it is important to have a 100 per cent fulfilment of EPR targets. The government is introducing concepts in which during a period of 3-5 years, the balance of 30 per cent will have to be collected and recycled in a 5 year period on pro-rata basis.

Segment wise rules

Since 2W are being supported by the government as part of FAME I and II and PLI, their numbers will continue to be large.

With average battery capacity at 3-4 kWh

- 2W – 3 kWh
- 3W – 5 kWh
- 4W – 30-40 kWh
- Bus – 200-320 kWh

2W battery starts from 15-20 kgs – battery weights are typically 15 kg to 900 kg. About 100-175 GWh of batteries will be available for recycling.

For two wheeler batteries, the recycling target starts from 2026-27 onwards and it starts from 70 per cent of the batteries placed from 2021-22. From 2033-34 onwards to 2039-40, in a 7 year cycle, it will be 80 per cent and above.

For three wheelers, the target starts from 2024-25 and it starts from 70 per cent of the vehicles placed in 2021-22 onwards.

For four wheelers, the compliance cycle is 70 per cent from 2029-30 till 2035-36 which is a 7 year cycle

According to some estimates, there will be over 14-16 million units which means 80-100 million units in operation by 2030.

ANNEXURE 2

Lessons from the lead acid experience

Depending on collection and recycling practices, the effects of improper processing of used lead acid batteries are listed below:

1. In the absence of a proper neutralisation or safe disposal system, the battery electrolyte (sulphuric acid) may be disposed of carelessly and percolate into the groundwater table, rivers and the sewage system.

2. There is a need for exhaust emission filters as the air in and around recycling and smelting units may have a high concentration of lead (along with cadmium, arsenic and other toxic elements) thus posing a serious risk to human health.

3. Furnace residues along with other components of batteries (like separators) which are often disposed of in and around lead smelting premises are unstable and can leach into the water table.

The design of current battery packs are not optimized for easy disassembly. Use of adhesives, bonding methods and fixtures do not lend themselves to easy dismantling either by hand or machine. The current commercial physical cell-breaking processes employ shredding or milling with subsequent sorting of the component materials. This makes the separation of the components more difficult than if they were presorted and considerably reduces the economic value of waste material streams. Many of the challenges this presents to remanufacture, re-use and recycling could be addressed if considered early in the design process.

Manufacturers do not share information about the content of their batteries, which makes it harder to recycle them properly. When recovered cells are shredded, creating a mixture of metal that can then be separated using recycling techniques or burning, the method wastes a lot of the lithium.

Because lithium cathodes degrade over time, they cannot simply be placed into new batteries (although some efforts are underway to use old vehicle batteries for energy storage applications where energy density is less critical).

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