NITI Aayog

GGEF TCF GREEN GROWTH EQUITY FUND TECHNICAL COOPERATION FACILITY

Perspectives of Global and Domestic Companies on Advanced Chemistry Cells Battery Reuse and Recycling

Supported by:

UK Government

Authors and acknowledgements

Authors

NITI Aayog: Sudhendu J. Sinha, Randheer Singh, Joseph Teja

Oxford Policy Management: Noemie de La Brosse, Safa Khan, Benjamin Klooss

PwC: Vaibhav Singh, Ankit Chatterjee, Mohammed Subhan Khan

Shanghai Cooperative Centre for WEEE Recycling, Shanghai Polytechnic University: Professor Jingwei Wang

pManifold: Akshay Gattu and Rahul Bagdia

Acknowledgements

The authors are grateful to: Mr. Neeraj Kohli (Tata Chemicals), Mr. Raman Sharma and Mr. ALN Rao (Exigo Recycling), Ms. Sonia Singh and Mr. Rohan Singh (Ziptrax), Mr. Abhinav Mathur and Mr. Nitin Gupta (Attero), Mr. Utkarsh Singh and Mr. Vikrant Singh (Batx), Ms. Richa Devale (Eco Tantra), Mr. Ajai Singh (E-Waste recyclers India) and Mr. Santosh Kumar (Li-Circle)

Suggested Citation

NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, Perspectives of Global and Domestic Companies on Advanced Chemistry Cells Battery Reuse and Recycling, July 2023

About the

Green Growth Equity Fund Technical Cooperation Facility

The Green Growth Equity Fund Technical Cooperation Facility (GGEF TCF) aims to catalyse private investments into Indian green infrastructure projects. The project is being delivered by an OPM-led consortium of PwC, Arup, Vivid Economics, and the UK India Business Council (UKIBC).

The GGEF TCF supports a flexible portfolio of technical assistance in developing and strengthening the pipeline of investable projects, tackling policy and regulatory barriers, and strengthening poverty and social benefits, while drawing from international expertise on expanding green markets. It is funded by the UK Government.

Executive Summary

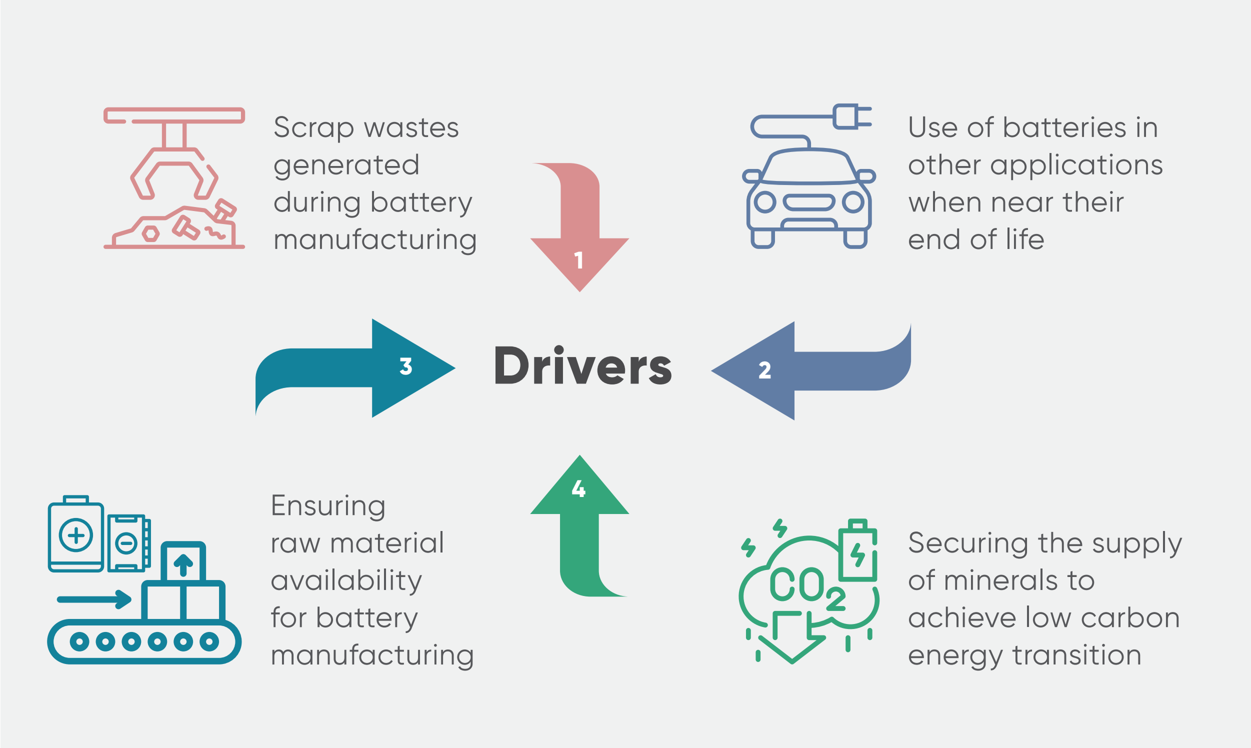
This study is a component of a three-phase programme for the reuse and recycling of ACC batteries in India carried out on behalf of NITI-Aayog as a part of the UK Foreign & Commonwealth Development Office-funded Green Growth Equity Fund Technical Cooperation Facility (GGEF TCF). In the first phase, we described the market for reuse and recycling and projected the chemistries used in those processes. We also discussed the quantity of raw materials needed for recycling that will be produced between 2022 and 2030. In the program's second phase, the viewpoint of the industry is being explored, and detailed discussions with several recyclers in India and overseas have taken place, including visits to their units. **This report assesses the perspectives of domestic and international battery recyclers on the evolving market, technology needs as well as opportunities and barriers for investment in India.** This is a very crucial step to enable the setting up of advanced recycling plants in India, as this will clarify the business requirements and different enablers required. It is based on interviews and engagement with eight domestic and ten leading international recyclers, and global experts, and a literature review. It focuses primarily on **recycling rather** than the reuse or repurposing of batteries. Both the Indian recycler study and this international recycler study build on our team's original analysis of the battery recycling market for NITI-Aayog.

There is a growing market for battery recycling and reuse in which companies are pursuing different strategies and priorities as they jostle for market share.

The background to this is that India and the world are on the cusp of surging demand for advanced chemistry battery cells for energy storage, which can further be used for varied applications including electric vehicles and renewable integration. International commitments under the Paris Agreement and other global and national targets to limit global temperature rises to well below 2°C and achieve net zero emissions on an urgent basis have led to policy attention towards Battery storage. In doing so, the transport sector comes under priority for the transformation and hence an increasing number of countries have launched campaigns to incentivise electrical transportation, thus requiring fast growth of battery manufacturing as well as EV manufacturing.

Battery recycling and reuse are driven globally by four imperatives.

First, battery manufacturing creates scrap waste that requires processing and recycling – the base of today's battery recycling business alongside waste from consumer electronics. Second, as batteries near their end of life, they will require recycling or reuse in other applications at scale. Third, the need for recycling or reuse is amplified as critical minerals required in battery manufacturing (e.g., cobalt, lithium, nickel, and rare earth elements) are finite and already subject to high costs. Fourth, these minerals are concentrated in a few countries – ensuring the security of supply is essential in achieving the low-carbon energy transition.

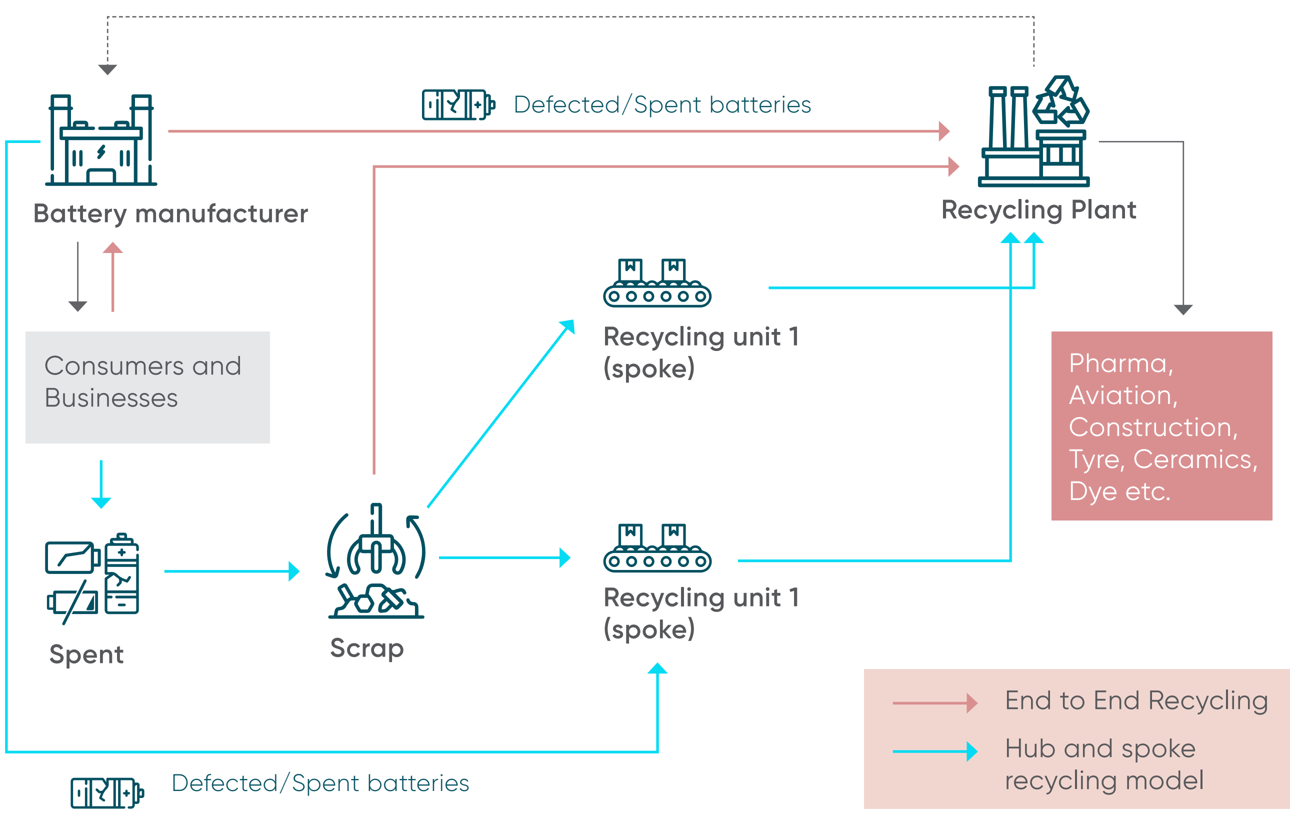


A circular economy for battery components is thus becoming an increasing necessity. Today, China plays a leading role in the manufacturing, reusing, and recycling of batteries. Other markets are catching up. Companies are positioning themselves for a share in this growing global market.

The battery recycling and reuse market is not only growing but also changing rapidly as battery chemistries, processes and policies evolve – with each of them shaping the priorities and investment strategies of recyclers.

Perspectives of domestic recyclers

According to the Central Pollution Control Board's (CPCB) authorisation issued under the E-Waste (Management) Rules 2016, there are about **472 dismantlers/recyclers** registered in India, with a total installed capacity of about 14,26,685 metric tonnes per year. In India, recycling lithium-ion batteries is majorly done via two channels, end-to-end recycling, and mechanical extraction of black mass. **End-to-end recycling** is a comprehensive process of recycling under which the company



undertakes the complete operational aspect of the recycled product starting from receiving the used batteries from collection centres, extraction of black mass, and segregation of critical minerals to finally making the recycled batteries. This model is not widely adopted yet in India due to policy and demand issues and technology barriers. Although, with the entry of big players into the market, the scenario is forecasted to change.

The other mode of LiB recycling in India is the **extraction of black mass via a mechanical process (dismantling).** In this, the companies receive the used batteries from the organized and unorganized sectors and by using the mechanical process extract the black mass (separating aluminium, cobalt, and plastic components from the rest of the materials left in the form of a black mass). They further send it to other large companies which are technologically equipped to extract minerals out of the black mass or transport it to their centralised hub in foreign countries.

The team interviewed eight domestic companies including TATA Chemicals, Attero, Exigo, Ziptrax, etc. that already have an established recycling facility in India.

Key recycling operators	Location	Technology	Lithium-ion Battery Recycling capacity (tonnes/year)	Battery Chemistries Preferred for Recycling
Tata Chemicals	Palghar, Maharashtra	Hydrometallurgy	1200-1400	LCO (most preferred), NMC
Exigo	Panipat, Haryana	Mechanical + Hydrometallurgy	10000 (7200 for Lithium-ion)	NMC (most preferred), LFP is also viable
Attero	Roorkee, Uttarakhand	Mechanical + Hydrometallurgy	4000	NMC (most preferred), LFP, LCO
Batx	Sikandrabad, Uttar Pradesh	Mechanical	4000-5000	LFP, NMC, LCO (Black mass)
Ziptrax	Delhi, NCR	Mechanical + Hydrometallurgy	350	NMC, LFP, LCO
Li-Circle	Bangalore, Karnataka	Mechanical	1000	NMC and LCO are most preferred as Nickel and Cobalt content is higher

Finally, the two companies namely **Eco Tantra** and **E-waste recyclers India** were interviewed. Although they are both well-known in the e-waste and lead-acid battery recycling industries, they have not yet begun recycling lithium-ion batteries. Instead, they are now preparing to build their lithium-ion battery recycling facility in India. Additionally, to have a first-hand understanding of the entire battery recycling process, the team and NITI Aayog visited two of the above-mentioned battery recycling facilities.

Alongside established recycling and reuse companies, new players and start-ups are entering the market and are experimenting with new technologies – often backed by venture capital firms or venturing arms of miners, EV manufacturers, etc. **To understand the determinants of corporate strategy and investment choices, we conducted interviews with leading international battery recyclers and have had discussions to visit one or two players (within Asia) to obtain varied feedback and perceptions about risks and opportunities in the battery recycling sector from a global perspective.** International recyclers interviewed included global mining leaders in Europe, three Chinese recyclers, and global recyclers. NITI Aayog validated the semi-structured questionnaire that served as the basis for these interviews.

The supply-demand gap along with the limited known reserves which can be commercially mined, of high-value metals (e.g., cobalt, lithium, nickel) will make recycling and reuse indispensable over time and recyclers unanimously expressed their expectation of high profitability of EV battery recycling given their industry-leading efficient processes, price expectations, and policy incentives and regulations such as extended producer responsibility (EPR) schemes. Life-Cycle Assessments (LCA) are becoming central in the sector and manufacturers and recyclers are positioning themselves to build up sustainable business models to avoid failing compliance. The recyclers are also wary of the fact that the machinery and plant itself should be operationally sustainable and emission-free.

Perspectives of international recyclers

Leading international recyclers' strategies reflect expectations of market growth, a desire for involvement along the battery value chain and a perceived better opportunity for sourcing spent batteries through business-to-business rather than direct business-to-customer relationships. Companies are seeking combined options across the reuse of batteries and recovery of valuable minerals from end-of-life LiBs through recycling. We also foresee that a Major chunk of the market for LiB would be B2B as LiBs are not only costly to buy have good value after the first and second use. In addition, these batteries wherever used are tracked (IOT enabled), therefore easy to collect in an organised manner, and also recently released Battery management rules and Extended producer responsibility further strengthens this argument.

Interviewed International recyclers anticipate lithium-ion battery (LiBs) recycling to grow rapidly globally, particularly in Asia and Europe. Key drivers for growth are around **policy and regulations** that support companies such as with transboundary movements of materials. **The scale of battery recycling operations** is also key. **Line of sight to sufficient market size** and partnership opportunities with EV and or battery manufacturers (OEMs) are driving investment choices as they can have a strong position in the EV market.

International battery recyclers are interested in investing in India, but the country is seen as a relatively nascent market. Whilst some international recyclers have early-stage in-country operations, others have established representation within India but are not active in recycling yet. All interviewed firms expressed a need to learn more about India's market growth potential and Government initiatives. **The lack of familiarity with the Indian market is a barrier for investors who do not yet have partners in India or operating experience in the country.** Battery collection and pre-processing are seen as major operational risks for recycling in India: the prevalence of informal dismantling and processing of battery scraps in India may present cost advantages, but it creates liability challenges for potential investors. The lack of battery and electronic waste traceability systems is also perceived as a barrier to investment.

Recommendations

The scale of the current domestic LiBs market in India is insufficient for international investors to set up large-scale operations within the country now. Interviewed recyclers see India as having a choice between becoming a 'spoke' or a 'hub' in the future global battery recycling market. The expected volume of batteries within India will imply rapid growth in recycling, but a modest profile by global standards over the medium-term. Allowing imports of black mass with lower duties and incentives could propel India as a regional hub. Ultimately, the economics of recycling and reuse in India relative to other countries will determine where international firms invest. A summary of recommendations based on our consultations with international and domestic recyclers, and a literature review are highlighted below:

Demand assurance measures

- Ensuring effective implementation of the EPR target and scheme
- Digitizing waste management to streamline and channel waste effectively
- Establishing proper battery collection channels through tie-ups
- Implementing battery traceability to keep track of the used batteries
- Establishing reuse targets for passenger and commercial electric vehicles

Policy Support

- Develop legislation for adequate storage and disposal of used LiBs
- PLI type incentive for setting up battery recycling facilities
- Fixing specific recovery rates to encourage more participation
- Specifying guidelines for transportation, labelling and handling
- of used LiBs
- Establishing guidelines and associate standards for battery reuse in the country

Financing & Incentivising

- Relaxing import restrictions on scrap metals and waiving the duties on special lab equipment required for recycling
- Incentives in the form of viability gap funding to make LFP recycling profitable
- Providing tax exemptions and subsidies for the establishment of lithium-ion battery recycling plants in the country
- Funding research organisations to come up with commercially viable recycling processes with high recovery rates

Miscellaneous

- Establishing new labs for faster validation and sample checks
- Examining battery degradation and developing diagnostic technology to determine a battery's feasibility for reuse
- Establish platforms for stakeholder consultation between the government and industry players on battery-related policies
- Support to battery recycling start-ups and recycling 'spokes'

This report is structured as follows. Section 1 highlights the recycling and reuse market in India and summarises domestic recycling companies' operations and portfolios. Section 2 provides a brief overview of the economics of battery recycling and reuse as well as the global focus of activity. Along with our approach to selecting international recyclers for an interview and summarising the perspectives of global battery recyclers on the evolving market. In Section 3, regulations and policies of leading countries and regions are highlighted on recycling and reuse. Section 4 contains the overall conclusions, opportunities, and recommendations for India to attract investments and improve the recycling and reuse ecosystem.

Table of contents

List of tables

List of figures

List of abbreviations

ACC	Advanced Chemistry cells
ASM	Artisanal and small-scale mines
BMW	Bearish Motored Werke AG
CAGR	Compound Annual Growth Rate
CPCB	Central Pollution Control Board
CN	China
Co	Cobalt
CO2	Carbon dioxide
EOL	End of Life
EPR	Extended producer responsibility
EU	European Union
EV	Electric Vehicle
FCDO	UK Foreign, Commonwealth and Development Office
FER	First Examination Report
GGEF	Green Growth Equity Fund
GHG	Green House Gases
HSE	Health, safety, and environment standards
HW	Hazardous waste
IN	India
JP	Japan
Kg	Kilo gram
KR	Korea
LAB	Lead Acid Battery
LCO	Lithium Cobalt Oxide
LFP	Lithium Iron Phosphate
Li	Lithium
LiB	Lithium Ion Battery
LMO	Lithium Manganese Oxide
LNO	Lithium Nickel Oxide
LTO	Lithium Titanate
NCA	Lithium Nickel Cobalt Aluminium Oxide
Ni	Nickel

NiCad	Nickel Cadmium
NiMH	Nickel Metal Hydride
NMC	Lithium Nickel Manganese Cobalt Oxide
OEM	Original equipment manufacturer
OPM	Oxford Policy Management
PRO	Producer Responsibility Organisation
RUL	Remaining useful life of battery
SOH	State of health of battery
SOS	State of safety of battery
TCF	Technical Cooperation Facility
TPA	Tons Per Annum
UKIBC	UK India Business Council
USA	United States of America
USD	United States dollar

Chapter 1

Overview of Recycling and Reuse Interventions

The global demand for batteries as such has grown at a CAGR of 25% in the last decade to reach an annual demand of over 730 GWh and by 2030 it is expected to grow fivefold, resulting in annual demand of about 5100 GWh[1]. This surge in market deployments throughout the global electric and transportation sector is majorly due to the increasing adoption of electric mobility as a response to decarbonising the transport sector, lower battery storage prices, and increased variable renewable energy generation. This demand in turn necessitates the need for increased extraction of raw materials. Recycling batteries, thus, becomes an important aspect of the entire supply chain. It is crucial not only for securing the supply of key raw materials for the future but also for reducing the need for new mineral extraction, thereby lowering the environmental footprint manifold. Strategically this is also important to achieve Net Zero and reduce dependency on future Oil (i.e. cell raw materials and their processing).

1.1. Need for recycling

LiB-based energy storage seems a promising solution to achieve the targets set by India on the global stage, however with growing supply chain concerns and the need for raw materials, it becomes important to have a robust recycling ecosystem to ensure that useable minerals from batteries can be extracted to manufacture new batteries. Several challenges need to be addressed to make the LiB value chain sustainable, including limited resources, environmental hazards, and geopolitical risks. Promoting recycling can overcome these challenges and also lead to better price discovery of the resale value of EVs (also second life of batteries). The following are some of the key drivers for battery recycling and reuse:

Limited raw material availability:
With the increasing battery demand, the demand for raw materials is also expected to grow significantly. According to BNEF, the global consumption of lithium-ion battery raw materials such as cobalt, lithium, and copper is expected to increase 20 times by 2030. However, the reserves of such battery minerals are limited in nature and as such, it is almost imperative to have recycling infrastructure and technology in place to fulfil the demand of battery manufacturers.

Environmental and Health Hazards:
If the increasing amount of battery waste is not handled properly, these batteries could end up in a landfill. The high percentage of hazardous heavy metals like nickel and cobalt could leak from the casing of end-of-life LiBs if left untreated and contaminate soil and groundwater. Additionally, lithium-ion battery wastes can get absorbed and accumulated in edible plants and can enter the food chain, thereby causing various genetic, reproductive, and gastrointestinal problems. A well-established recycling ecosystem will encourage the key stakeholders along the LiB value chain to

[1] NITI Aayog, GGEF Report - Advanced Chemistry Cell Battery Reuse and Recycling Market in India, 2022 https://www.niti.gov.in/sites/default/files/2022-07/ACC-battery-reuse-and-recycling-market-in-India_Niti-Aayog_UK.pdf

participate in recycling and avoid the unsafe disposal of batteries in the country thereby reducing the negative effects of batteries on the environment.

Geopolitical Risks:

India is expected to depend on imports from neighbouring and developed countries to cater to the growing LiB market. Metal prices could fluctuate as a result of supply chain disruptions, political instability, pandemics, etc., which could directly affect the price of batteries and associated products. India could take advantage of these situations by attracting both global and domestic recyclers to set up LiB recycling facilities in the country. This also includes the risk from the factors such as Russia Ukraine war. This has resulted in supply chain disruption for Nickel (Russia and Ukraine command 10-12% of Nickel supply market in the world). Hedging such risks is not an easy task.

Furthermore, with a well-established recycling ecosystem for batteries, part of the metal or cell component import can be offset with recycled materials, which can reduce dependence on imports and save forex for the nation while avoiding various geopolitical risks.

Reduction of GHG emissions:

Mineral mining creates environmental pressure as it has several negative effects on the environment. For example, the production of nickel from its naturally occurring form of oxides needs huge rotary kilns to remove the high-water content. which involves the burning of fossil fuels for energy leading to GHG emissions.
The environmental impact of metal recycling from LiB waste is thus significantly less than from metal extraction from the mines as it can reduce the CO2 emissions from the production cycle by up to 90%.

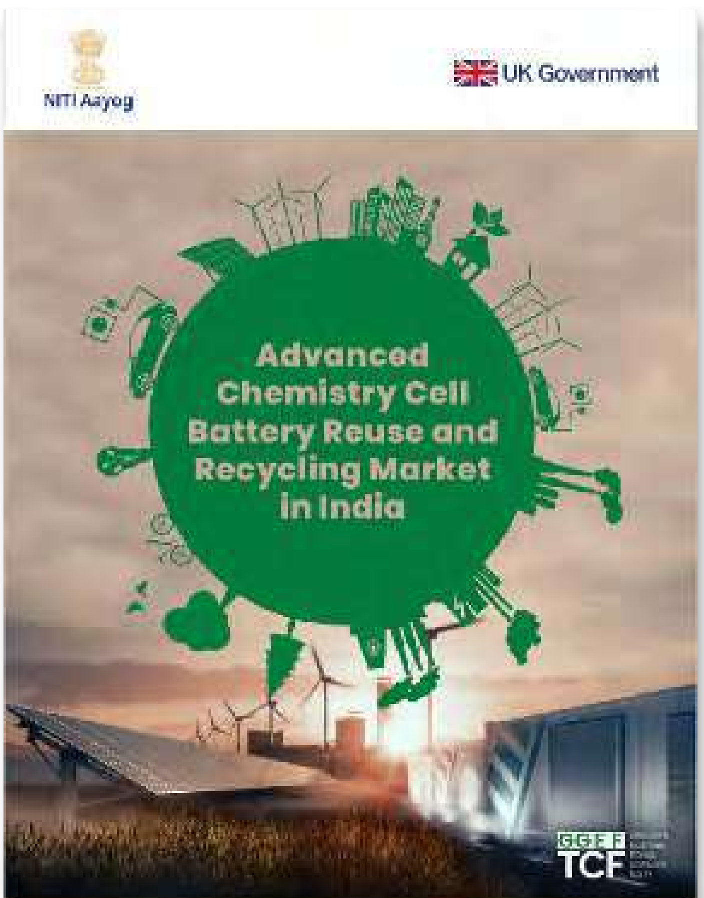
Price Discovery:

Resale risk is one of the asset risks that is currently hindering the confidence of financial institutions in mobilising finance for EVs. Creating a well-established reuse/recycle ecosystem can help discover the resale value of batteries for reuse/recycling applications. While collection and recycling of end-of-life LiBs will recover the value of the minerals, the value of the residual capacity can be captured through second-life applications. Reuse prolongs the use of an EV LiB, delaying the need for recycling. This way, creating a resale market for batteries from EVs, can reduce the asset risk that financial institutions perceive. This will increase the mobilisation of finance for EVs, thus improving the adoption of EVs.

1.2. Overview of recycling technologies

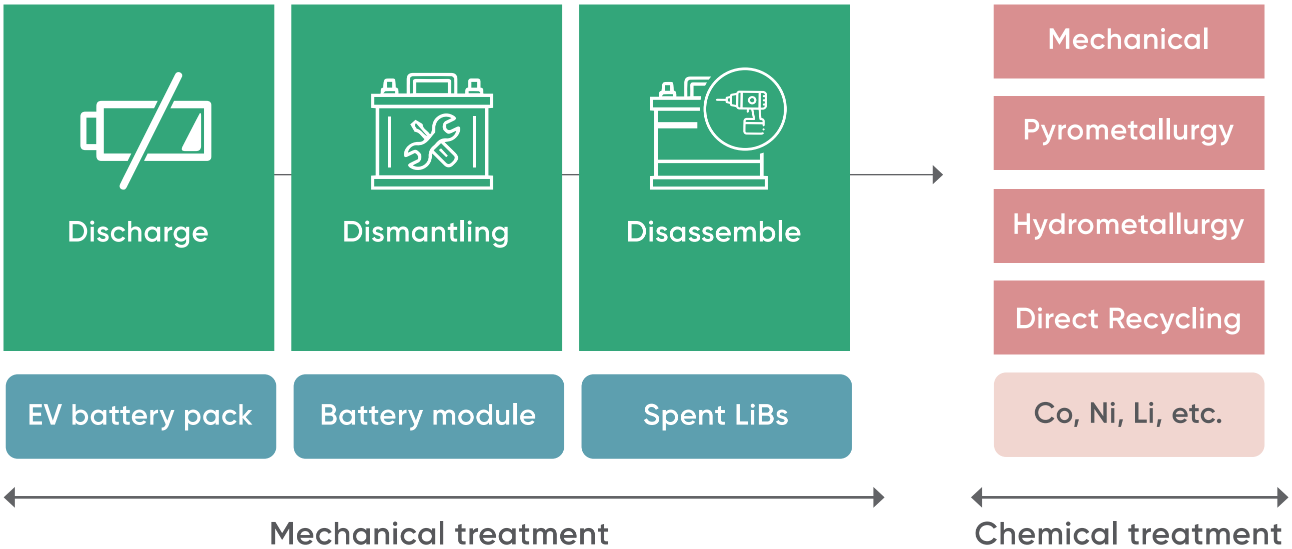
The recycling technology of LiBs is a complex process compared with battery technologies such as Lead Acid Batteries (LABs), Lithium Nickel Cadmium (NiCad), Lithium Nickel Metal Hydride (NiMH) and others. This is because the electrochemical reaction between the anode and cathode material of later batteries is quite simple, and their water-based electrolyte makes them insensitive to thermal or mechanical damage or abuse. The material used in these battery technologies can contribute to ecological and human toxic effects. On the other side, **LiBs contain volatile, flammable electrolytes, and fine solid particles such as metal oxides and graphite, which possess a risk of fire and pollution in case of any leakage.** Therefore, LiBs need to be recycled with great caution and in a safe environment.

There are primarily four recycling methodologies namely, mechanical, pyrometallurgy, hydrometallurgy, and direct recycling. These have been discussed in detail in the first part of this study on the Advanced Chemistry Cell Battery Reuse and Recycling Market published by NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, May 2022[2] .



[2] NITI Aayog, GGEF Report - Advanced Chemistry Cell Battery Reuse and Recycling Market in India, 2022 (Page 92) https://www.niti.gov.in/sites/default/files/2022-07/ACC-battery-reuse-and-recycling-market-in-India_Niti-Aayog_UK.pdf

Figure 1: Lithium-ion battery recycling process *Source: IFRI, France*



Mechanical:
In mechanical processing, the batteries are dismantled using a two-step crushing technique. In the first crushing process, a cyclonic air separator removes all the electrolyte and reaction gases, including hydrogen and oxygen, accumulated within the crusher. This process may not be required if the input to the crusher is received after thermal pyrolysis pre-treatment. In the second crushing process, the crusher reduces the raw material to small pieces of 0–6 mm. All the gases and dust generated in this process are removed/collected in a second air mover. The output is separated (i.e., sorted) into two parts: iron, copper and aluminium flakes; and cobalt and nickel electrode powder.

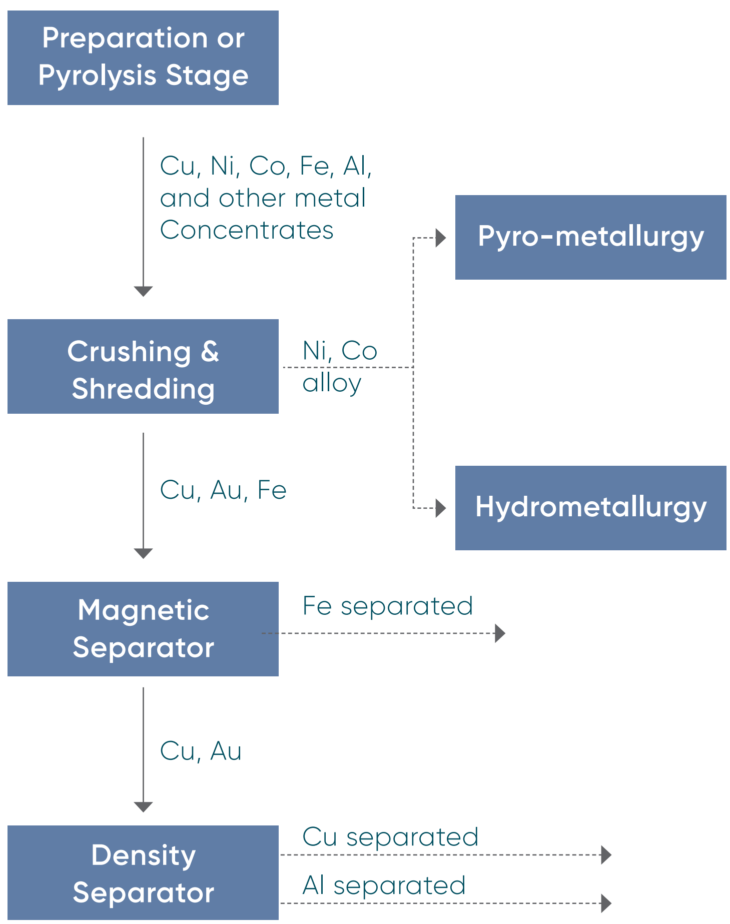


Figure 2: Mechanical recycling process

Pyrometallurgy:
It involves putting the batteries into a high-temperature smelter to reduce the component metal oxides into alloys. These alloys so obtained are put through chemical processes to obtain the desired materials. The advantage of this technology is that it removes undesirable materials like electrolytes (containing fluorine), phosphorous, graphite, and plastics, and the output metal alloy contains far fewer impurities, which is beneficial for hydrometallurgical performance and recovery efficiency.

This method is suitable for all except LFP because the presence of phosphorous ions can affect the process. Furthermore, Pyrometallurgy is operationally very expensive since it requires the minimum temperature to start smelting and reduction, batch processing cannot be started with minimal quantity.

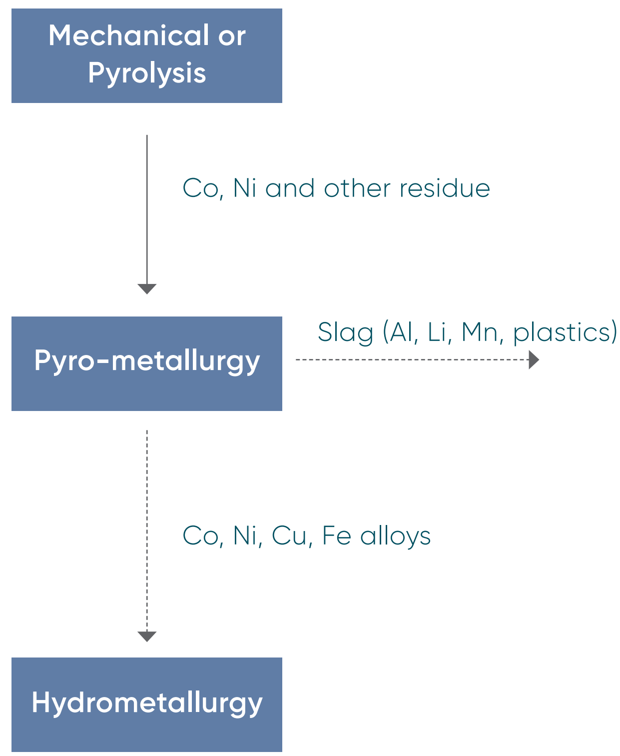


Figure 3: The pyro-metallurgy recycling process

Hydrometallurgy:
The battery waste containing precious metals undergoes acid-based leaching (using chlorine) and then metal ions such as Cu^{2+}, Al^{3+}, Fe^{2+}, Co^{2+}, and Ni^{2+} are separated into various solutions. These metal ions are then passed to a solvent extraction chamber (liquid-phase synthesis and high temp treatment) to produce cobalt and nickel salts used in battery production which can be further extracted to recover precious metals like nickel and cobalt and other metals.

The hydrometallurgical route has significantly lower carbon emissions and energy usage in comparison to pyrometallurgy.

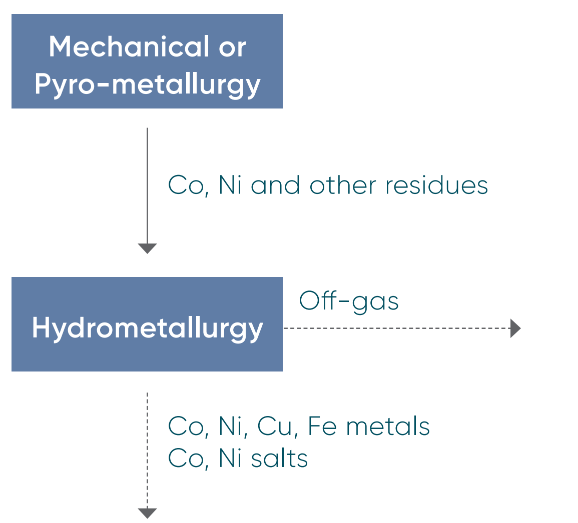


Figure 4: The hydrometallurgy process

Direct Recycling:

In this method, cathode and anode materials are separated (by mechanical separation), reconditioned, and then directly reused for LiB manufacturing. The main recycling steps are the mechanical separation of electrodes, followed by washing, filtering, and drying. This method shortens the recycling process and most of the LiBs constituents can be recycled. This kind of recycling technique is applicable to pouch and prismatic cells but less suitable for cylindrical cells.

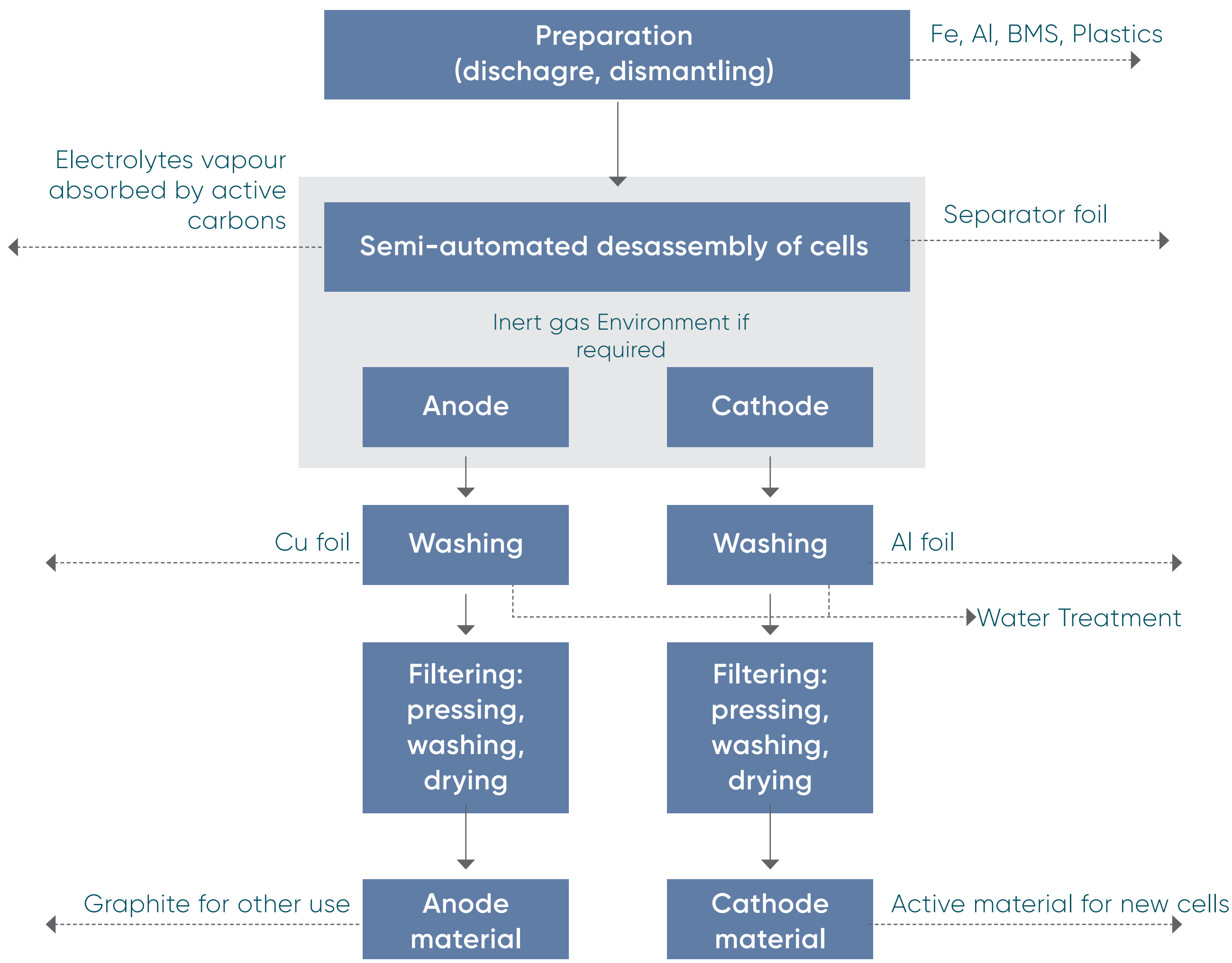


Figure 5: Direct recycling process

Keeping in mind that Lithium-ion chemistry is expected to remain the mainstay in the future coupled with the environmental impacts of various recycling technologies, hydrometallurgy is considered an ideal choice for recovering materials from batteries. Furthermore, the recovery efficiency of up to 95% is possible with hybrid technology such as mechanical + hydro processing.

1.3. Recycling and Reuse Market in India

India has set an ambitious target of 500 GW of non-fossil fuel-based energy generation and to reduce one billion tonnes in total projected carbon emissions by 2030 . To meet these targets, India will need to ramp up its grid storage and significantly increase the number of electric vehicles (EVs). Lithium-ion batteries are expected to play a crucial role in India's energy transition by enabling deep decarbonisation of the transportation and power sector. It is expected that the next decade will be dominated by lithium-ion batteries owing to the rapid technological development of chemistry and falling prices. Therefore, with this rapid growth of battery demand, adequate implementation of reuse and recycling of batteries will not only enhance the resource security implication of the country's vehicle electrification and energy transition ambitions but also result in economic development and job growth, while ensuring improved public health and environmental safety.

As per a study conducted by NITI Aayog and GGEF on the ACC reuse and recycling market in India, it is estimated that the cumulative potential of lithium-ion batteries in India from 2022-30 across all segments will be around 600 GWh (base case) and the recycling volume coming from the deployment of these batteries will be 128 GWh by 2030, out of which almost 59 GWh will be from electric vehicles segment alone. In addition to this, batteries from electric vehicles can also be reused at the end-of-life in small and large grid-scale storage resulting in a cumulative reuse volume potential of around 49 GWh by 2030 in the country[4] .

1.3.1. Lithium-ion battery recycling

Lithium-Ion batteries contain critical minerals like lithium, cobalt, manganese, graphite, and nickel which have high energy density thus extracting them is essential both economically and commercially. The e-waste management rule, of 2016 overlooks the Lithium-ion battery recycling market in India, and the recent amendment made in it aims to formalize the e-waste recycling sector, tackling the problem of the unorganized battery collection sector.

Table 1: Stationary applications

Metals	Share of minerals in Lithium-ion batteries	Abundance	Used in Industries
Cobalt	LCO (15%), NMC 111 (5%), NMC 622 (2%) NMC 811 (3%) and NCA (2%)	Rare Metal	Healthcare, cutting tools, Battery Manufacturing, Aerospace

[4] NITI Aayog, GGEF Report - Advanced Chemistry Cell Battery Reuse and Recycling Market in India, 2022 (Page 64) https://www.niti.gov.in/sites/default/files/2022-07/ACC-battery-reuse-and-recycling-market-in-India_Niti-Aayog_UK.pdf

Nickel	NMC 811 (13%), NCA (11%), NMC 622 (10%) and NMC 111 (5%)	Rare Metal	Steel making, Electroplating, Battery Manufacturing
Lithium	NMC, LFP, LCO, NCA and LTO [All 2-3%]	Abundant	Ceramics, Pharma, Aviation, Battery Manufacturing
Copper	LMO (16%), NCA (12%) and LFP (11%)	Abundant	Power, cables, Battery Manufacturing
Graphite	LCO, NCA and LMO (15% each)	Abundant	Construction, Foundry, Tyre and Dye Industry, Battery Manufacturing

**Note: Only battery chemistries having high percentage share is mentioned*
Source: Author's Analysis

Lithium-ion is rationally harmless if disposed of properly. They can't be landfilled on account of harmfulness and risk of explosion, nor they can at any point be burned as the ashes are additionally poisonous in a landfill. Apart from this, the major concerns come from cobalt and agents that bind the electrode material together.

In order to recycle lithium-ion batteries, they are first fully discharged to remove any stored energy and to eliminate any explosion in case of a thermal event. Further crushing and dismantling of batteries are done through mechanical treatment. Once dismantled, separation of copper foil, aluminium foil, separator, and the coating material is done. Nickel, cobalt, and copper can be reused from the cast, however, lithium and aluminium stay in the slag. A hydrometallurgical interaction is important to recover lithium. This incorporates filtering, extraction, crystallization, and precipitation from a fluid arrangement. Hydrometallurgical treatment is utilized to recuperate unadulterated metals, for example, lithium gathered from isolated covering materials after mechanical cycles or from slag in pyrometallurgical processes[5] .

In India, recycling lithium-ion batteries is majorly done via two channels, end-to-end recycling, and mechanical extraction of black mass. **End-to-end recycling** is a comprehensive process of recycling under which the company undertakes the complete operational aspect of the recycled product starting from receiving the used batteries from collection centres, extraction of black mass, and segregation of critical minerals to finally making the recycled batteries. This model is not widely adopted yet in India due to policy and demand issues and technology barriers. Although, with the entry of big players into the market, the scenario is forecasted to change.

The other mode of LiB recycling in India is the extraction of **black mass** via a mechanical process (dismantling). In this, the companies receive the used batteries from the organized and unorganized sectors and by using the mechanical

[5] Duesenfeld, n.d. Ecofriendly Recycling of Lithium-Ion Batteries, Accessed 2 June 2022 https://www.duesenfeld.com/recycling_en.html

process extract the black mass (separating aluminium, cobalt, and plastic components from the rest of the materials left in the form of a black mass). They further send it to other large companies which are technologically equipped to extract minerals out of the black mass or transport it to their centralised hub in foreign countries. This gives rise to a hub-and-spoke model in the recycling industry. Currently major players in recycling of batteries and electronic waste in India are either doing black mass only or stops after extracting 2-3 metals.

The metals extracted from black mass like lithium, nickel, cobalt, etc have other industrial applications as well. Lithium finds its applicability in ceramics, pharmaceuticals, aviation industry. Cobalt has its industrial applicability in aerospace, electricity generation, aircraft, medical, automotive, and military-related industries. Nickel is demanded in electrical & electronics, oil & gas, energy & power, and automotive industries.

Recycling Li-ion batteries is still in its nascent stage and has some pressing barriers linked to it like cost feasibility. Therefore, reusing and repurposing used Li-ion batteries proposes a great substitute for the recycling method. The idea behind Li-ion battery reuse is that, even after the Li-ion battery are declared unfit for EV vehicle application, they still possess 80% capacity which has a wide variety of applications in stationary energy storage. Forecasting the EV market, projected growth over the next 10 years of second-life battery supply for stationary applications could exceed 48 gigawatt-hours by 2030.

1.3.2. Role of informal segment in the supply chain

Currently, the collection and transportation of scrap including the lithium-ion batteries in India is majorly done by unorganized scrap dealers, as they are local aggregators present in every city. They deal with any sort of scrap like newspaper stacks, iron waste, plastic bottles and containers, glass, etc. Once the collection is done, the goods are sorted based on types and which industries or recyclers they can be sold to.

At present, the unorganised scrap dealers govern this informal sector with almost 80-90% of market share in collection and transportation of waste in India. However, with increase in penetration of electric vehicles, more formal channels are progressing as EV OEMs have bilateral agreements directly with recycling companies.

The business model of these scrap dealers is such that their economy is not dependent on a single good or product. They sell almost anything to everything if the end product has value in it.

Figure 6: Informal scrap dealers *Picture courtesy: Medium and Pure Earth*

Hub and spokes model:
Since setting up an end-to-end recycling plant is capital intensive with dealing with hazardous chemicals coming from different batteries, many recyclers only deal in dismantling lithium-ion batteries through a mechanical process and selling the black mass directly to major recyclers (who are mostly located outside India as of now), capable of extracting useful mineral-like Lithium, Cobalt, Nickel etc and sell these to either battery manufacturers or industries like pharma, ceramics and paint etc.
Under direct recycling, the company procures scrap batteries and then extracts useful minerals. It also procures black mass from different recyclers.

Hub and spokes model:

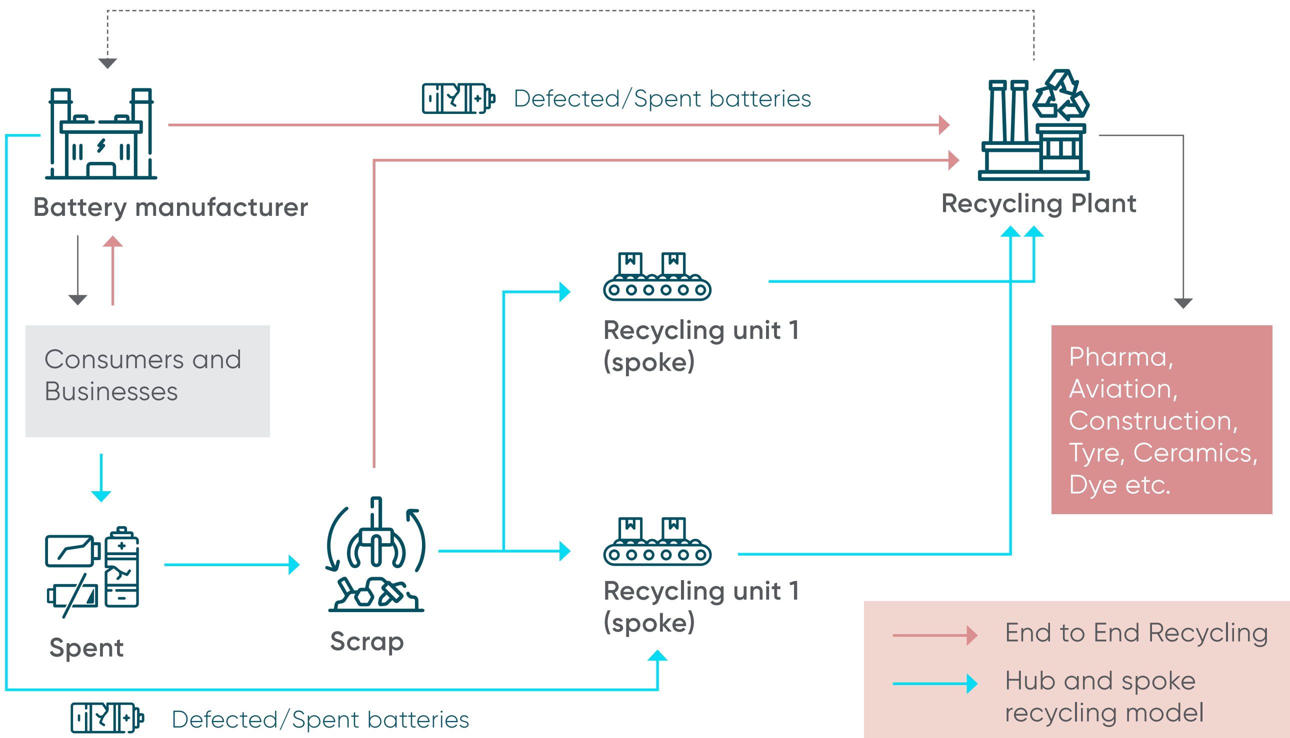


Figure 7: Battery Recycling Models

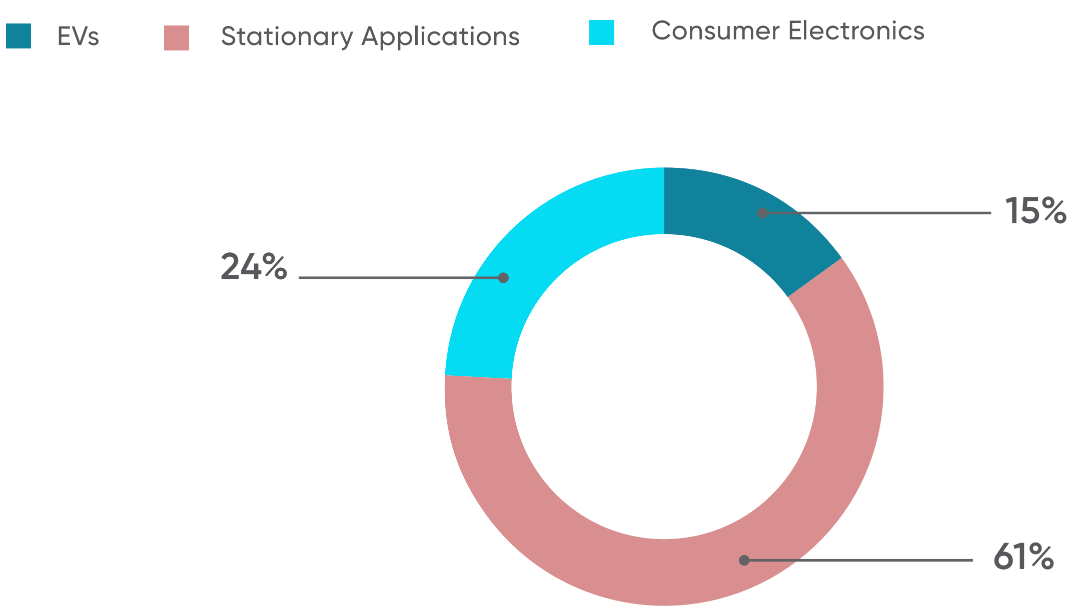


Figure 8: Lithium-ion battery waste produced in India (2021) *Source: Author's Analysis*

Currently, most batteries coming for recycling in India are from the stationary applications like telecom, UPS and inverter segment, followed by consumer electronics , hence unorganized sector is dominant (scrap dealers act as waste collectors) in the collection mechanism. However, with the growth and higher adoption of electric 2 and 3-wheelers in the last 3-4 years, EV and battery manufacturers are adopting direct channels with recyclers to effectively dispose of the end-of-life and defective batteries. The draft battery swapping policy shared by NITI Aayog earlier this year also highlights mechanisms for battery swapping agencies to ensure proper end-of-life recycling of EV batteries. Hence creating an organized channel for collection between battery manufacturers/swapping agencies and recyclers. It is forecasted that going forward the unorganized sector will not be as dominant as it is today, and it will be replaced with organized channels for collection and transportation.

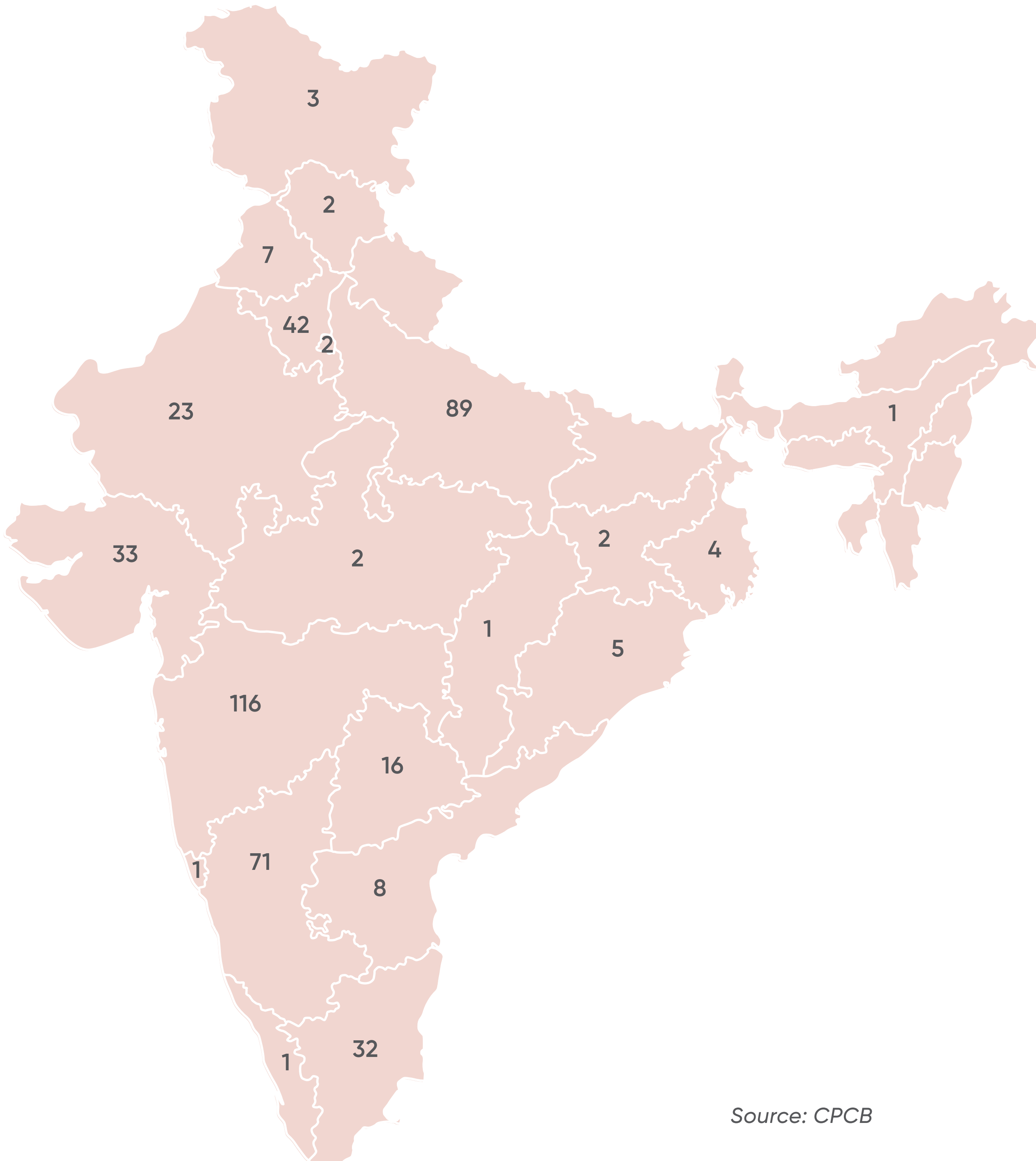
The recycled minerals and metals are being utilized in different industries like pharma, construction, aviation, etc. However, to complete the circularity of the whole process, it should be used in battery manufacturing.

1.4. Domestic recycling companies consulted

As of April 2022, there are around 472 dismantlers/recyclers registered as per the authorization issued by the Central Pollution Control Board (CPCB) under the E-Waste (Management) Rules 2016 with an overall installed capacity of around 14,26,685 metric tonnes per annum[6] . Amongst these e-waste recyclers, there are only a handful of companies dealing in lithium-ion batteries. A major practice that governs the collection of used batteries and emphasises stakeholders' responsibility is EPR (Extended Producer Responsibility). India has inculcated EPR for lead-acid batteries since the formulation of battery waste management rules, in 2001.

[6] CPCB, 2022 - List of E-waste Recycler, Accessed on June 2022 https://cpcb.nic.in/uploads/Projects/E-Waste/List_of_E-waste_Recycler.pdf

Figure 9: State-wise authorised dismantlers/recyclers of e-waste in India



Source: CPCB

The Battery Waste Management Rules, 2022 mandates lithium-ion battery producers to either structure a take-back system or establish collection centres for used batteries[7] ; either individually or collectively through a Producer Responsibility Organization (PRO) recognised by the producer or producers in their Extended Producer Responsibility Authorization (EPRA). The responsibilities levied on the producers under the EPR can also be fulfilled by the policy of buyback, deposit refund scheme, or any other scheme/model. The rules also introduce the policy of exchanging the EPR Certificate from the recycler to the producers in return for the waste battery.

Table 2: EPR Targets under Battery Waste Management Rules, 2022

SL No.	Type of battery	Recovery target for the year in %		
		2024-25	2025-26	2026-27
1.	Portable Battery	70	80	90
2.	Automotive Battery	55	60	60
3	Industrial Battery	55	60	60
4.	Electric Vehicle Battery	70	80	90

The above table lists down the EPR targets for collection and recycling across the four distinct types of battery categories[8] according to the recently established Battery Waste Management Rules. These targets are framed by the government to safeguard battery manufacturers' responsibility for recycling the batteries sold by them in the market and eventually control the growing pollution from battery waste.

There are around 472 plus e-waste recyclers/ dismantlers in India and only a handful of them recycle lithium-ion batteries. From this long list, a subset was chosen for our interview based on their overall significance in the growing battery recycling market in India.

For instance, companies such as Attero, TATA Chemicals, and Exigo have already set up their own lithium-ion battery recycling plants across the country and thus have established themselves as key players in the battery recycling industry ecosystem of the country. Attero being the only company currently to recycle LFP batteries profitably wants to capture 22% of the total potential battery recycling market in India with an investment of around 300 crores (INR). Ziptrax uses advanced technology like artificial intelligence in their recycling facility (patent-pending technology for recovery and rejuvenation of cathode and critical battery materials) to increase the life and monitor the performance of the battery. Additionally, firms like Batx, Li-Circle, and E-Waste recyclers India are also to set up

[7] Ministry of Environment, Forest and Climate Change, Battery Waste Management Rules, 2022, , Accessed on October 2022 https://cpcb.nic.in/uploads/hwmd/Battery-WasteManagementRules-2022.pdf

[8] **Automotive batteries** - Batteries used only for lighting, ignition power, or automotive starter,
Electric Vehicle Batteries - Batteries that are mainly designed to give power to electric or hybrid vehicles,
Industrial Batteries - Includes all batteries that are used in industries to manage heavy machines like forklifts, trucks, etc.
and **Portable Batteries** – Batteries that weigh less than five kilograms and are primarily used in mobile phone, tablets etc.

lithium-ion battery recycling plants across the country in the next two years with plans to expand the capacity further by 2025. The section below provides a brief overview of each of the firms interviewed and their role in the Indian battery recycling value chain.

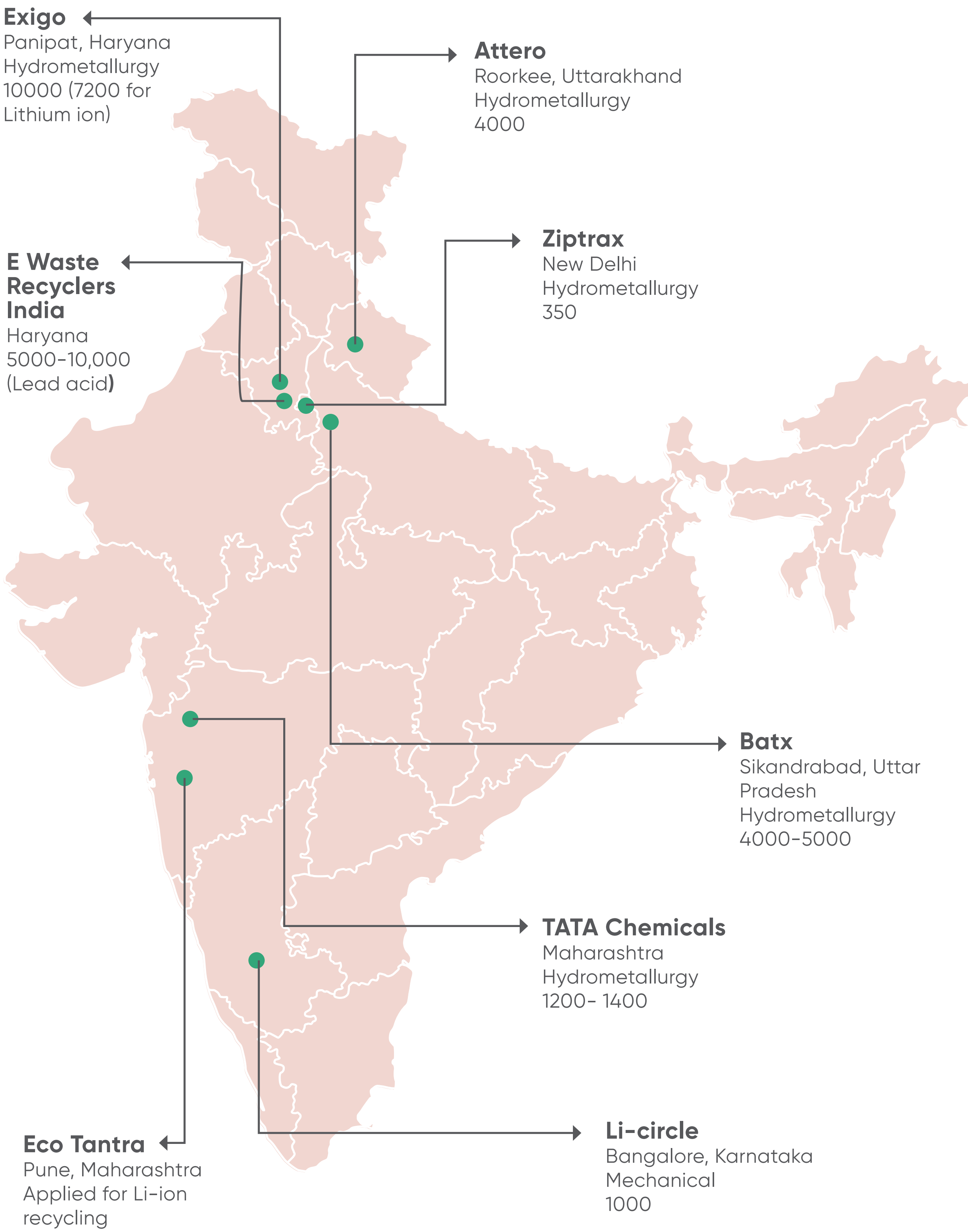
The team interviewed a total of eight companies engaged in recycling lithium-ion batteries, out of which six have an established facility. The remaining two companies namely Eco Tantra and E-Waste recyclers India are yet to start their facilities. Although both are already established players in e-waste and lead-acid battery recycling.

Table 3: List of domestic recyclers interviewed and analysed for this study

Key recycling operators	Location	Technology	Lithium-ion Battery Recycling capacity (tonnes/year)	Battery Chemistries Preferred	Output (Black mass / metals viz)
Tata Chemicals	Palghar, Maharashtra	Hydrometallurgy	1200-1400	LCO (most preferred), NMC	Lithium, Cobalt Sulphate
Exigo	Panipat, Haryana	Mechanical + Hydrometallurgy	10000 (7200 for Lithium-ion)	NMC (most preferred), LFP is also viable	Lithium, Graphite, Cobalt, Nickel
Attero	Roorkee, Uttarakhand	Mechanical + Hydrometallurgy	4000	NMC (most preferred), LFP, LCO	Lithium, Cobalt, Nickel, Manganese, Titanium
Batx	Sikandrabad, Uttar Pradesh	Mechanical	4000-5000	LFP, NMC, LCO (Black mass)	Black Mass
Ziptrax	Delhi, NCR	Mechanical + Hydrometallurgy	350	NMC, LFP, LCO	* Lithium, Cobalt, Nickel, Graphite
Li-Circle	Bangalore, Karnataka	Mechanical	1000	NMC and LCO are most preferred as Nickel and Cobalt content is higher	# Lithium, Nickel, Cobalt
Eco Tantra	Pune, Maharashtra	-	Currently into e-waste recycling, applied for battery recycling licence	LCO is being targeted due to its high profitability	NA
E-waste recyclers India	Haryana and Uttar Pradesh (*In process of establishing Li-ion battery recycling plant in Gujarat)		5000-10000 (Lead Acid)		NA

**Information has not been verified by the author.*
#This is proposed

Figure 10: Distribution of domestic recyclers along with their capacity (tons/year)



1.5. Summary of domestic companies' interviews

Tata Chemicals:

Tata Chemicals' recycling process started with a lab-scale 100 Kg in July 2019, utilizing hydrometallurgy technology to break down most types of lithium-ion batteries, including those based on lithium cobalt oxide (LCO), nickel manganese cobalt oxide (NMC), nickel cobalt aluminium oxide (NCA), etc.

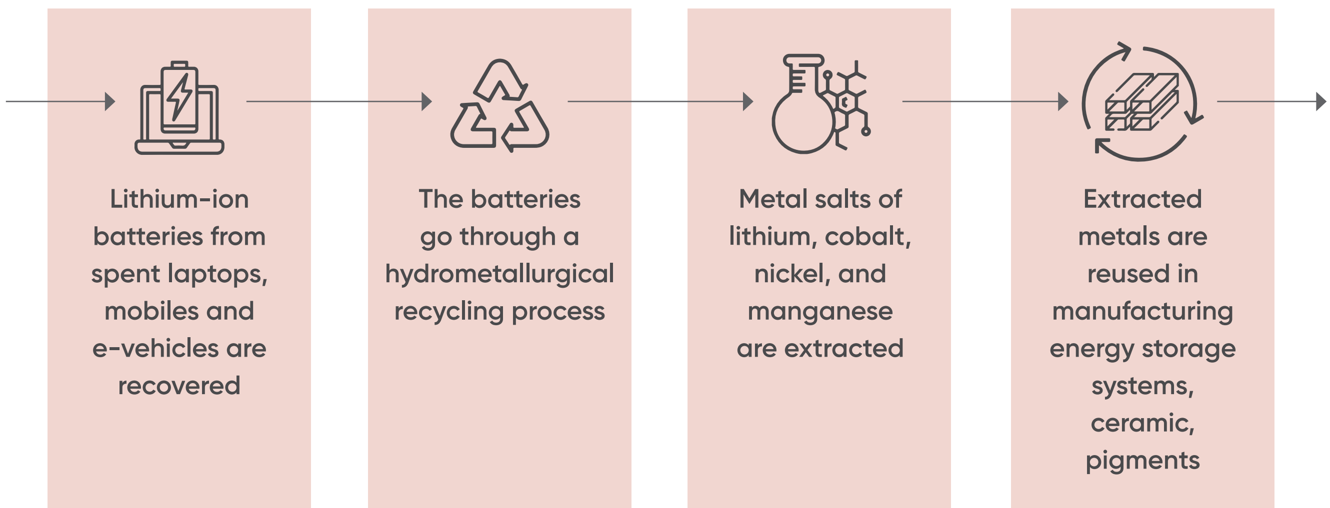


Figure 11: Li-ion battery recycling flow chart for TATA Chemicals

Average rate at which spent batteries are bought are:

- LCO- INR 350-400 per Kg
- LFP- INR 30 to 50 per Kg

The current annual recycling capacity is around 1200 to 1400 tons with a major focus on LCO batteries coming from mobile and laptop segments as they have higher cobalt content. **The extracted cobalt sulphate is sold to various industries namely, animal feed dye, cutting tool industries, etc.** Currently, the company is majorly sourcing the used batteries from consumer electronics applications (laptops, mobile phones, tablets, etc.); however, they can recycle 60 to 120 tons of scrap batteries coming from automobile OEMs annually. This is expected to increase especially due to the growth of the EV market in the next 4 to 5 years.

The company is also working on improving the extraction efficiency percentages beyond 80-90 % to improve the economics of the operation and use the recycled cobalt sulphate or later lithium for battery manufacturing.

One of the primary issues they noticed throughout their time as an established battery recycler is obtaining used or spent batteries directly from the unorganised sector, as costs vary greatly from place to place and are dependent on local waste collectors. However, to solve this problem they suggested the following:

Exploring the import of used batteries and then recycling can be one of the ways to collect batteries and become a global battery recycling hub. However, the government must relax some of India's scrap battery import restrictions to make it more economically feasible.

Exigo recycling:

Exigo recycling has set up its plant in the Panipat district of Haryana with an annual recycling capacity of 10,000 tons out of which 7200 tons are for Li-ion batteries. Currently, they are utilizing end-of-life and scrap batteries coming from electric vehicles and consumer electronics. **The state-of-the-art recycling plant of Exigo is equipped with European Machinery for size reduction, segregation, and pulverization. In addition to this, they also have an indigenously developed hydrometallurgical plant for the collection of precious metals which enables them to recycle and recover up to 98% of recyclable products.** The remaining waste is disposed of through TSDF (Treatment, Storage, and Disposal Facilities). Finally, through designated traders, the recycled minerals are subsequently sold to sectors such as paints, ceramics, and dyes.

Exigo has tie-ups with efficient logistics partners across India to transport the waste in a secure and environmental-friendly way. The reverse logistics service provider for Exigo is Delivery on time Logistics Private Limited (Bizlog) which also operates several collection centres across India for the same.

Exigo is also working towards adding more informal sector partners to collect battery waste and channel e-waste to its recycling operations. In September 2021, they formed a joint venture with MTC Group, the largest metal scrap processor in India, to form MTC-Exigo Recycling Pvt. Ltd (MERPL) to process e-wastes and ramp up recycling capacity. The company feels that the hub and spoke model is the most practicable to run in India right now, but that a plant-in-plant model can be adopted in the future to carry out the mechanical process.

Moving forward, **the company plans to invest in advanced labs and equipment, skilled manpower for running labs and working on technically feasible solutions for industrial projects.** Its R&D also focuses on the material being recycled as knowing the design and composition of Li-ion batteries greatly benefits the recycler in high quality and cost-feasible production.

The following challenges in the current Indian battery recycling market were identified by the company:

- Financing recycling plants is a capital-intensive game that includes land, machinery, and logistics costs. However, banks want collateral, which is difficult for start-ups to offer, thereby restricting them to enter the market as a recycler.

- Challenge in processing includes dealing with heterogeneous material (various battery chemistries), which makes creating processes for high yield and good quality difficult.

- Regulations and restrictions on the import of used batteries act as a hindrance for companies that have the capabilities to steer India as a global recycling hub.

After listing the challenges, they also recommended the following suggestions for policymakers and stakeholders to help attract recyclers to set up recycling facilities in India.

- There should be an entrance level requirement for getting a recycling license because 400+ of the 467 registered recyclers don't even have a plant facility, they merely trade the batteries. This will aid in the elimination of end-to-end pseudo recyclers.

- Incentives should be based on bucket of qualities (70-80%, 80-90%) or on how many metals a company is able to extract from the available scrap batteries.

- Seating up an online portal for monitoring of batteries and cell to ensure safety (currently e-way bill and form 6 are there but it lacks proper monitoring).

- Manufacturers should mention chemistry composition for ease of recycling

- Finally, waive off duties on special lab equipment required for recycling and lessen the import restrictions on scraps materials

Attero:

Attero Recycling has been a pioneer in electronics waste and lithium-ion battery recycling, founded as early as in 2008 it is one of the earliest and the largest electronic waste recycling companies in India. It has invested significantly in research and development and is the only e-waste and lithium-ion battery recycling company that focuses on developing intellectual property and has a rich patent portfolio with more than 30 patents and an extremely large and capable team.

It collects all kinds of lithium-ion batteries, whether it is from consumer electronics like Samsung, Oppo, etc., or coming from stationary storage such as Reliance Jio, or EVs like Hyundai, MG Motors India, etc. The collection of batteries is done through direct contracts with battery manufacturers, EV OEMs, and waste collectors. A team from the electric vehicle maker Tesla has visited Attero's Roorkee plant and there are ongoing conversations to supply battery materials for its Gigafactories. Attero has signed MoUs with almost all the leading EV manufacturers in India for recycling their end-of-life/defected/recall batteries, **catering to almost 75% of the Indian electric vehicle market**. In other words, Attero has secured a lot of contracts and agreements with several batteries and car manufacturers and has partnerships with local as well as global players.

Attero offers world-class Li-ion battery recycling solutions, which are backed with cutting-edge green technology that enables the recovery of critical materials from all types of lithium-ion batteries with an efficiency of more than 98% and claims to be the only company in the world that can **recycle LFP batteries profitably**. It extends a 360-degree recycling process to meet up the scale of recycling lithium-ion batteries and ensure waste goes to landfills. Therefore, Attero enables a carbon-positive circular economy by recovering metals with a high-grade battery purity, and the entire process has a positive impact on the environment and other ESG parameters. They are one of the only companies in the world to be permitted to get carbon credits for each tonne of waste processed in this space.

Currently, Attero has a battery recycling capacity of around 4000 tonnes per year at the plant located at Roorkee, Uttarakhand, of which 30% share already come from EVs, 60% from stationary storage, and 10% from consumer electronics. In the plant, a mechanical process is used to crush the batteries at first to generate the black mass upon which the hydrometallurgy process is applied to take out the recycled materials. With its in-house R&D facility, Attero has developed the majority of the apparatus and processes in-house, and is constantly striving to increase extraction efficiency, product range, and product purity. The battery-grade recycled and green materials (>99% purity) such as Lithium, cobalt, nickel, manganese, and titanium are now being sold to battery cell manufacturers and to traders who in turn supply to battery cell manufacturers. Furthermore, Attero can extract metals and minerals in different forms and at the desired levels of purity and forms based on the requirement of the customers. Some material is also sold at commodity prices to healthcare, ceramics, steel, and other industries.

Some of Attero's lithium carbonate gets sold to pharmaceutical companies for use in medications that treat some neurological disorders. The use of Attero's output by pharmaceutical companies indicates the quality and purity of Attero's end product.

Attero plans to invest 300 crores (INR) in India to raise its recycling capacity to 11000 metric tonnes per year by October 2022, and over 7500 crores (INR) in Europe, the United States, India, and Indonesia to recycle more than 3,00,000 tonne of lithium-ion battery trash per year by 2027. Therefore, by increasing its capacity, Attero wants to capture 22% of the total potential battery recycling market in India. In terms of their domestic expansion

Attero plans to invest 300 crores (INR) in India to raise its recycling capacity to 11000 metric tonnes per year by October 2022, and over 7500 crores (INR) in Europe, the United States, India, and Indonesia to recycle more than 3,00,000 tonne of lithium-ion battery trash per year by 2027. Therefore, by increasing its capacity, Attero wants to capture 22% of the total potential battery recycling market in India. In terms of their domestic expansion strategy, Attero is aiming to set up plants of 5000 tons annual recycling capacity in different states in India namely Tamil Nadu, Gujarat, Maharashtra, Karnataka, Telangana, etc. They have already signed an MoU with Tamil Nadu Government and have identified 120 acres of land in Dharmapuri to set up such plants. The reasons for shortlisting these locations are due to their proximity to a port and the presence of EV and battery manufacturers along with logistic minimization. The company is also planning to set up battery recycling plants in Poland (EU) and Ohio (USA) due to the presence of leading battery manufacturers like LG energy solutions, and SKI along with leading EV manufacturers like Mercedes, BMW, etc.

Attero has a deep focus on the recycling industry and has started to explore the reuse market as well. The reason is that the reuse market is still in a very nascent stage and will depend on how batteries are being utilized. The current battery ecosystem needs to be developed to have proper standards or checks and measures to ensure that the batteries available for reuse can deliver performance. Hence, this segment will not be affecting the recycling market or be utilized at its fullest in near future. Beyond issues with policy and regulation, Attero claims that import limitations on used batteries and black mass are a significant impediment to India being a centre for battery recycling.

Attero is keen to contribute to making India a global hub for environmentally safe lithium-Ion battery recycling. This will allow India to enable the circularity of these highly critical materials which are not available in India and are only available in finite quantities globally. This will be key to ensuring material security which is critical for India's energy security and the success of its EV program.

Some recommendations to enhance the battery recycling ecosystem in the country

- **To turn India into a global hub for battery recycling, strong and aggressive policy support schemes should be initiated by the government and ensured that they are properly implemented**
- **Regulations and certifications should be issued to enable the participation of only mature players with good technology to avoid harmful environmental impact**
- **Central and state governments should provide grants or subsidies in terms of tax exemptions for lithium-ion battery recyclers**
- **Encourage lithium-ion battery recycling companies by providing low-cost loans to support their business expansion**
- **Government should promote duty free import of black mass for recyclers whose technology, efficiencies, and environmental impact have been approved by credible agencies**
- **Usage of recycled minerals should be mandated for cell or battery manufacturers, to highlight commitment to recycling and mineral security in the country**

Batx:

Batx Energies Pvt. Ltd. was founded by Utkarsh and Vikrant Singh in 2020 after three years of research and development, to work on the complete life cycle of lithium-ion batteries. They recycle used lithium-ion batteries to extract battery metals chiefly lithium, nickel, cobalt, and manganese which are then supplied to battery cell manufacturers to create a closed-loop circular economy for lithium-ion cell manufacturing. For this purpose, they have built a 4000 –5000 ton per year lithium-ion battery recycling factory at Sikandrabad, Noida.

The company has recently **raised USD 2.3 million** in a seed funding round led by JITO Angel Network and Hero Family office to **establish** a commercial-scale **rare earth battery materials extraction plant** with artificial intelligence (AI).

Their current **battery recycling plant** in Sikandrabad **is chemistry agnostic i.e., it can recycle batteries used in all types of applications ranging from electronics to electric vehicles.** After years of scientific research and experimentation, Batx has developed its own proprietary Net Zero Waste, Zero Emissions process for recycling end-of-life Lithium-ion batteries.

The batteries coming for recycling are initially completely discharged (pre-treatment) and are then crushed using a mechanical separation unit for the physical separation of the core elements. **Thereafter, using their proprietary process, they extract the highest quality salts of critical minerals such as Li, Co, Ni, etc. These extracted minerals are then sold to the national and international battery material leaders and refining companies** following a global pricing mechanism based on market discovery (LME & Fastmarkets).

Batx Energies is also planning to expand its recycling capacity to 10,000 tonnes/ year by setting up micro lithium-ion battery recycling plants in different parts of India and sourcing its technology to other global players by the end of the year.

Moreover, they are constantly working with global institutes like MIT and prominent domestic colleges like IIT Delhi to develop more sustainable technology for battery recycling, and direct restoration of cathode and cell manufacturing using recycled minerals along with tech development for second-life battery solutions.

Apart from the policy and regulatory challenges, the lack of technological know-how in terms of cell manufacturing, equipment testing, and lack of skilled labour are some of the challenges and risks associated with the battery recycling market in India. During our consultation, they suggested the following recommendations that are needed to boost the recycling segment in India.

- Design a portal wherein OEMs can register the batteries that are being sold, which in turn can be used to keep a track of the reverse logistics
- Subsidies and incentives can be provided to the players setting up battery recycling plants

Ziptrax:

In December 2016, Ziptrax technology was founded to repurpose the discarded Li-ion batteries to eliminate battery waste and reduce environmental damage. **With their 350 MT annual Li-ion battery recycling facilities based in Delhi-NCR and IMIT Mansar, Ziptrax aims to provide a facility to recycle and repurpose these lithium-ion batteries** which retain 70% to 80% of their usability even after they are considered dead. It collects the used batteries, tests, grades, checks, does quality checks, packages them, and makes them available to electric vehicle manufacturers.

Their recycling facility uses advanced technology like artificial intelligence **(patent-pending technology for recovery and rejuvenation of cathode and critical battery materials)** to increase the life and monitor the performance of the battery. **Ziptrax has a zero-waste approach,** as they endeavour to give batteries a second life in mobility and storage applications and **100% of materials that are received by Ziptrax are either recycled or reused.** After recycling, **they sell the extracted minerals such as Lithium, Cobalt, Nickel, and Graphite to cathode manufacturing and chemical/ material refining companies** with a pricing mechanism that is based on LME or Metal bulletin mechanism.

Their target clientele includes stationary storage, EV, and consumer electronics. On the supply side, Ziptrax has great synergies with all three entities stated above and can combine forces with any of the above, however, the most direct association is possible with cell manufacturing companies since 8-10% of cells manufactured will be defective at source and need to be recycled on-site the Gigafactory.

Ziptrax also has a direct association with Cell Manufacturing companies and has long-term agreements with E-waste Management, and EV makers to process their waste volumes. Since August 2021, **Zipbolt Innovations** (their re-use and repurposing company) has diagnosed and deployed over **50 re-purposed battery systems (4-5 kWh/pack)** under collaboration with **Villgro, Mercedez Benz, and WRI India**, for swapping in e-rickshaws and electric scooters. They are also expanding this venture further with **Tata Motors and MG Motors,** with the target of **10 MWh in repurposed batteries** for electric mobility and stationary storage by **March 2024**. Furthermore, Ziptrax is seeking strategic partners and investors to **expand its recycling capacity to 5000 tons per annum** across five key cities in India **by 2025.**

They highlighted governmental and regulatory constraints, logistical challenges, lack of government grants, and a lack of knowledge are the most significant issues in the current situation of battery recycling in India. With these issues in mind, they have already made recommendations to the government under the Committee for Circular Economy of Li-Ion Battery. The key point of those recommendations is as follows:

> In order to implement the proposed rules by the government, EPR is critical and integration with National Energy Storage Mission as well as FAME 2, Battery Swapping Policy, State EV policies and PLI Scheme for ACC manufacturing are important.

Li-Circle:

Li-Circle is a battery recycling start-up based out of Bangalore, India. They have a robust mechanism for safe and reliable reverse logistics/ collection mechanism for end-of-life lithium-ion batteries pan India and soon shall be commercially operating th**e lithium-ion battery recycling plant** of 1000 MT per annum in Bangalore. They collect and recycle lithium-ion batteries irrespective of their chemistry, composition, or application. Li-Circle is majorly working with the EV OEMs and is now exploring partnerships and agreements with battery manufacturers, consumer electronics, and other applications sector OEMs. They are also exploring synergies with recyclers pan India owing to **their target of 25000 MT per annum recycling capacity by the year 2027.** Currently, **they are partnered with a South Korean company for black bass refining**, and parallelly, they have been looking into ways to work with international players for joint implementations in India as they seek ways to refine the extracted minerals in India with the aid of renowned metallurgical research universities. The final extracted minerals are **sold to various industry players like paints, ceramics, pharma, etc.** The following figure gives an overview of the battery recycling process of Li-Circle.

There are several challenges that they have identified over two years since they started lithium-ion battery collection, reverse logistics, and recycling in India. **One of the major issues that they came across is the dominance of the informal players in the market as they dictate the entire pricing mechanism in the supply chain**. Similarly, there are issues with the process level of the battery manufacturing as well that need to be sorted out, for example, **there is currently no design level standardization on battery manufacturing such that they are easy to dismantle when being recycled.** Furthermore, th**e lack of proper incentive and non-profitability of LFP recycling** are also some of the challenges associated with the current battery recycling ecosystem in the country

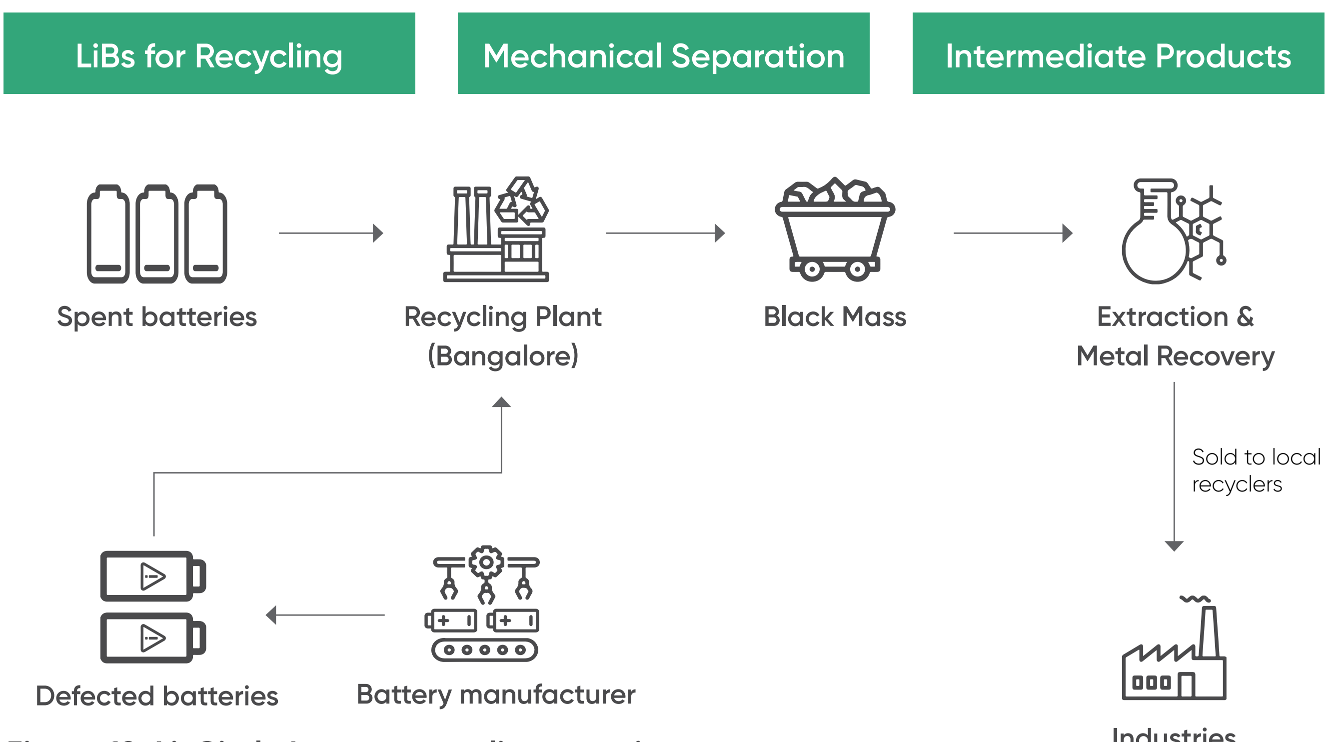


Figure 12: Li-Circle battery recycling overview

In order to find a solution for the above challenges, they have also come out with few suggestions and recommendations of their own. For example, to make LFP recycling profitable, a separate policy might be implemented that allows for the leasing of LFP batteries and the inclusion of some of the cost of recycling in the battery's manufacturing cost.

Eco-Tantra:
EcoTantra is a government-authorized E-Waste Management Company in India that specializes in the collection, transportation, and disposal of wide-ranging e-Waste materials. They boast a unique business model that is continuously evolving to meet changing customer needs and regulatory requirements of India's E-Waste Management industry. They also provide end-to-end services starting from the removal of the asset from the client's premises, packing, reverse logistics, dismantling, E-Waste Recycling, Extended Producers Responsibility (EPR) Implementation, Corporate Social Responsibility (CSR), enabling on pan India basis as well as in other neighbouring countries either directly or through its association with world-class E-Waste Recycling companies.

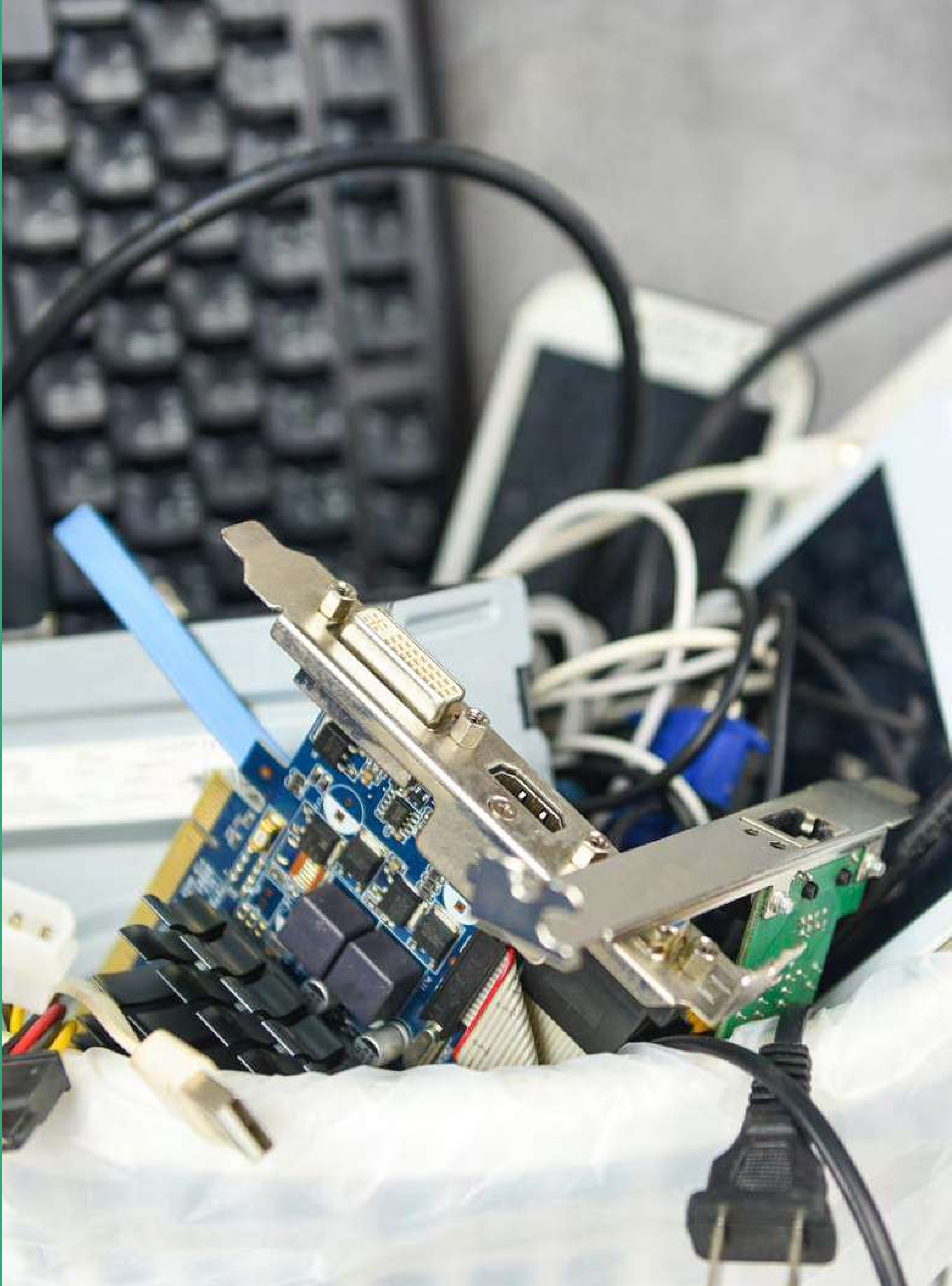
Although currently only into e-waste recycling which includes recycling batteries from mobile phones, they have applied to set up a lithium battery recycling plant of their own with Hybrid technology (leaching). They are expecting a huge demand for battery recycling, especially from the transportation sector, and as such have already started battery recycling experiments using leaching as it requires fewer resources in comparison to other methods. **Having previously partnered with a Japanese company to recycle mobile phone batteries, they have also started approaching several global recycling partners to set up lithium-ion recycling plants in India.**

With their vast experience in e-waste recycling, one of the main challenges that they have identified regarding setting up such lithium-ion battery recycling facility in India is the lack of a proper channel for the collection of used or spent batteries, especially from the consumer electronics applications sector.

Therefore, they recommend the central as well as the state governments to set up mandates on battery recycling for manufacturers and consumers and provide incentives and funding to establish a proper channel for collection of batteries after they are depleted.

E-waste recyclers India:
E-Waste Recyclers India (EWRI) is a leading electronic waste management company in India. It has provided a variety of services since its inception, including collection, data removal and disposal, E-Waste recycling, and scrap management. They serve an ever-growing community of environmentally conscious Indians with cutting-edge technological recycling processing tools and infrastructure that provides customers with cost-effective and timely services.

They are currently only into lead-acid battery recycling with plants installed in Uttar Pradesh and Haryana having an annual capacity of around 5000 to 10000 MT. They crush the spent lead-acid batteries mechanically and then either sell the material to other players or process it themselves. **They are currently also planning to set up a lithium-ion battery recycling plant in Gujarat and are looking for collaboration and partnership with international battery recycling players.**



Chapter 2

International battery recycling and reuse market

Battery recycling and reuse have attracted attention from the government, industry, and financial circles. It is seen as key to ensuring the availability of raw materials for batteries, diversifying the overall battery supply chain, managing battery waste, and securing the environmental benefits of electric transport and renewable energy.

Policy plays a critical role in enabling and accelerating this market. Companies are jostling for market share – and changes within the battery recycling and reuse market is in turn shaping the priorities and investment strategies of recyclers, including in India.

This section provides a brief overview of the global market context. Subsequent sections will explore the perspectives of recyclers within this changing market, lessons from the global literature, and policy recommendations for the Government of India.

The backdrop is a rapidly changing global outlook for mobility, electricity storage, and sustainability:

- Nearly 10% or 6.6 million of global car sales were electric in 2021, **while the global stock of electric vehicles (EVs) could reach 200 million vehicles by 2030** under the stated environmental policies of countries globally.[9] Globally 286.2 GWh of passenger EV deployed onto roads (113% uptick vs 2020)
- **Batteries are needed for electricity storage** to balance intermittent renewable energy as the wind does not always blow and the sun does not always shine. By the end of 2021, the total deployed grid-scale battery storage capacity was close to 16 GW/ 32GWh (6.4 GW deployed in 2021 alone)[10] .
- **Critical minerals for batteries are scarce,** with prices for raw materials on the rise.[11]
- **Critical minerals for batteries such as cobalt, lithium, and nickel are highly concentrated in a few countries,** raising concerns over the security of supply and there are ethical and environmental concerns about mining practices.
- **The battery value chain is highly centred around China.** The country accounts for 75% of all lithium-ion battery production, 70% of production capacity for cathodes, and 85% of production capacity for anodes. Over half of lithium, cobalt, and graphite processing and refining capacity is in China.[12]
- EVs emit less CO_2 than internal combustion engine vehicles, but their **batteries are expensive and difficult to recycle.**

[9] International Energy Agency (2022), Global EV Outlook 2022, May 2022. https://www.iea.org/reports/global-ev-outlook-2022/executive-summary
[10] IEA, https://www.iea.org/reports/grid-scale-storage
[11] Ibid.
[12] Ibid.

While consumer choice has resulted in a growing demand for battery-powered appliances, the major future growth opportunity for battery recyclers comes from EVs. Battery manufacturing creates scrap waste and depleted batteries need safe disposal, creating both a necessity and opportunity for recycling and reuse. The first set of large-scale supplies of end-of-life (EOL) batteries is likely to reach the market around 2025 from public transport and 2- or 3-wheelers. This is because batteries in buses are charged and discharged more frequently, and the battery use for 2-3 wheelers will make them reach their end of life faster. Yet perhaps as little as half of the batteries currently reach recyclers, since some of them are stored, disposed of but not recycled, or reused for other purposes.[13]

All recyclers we interviewed anticipate lithium-ion battery (LiB) recycling to grow rapidly in Asia and the European Union (EU) in particular. The policy is the key driver for this. China has been among the first countries to incentivise EV deployment at scale, making it also the likely first country to recycle EV batteries. Key players started setting up recycling and reuse operations in the country in 2017 with Government subsidies. China recycles all battery scrap and 'black mass' (the shredded material containing the valuable elements of batteries after they have been dismantled and shredded) in-country, and the country's import regulation currently allows for importing metals. A revision made in 2021 to the Chinese regulation to allow imports of black mass will enable China to establish a regional position as a battery recycling hub for their scrap metal, black mass from recycling, and imports of old batteries to feed into the domestic battery manufacturing industry. Meanwhile, the European market is catching up, with strong EV sales since around 2020. Given the average warranties and life expectancies of EV batteries, large quantities of batteries should become available for recycling in both China and Europe at similar times. Other countries, including India, will create a significant supply of end-of-life batteries thereafter, given a later start of electric mobility deployment at scale.

[13] Melin, H.E., (2018), The lithium-ion battery end-of-life market - A baseline study for the Global Battery Alliance, World Economic Forum. https://www3.weforum.org/docs/GBA_EOL_baseline_Circular_Energy_Storage.pdf

There is a critical need for circular thinking. Limited availability of critical minerals for batteries is leading to price rises, with disruptions due to Russia's invasion of Ukraine contributing to increases in 2022. Prices for cobalt, lithium, copper, and other minerals would surge to unprecedented levels, given the expected demand for them if the world wants to achieve net zero greenhouse gas emissions to limit global temperature rises to 1.5°C, according to detailed modelling by the IMF[14] (see Figure 13). Such rises would challenge the feasibility of achieving net zero outcomes. Yet they also enhance the opportunity for recovery of high-value critical metals through recycling and battery reuse. The sourcing of recycled cathode materials will similarly be of interest for battery manufacturers as this will help establish a supply chain that is resilient to geo-political concerns. Security of supply overall will be crucial, given that, for example, around 45% of global copper, 80% of cobalt, and 75% of lithium reserves are concentrated in just three countries each (see Figure 13).

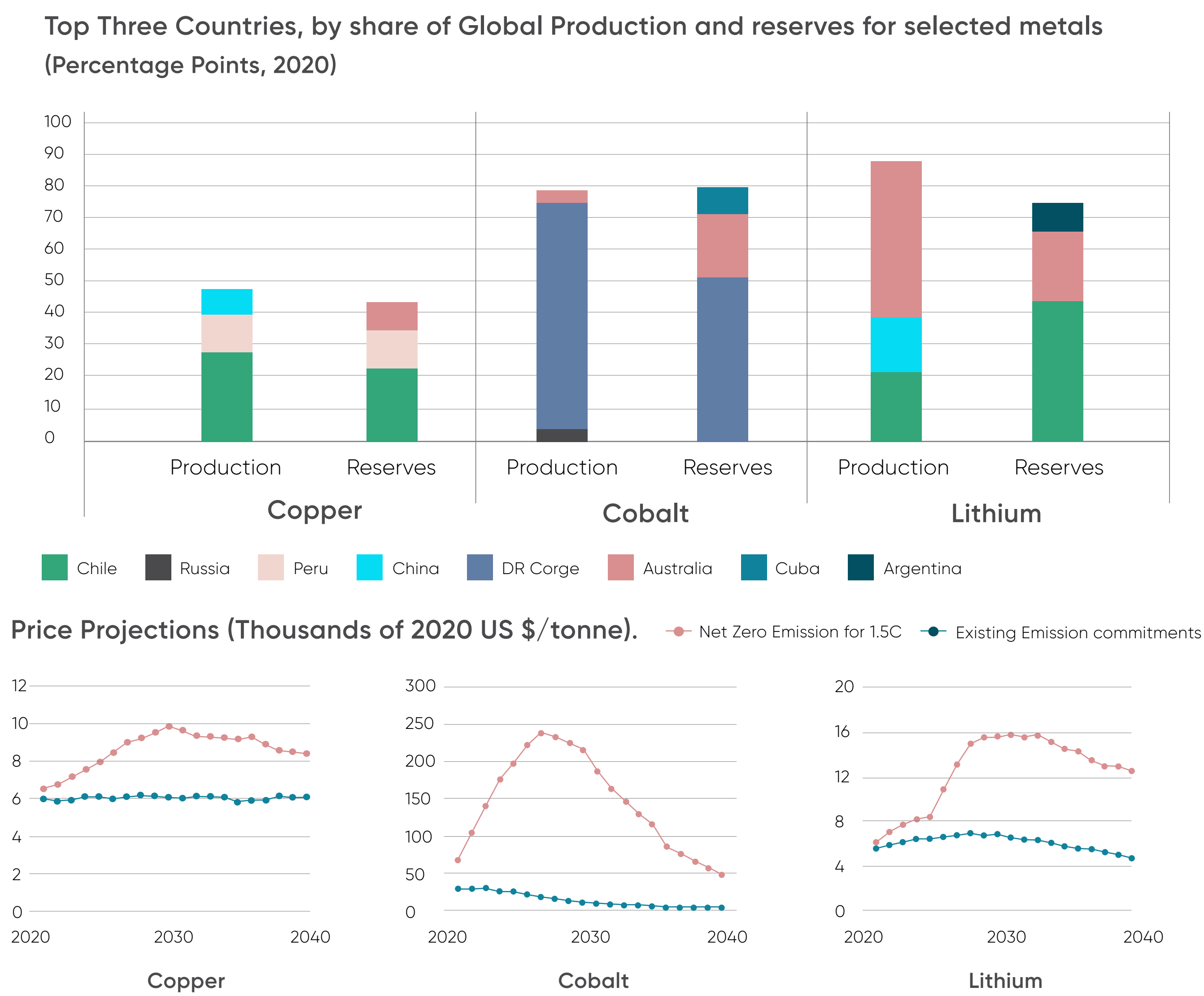


Figure 13: Critical mineral supply concentration and price scenarios

[14] Boer, L. et al. (2021). Energy Transition Metals. International Monetary Fund, October 2021. https://www.imf.org/en/Publications/WP/Issues/2021/10/12/Energy-Transition-Metals-465899

The end-of-life market for LiBs is a nascent market with room for innovation and change, which global EV manufacturers and recyclers have started to embrace. For example, 10% of the global cobalt supply was available from recycling in 2018.[15] Meanwhile, battery manufacturers are changing the composition of batteries to limit the amount of required cobalt (e.g. Lithium-Nickel-Cobalt-Aluminium Oxide (NCA) and Lithium-Nickel-Manganese-Cobalt-Oxide (NMC) batteries)[16]. In parallel, battery refurbishment for reuse or second-life applications is already common in several countries. Repurposing end-of-life batteries can improve the economics of batteries and reduce the need for new batteries. Life extension may also be environmentally beneficial relative to immediate recycling.[17] For example, Nissan takes back all spent EV batteries for its Leaf model in Japan for testing and refurbishment. A new Leaf battery is reported to cost about $6,500 and Nissan offers refurbished batteries in Japan for a cost of $2,900.[18] But not all car and battery makers support EV battery reuse, because of concerns over inefficiencies, potential malfunctions, and liability.[19]

The changing patterns of demand, battery chemistries, metal prices, and efficiencies will shape the relative economics of battery recycling and reuse over time. There is an emerging consensus that new battery costs will decline due to manufacturing efficiencies, which coupled with battery recycling process innovation will allow recycling to become favoured over reuse.[20] Moreover, the availability of sufficient quantities of high-quality batteries for reuse will be a constraint for this segment, according to the firms we interviewed.

Amid the shifting market, regulations are evolving to incentivise, standardise and formalise recycling and reuse processes. The interplay of politics, markets, and technology is causing the market to be in flux. This report provides insights into the changing strategies and priorities of global battery recyclers, and the potential lessons for India.

[15] Melin, H.E., (2018), The lithium-ion battery end-of-life market - A baseline study for the Global Battery Alliance, World Economic Forum. https://www3.weforum.org/docs/GBA_EOL_baseline_Circular_Energy_Storage.pdf

[16] Ibid.

[17] Research Study on Reuse and Recycling of Batteries Employed in Electric Vehicles: The Technical, Environmental, Economic, Energy and Cost Implications of Reusing and Recycling EV Batteries EV Battery Reuse and Recycling, Project report by Kelleher Environmental for Energy API (September 2019) https://www.api.org/~/media/Files/Oil-and-Natural-Gas/Fuels/Kelleher%20Final%20EV%20Battery%20Reuse%20and%20Recycling%20Report%20to%20API%2018Sept2019%20edits%2018Dec2019.pdf

[18] Ibid.

[19] Melin, H.E., (2018), The lithium-ion battery end-of-life market - A baseline study for the Global Battery Alliance, World Economic Forum. https://www3.weforum.org/docs/GBA_EOL_baseline_Circular_Energy_Storage.pdf

[20] Ibid.

2.1. Approach of selecting global recycling companies

An increasing number of firms have entered the LiB recycling market and claimed they are recyclers. In practice, however, some of them are brokers or collectors and some of them are beginners in this area. Recycling hereinafter is defined as the reclamation of materials from spent LiBs rather than reuse for power storage and reuse for other purposes.

To understand the changing dynamics within the rapidly evolving recycling, we have conducted stakeholder interviews with leading international recyclers. Companies were selected from the universe of international recyclers according to the following criteria:

01 Global or regional leader in recycling LiBs and producing metals

02 Large volumes and scale of recycling

03 Established history of recycling

04 Role in the value chain

05 Research and development (R&D) ability

The identified leading international recyclers are the predominant players for LiBs recycling in Asia, North America, and Europe. According to global battery demand from 2015 to 2021[21] , the market size of LiB recycling in these three regions would make up more than 90% of the world's total in 2021. The recyclers are summarised in Table 4.

Recyclers can be divided into three categories:
Group 1 (in green highlighting in Table 4) are mining companies of relevant metals that started a recycling business by using already existing facilities;

Group 2 (purple highlighting) includes recyclers with a background in or collaboration with battery/EV manufacturing, and

Group 3 (yellow highlighting) consists of the traditional recyclers of electronic waste and metals.

LiBs recycling is seen as a new opportunity not only for traditional recyclers but also for battery manufacturers and even EV manufacturers since it helps environmental objectives, improves resource availability and efficiency, and growth of green transport. Table 4 provides and overview of leading international battery recyclers.

[21] International Energy Agency (2022), Global EV Outlook 2022, May 2022, pp136. https://www.iea.org/reports/global-ev-outlook-2022/executive-summary

Table 4: Overview of leading international battery recyclers

Region	Key recycling operators	Headquarter country	Role in the value chain	Start date of LiBs recycling activities
Asia	Huayou Cobalt	China	Co Mining & LiBs recycling	2017
	GEM	China	Ni Mining & LiBs recycling	2001
	Ganzhou Highpower	China	LiBs recycling	2012
	SungEel	South Korea	LiBs recycling	2017
	4R Energy (a joint initiative between Nissan and Sumitomo corp.)	Japan	LiBs recycling	2018
	JX Nippon M & M	Japan	LiBs recycling	2010
	Sumitomo Metal Mining	Japan	LiBs recycling	2017
North America	Retriev (formerly Toxco)	Canada	LiBs recycling	2013
	Glencore	US (for recycling business)	Mining, LiBs recycling	2013
	Li-Cycle	Canada	LiBs recycling	2016
	Redwood Materials	US	LiBs recycling	NA
	Neometals	Australia / US	LiBs recycling	2017
Europe	Duesenfeld	Germany	LiBs recycling	2018
	Redux	Germany	LiBs recycling	2018
	Accurec	Germany	LiBs recycling	2016
	Northvolt	Sweden	LiBs manufacturing & recycling	2018
	Boliden	Sweden	Consumer electronics and lead-acid battery recycling	None
	Valdi (ERAMET)	France	LiBs recycling	2017
	TES-AMM (Recupyl)	France	LiBs recycling	2019
	Umicore	Belgium	Mining, LiBs recycling	2006
	Fortum	Finland	LiBs recycling	2019
	Akkuser	Finland	LiBs recycling	2006
	Batrec	Switzerland	LiBs recycling	2018

Color coding:

Group 1:	Mining business or history
Group 2:	Collaboration or background of battery manufacturing or EV manufacturing
Group 3:	Expanding from metal e-waste or metal recycling to LiBs recycling

Acronyms: Li: Lithium; Co: Cobalt; Ni: Nickel
** Planned; NA not available

2.2. Perspectives of global battery recyclers on the evolving market

To understand the determinants of corporate strategy and investment choices, we conducted interviews with 8 leading international battery recyclers. The focus of our analysis was to obtain varied feedback and perceptions about investment risks and opportunities in the battery recycling sector from a global perspective. The semi-structured questionnaire used to guide the interviews (available in Annex B) was designed in consultation with PwC and pManifold, and validated by NITI Ayog. Our findings aim to explore preliminary insights into the interest and investment priorities of international recyclers.

Our interviews focused on a subset of the long list of key recyclers illustrated in the preceding section. These firms were chosen because of their overall significance in the rapidly evolving international battery recycling market in different parts of the world, based on geographical presence and their scale of operations and accessibility of their information. In total, the selected firms have the capacity to recycle approximately 60% of the global market's end-of-life batteries in 2021.

The section below provides a brief overview of each of the role of the firms in the global battery recycling value chain. Section 2.3. then summarises insights from our stakeholder interviews on the key drivers of investment decisions and performance.

2.2.1. Role of international recyclers in battery value chain

The global battery recycling market is evolving at pace – and with it the role of recyclers within the overall value chain of batteries. Most of the recycling processes employed are hydrometallurgical. LiB recyclers are currently mostly based in Europe, the US, Canada, South Korea, Japan, and China. This is set against a market dynamic in which, for example in 2018, an estimated 97,000 tonnes of batteries reached recyclers, of which 67,000 were processed in China, and 18,000 in South Korea. Those two countries were and still are leading the manufacturing of battery materials and the production of cells. This activity has "created a strong demand for raw materials, which consequently lays the foundation for an important market for recyclers, or opportunities for material companies to become recyclers themselves"[22] .

Our research on international firms confirmed that LiBs recyclers, battery manufacturers, and EV producers are playing multiple roles and are more than ready to collaborate with each other to strengthen their position and competitiveness. For example:

[22] Melin, H.E., (2018), The lithium-ion battery end-of-life market - A baseline study for the Global Battery Alliance, World Economic Forum.

- GEM, a traditional Chinese recycler, has expanded into mining in Indonesia through the purchase of nickel and cobalt from a high-pressure acid leaching (HPAL) plant built by an Indonesian and Chinese joint venture[23] . In parallel, GEM continues to assess global investment opportunities in recycling.[24] GEM also provided technology to EcoPro's recently opened recycling plant in Pohang, South Korea.[25]

- Glencore in 2022 entered a long-term cobalt supply agreement with Britishvolt[26] and separately established a partnership with Li-Cycle[27] to combine primary and recycled battery raw materials to produce battery-grade end products and. Li-Cycle is a company that recycles batteries and black mass and specialises in Lithium recycling. Glencore (US extractives company that recycles nickel and cobalt) is investing in Li-Cycle to help grow its battery recycling capacity to Lithium and reach a broader international demand for high-value materials. This partnership explores opportunities to close the loop with considerable economies of scale across North America, Europe, and soon Asia. Glencore's multi-year cobalt supply agreement with General Motors Co. (GM) could be used to secure batteries for recycling in the future, as GM plans to build one million electric vehicles in North America by 2025[28] .

- Korea's SungEel and China-based precursor producer CNGR signed a memorandum of understanding on jointly setting up facilities in Europe for disassembly, pre-processing, and hydrometallurgical processing of waste batteries.[29]

- Huayou recently reached an agreement with BMW[30] to co-develop innovative cooperation model on closed-loop recycling and cascade utilization of power battery raw materials, in addition to existing partnerships with Volkswagen, TOYOTA, Volvo, SAIC Motor, and GAC GROUP.

- Duesenfeld, together with car manufacturer BMW Group intends to develop a method that can achieve a recycling rate of up to 96% – including graphite and electrolytes.[31]

- Volkswagen AG has formed a partnership with Redwood for recycling electric vehicle batteries wherein partnership, Redwood will recycle electric vehicle batteries from Volkswagen and Audi in the United States.[32]

- Umicore reached an agreement with Automotive Cells Company on battery recycling and entered into a patent cross-license agreement with BASF.[33]

[23] Source: Mining Magazine, September 2020: https://www.miningmagazine.com/supply-chain-management/news/1394450/chinas-gem-signs-indonesia-nickel-cobalt-deal
See for example recent deal in Hungary.
[24] Source: Circular Energy Storage online, May 2022: "Chinese recycler GEM signs cooperation agreement with Hungary" https://www.circularenergystorage-online.com/post/chinese-recycler-gem-signs-cooperation-agreement-with-hungary
[25] Source: Yicai Global, October 2019: "China's GEM, Korea's EcoPro to Build Power Battery Recycling Plants" https://www.yicaiglobal.com/news/china-gem-korea-ecopro-to-build-power-battery-recycling-plants
[26] Source : Glencore website: https://www.glencore.com/media-and-insights/news/glencore-and-britishvolt-strengthen-relationship
[27] Source : Glencore website: https://www.glencore.com/media-and-insights/news/glencore-and-li-cycle-announce-innovative-partnership-to-advance-circularity-in-battery-raw-material-supply-chains
[28] Source: GM website (Newsroom): https://news.gm.com/newsroom.detail.html/Pages/news/us/en/2022/apr/0412-glencore.html
[29] Source: Circular Energy Storage online, November 2021: "CNGR partners with Sungeel Hitech to set up European recycling plant" https://www.circularenergystorage-online.com/post/cngr-partners-with-sungeel-hitech-to-set-up-european-recycling-plant
[30] Source: Benchmarch minerals website : https://www.benchmarkminerals.com/membership/bmw-teams-up-with-huayou-to-recycle-batteries/
[31] Source: Inside EVs, July 2020: "BMW Group To Take EV Battery Recycling Rate To 96%" https://insideevs.com/news/436066/bmw-group-ev-battery-recycling-rate-96/
[32] Source: India Times, July 2022: "VW of America teams with Redwood on EV battery recycling" https://auto.economictimes.indiatimes.com/news/auto-components/vw-of-america-teams-with-redwood-on-ev-battery-recycling/92832821
[33] Source : ACC Press Release, 22 April 2022 https://www.acc-emotion.com/newsroom/umicore-and-acc-enter-strategic-partnership-ev-battery-materials-europe#:~:text=Umicore%20and%20Automotive%20Cells%20Company,production%20plant%20in%20Nysa%2C%20Poland

- Fortum, BASF, and Nornickel reached an agreement on battery recycling to establish a closed loop to reuse critical minerals from the batteries.[34]
- MG Motor India has announced that it has partnered with Attero Recycling to recycle electric vehicle batteries in the country[35] .

These interdependencies and collaborations can be seen as a key instrument in 'closing the loop' of the evolving circular economy associated with batteries. They ensure resource availability for all parties – direct access to inputs for battery recycling and reuse firms; availability of raw materials for material processors, assemblers, and manufacturers; and long-term involvement in the value chain for mining corporations. This loop is illustrated in Figure 14 for two leading international recyclers:

- China's GEM is a recycler, but also has a strategic collaboration with Huayou, another Chinese recycler. Together they have established strong partnerships with companies like CATL, BYD, LGC, Ecopro, Samsung and XTC for the supply of raw materials.
- Finland's Fortum is similarly working with another recycler – Nornickel – to strengthen its role in high-value mineral recovery. Fortum has partnerships with EV manufacturer Valmet Automotive to support closed-loop recycling at scale.[36]

Table 5: Recycler involvement and partnerships in the battery value chain

	Fortum	GEM
Material supplier and battery manufacturer	BASF	CATL, BYD, LGC, Ecorpro, Samsung, XTC
EV manufacturer	Valmet Automotive	BYD, NIO, NISSAN, GM, TOYOTA, JAGUAR
Recycler	Nornickel	Huayou

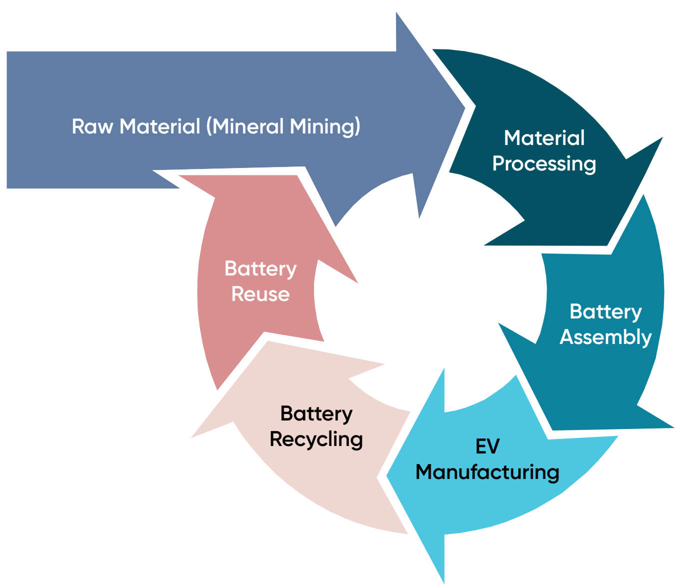


Figure 14: Recycler involvement in battery value chain – examples of Fortum and GEM

[34] Source: Fortum website: https://www.fortum.com/media/2020/03/finnish-battery-industry-intensifies-cooperation-fortum-basf-and-nornickel-sign-cooperation-agreement-battery-recycling
[35] https://etn.news/buzz/mg-motor-india-attero-recycling-collaboration-successfully-recycles-first-zs-ev-batyery
[36] Source: Valmet website: https://www.valmet-automotive.com/media/valmet-automotive-and-fortum-cooperate-in-sustainable-recycling-of-battery-materials/

Similar findings were made about India, where battery recyclers cited partnerships and collaborations as a crucial tool for achieving circularity.

- Attero, an Indian battery recycler, collects all types of lithium-ion batteries, whether from consumer electronics market players like Samsung, and Oppo or from stationary storage players like Reliance Jio. They have also signed MoUs with almost all of India's leading EV manufacturers (MG Motors India, for example) to recycle their end-of-life or defective batteries, catering to nearly 75% of the Indian electric vehicle market.

- Ziptrax technology, another battery recycling firm in India has collaborations with Villgro, Mercedes Benz, and WRI India, for swapping in e-rickshaws and electric scooters. They are also extending this partnership with Tata Motors and MG Motors, to achieve 10 MWh in recycled/ repurposed batteries for electric mobility and stationary storage by March 2024.

2.2.2. Published strategies of leading international recyclers

At a high level, published corporate strategies of leading international recyclers to reflect strong expectations of market growth, a desire for involvement along the battery value chain (encompassing collaborations among recyclers, EV manufacturers, cell manufacturers, and miners), and a perceived better opportunity for sourcing spent batteries through business-to-business rather than direct business-to-customer relationships. Moreover, companies are seeking combined options across the reuse of batteries and recovery of valuable minerals from end-of-life LiBs through recycling. Companies have a preference for NCM rather than lithium iron phosphate (LFP) batteries due to their profitability. Below we provide a brief overview of publicly available corporate strategy documents before analysing the views of these firms in detail in Section 2.3:

Both battery recycling and reuse are part of the business strategy of leading international battery recycling firms: Chinese companies have grown their interest in the reuse of power storage since 2018. The reuse of power storage is likely to be relevant to India for small-scale stations. China's EV usage regulation requires that EV batteries operating at 80% capacity should be removed from Evs and used for other purposes. Old LiBs from Evs are currently reused for two applications: energy storage or low-speed vehicles. Most of the reused LiBs are LFP as the first generation of EV battery packs were made of LFP batteries (vs. 10% made of NMC). Until 2018, LiB recycling was not seen by Chinese companies as cost-effective. This meant reuse became promising for stationary energy storage, uninterruptible power supply systems of telecommunication towers, and intelligent street lighting system. Stationary energy storage systems in China indicated that the reuse of LFP was more profitable than recycling and would allow short-term breakeven at a small scale. Large-scale stationary energy storage systems are normally for commercial usage which requires sophisticated auxiliary equipment for installation, operation, and safety control, and tends to delay the breakeven point. **Since 2020, the soaring prices of**

battery materials have increased the profitability of LFP recycling, reflecting the rapid change in the battery recycling and reuse markets.

New initiatives and expansion plans: Firms continue to make progress with respect to new business models and new source geographies:

- According to **GEM's** 2021 Annual Report (May 2022)[37] , their strategy is to secure successful projects in Indonesia and to start construction of an innovative production factory in Europe. According to GEM, the volume of waste EV batteries in the first quarter of 2022 was around 3,407 tonnes, representing a 341% increase year on year, with over 400 MWh of batteries reused.[38]
- **Umicore,** as per its Annual Report (2021)[39] , has also deployed a closed-loop business model that has helped it meet the needs of both automotive manufacturers and the wider EV supply chain. Umicore has set up a dedicated business unit ('Battery Recycling Solutions'), focused on improving recycling performance, with increased extraction efficiency of cobalt, nickel, and copper. This has also included the capability to recover most of the lithium in EV batteries, therefore addressing a key constraint in existing recycling. Automotive Cells Company has recently become a customer of this new unit, using the technology for its pilot plant in Nersac, France.[40]
- In May 2022, BMW and **Huayou** signed an agreement for close-loop cooperation in Shenyang, the capital city of Liaoning Province, where BMW (China) manufactures batteries.[41] This further cements Huayou's participation along the battery value chain.
- **SungEel** specialises in recycling LiBs and pursues a strategy of building facilities in locations where batteries can be easily sourced. This currently includes plants in Korea (its headquarters country), Hungary, Poland, Malaysia, and China, and a dismantling/pre-processing business in India. Other locations are being pursued in the hope of attaining a 10% global market share by 2030.[42] The company announced in May 2022 plans for a stock market launch in the second half of 2022.[43]
- **Fortum** uses low CO_2 processes (a combination of mechanical and hydrometallurgical technologies) to recover lithium, cobalt, manganese, and nickel. Fortum's hydrometallurgical battery recycling operations were shortlisted for the European Union's Innovation Fund for low-carbon technologies.[44] Fortum has recently decided to expand its lithium-ion

[37] China GEM Holdings Limited 2021 Annual Report https://www1.hkexnews.hk/listedco/listconews/sehk/2022/0506/2022050602024.pdf
[38] Source: SEC Online, May 2022, "Chinese recycler GEM signs cooperation agreement with Hungary" https://www.circularenergystorage-online.com/post/chinese-recycler-gem-signs-cooperation-agreement-with-hungary
[39] Source: Umicore 2021 Annual report: https://annualreport.umicore.com/en/2021
[40] Automative Cells Company website: https://www.acc-emotion.com/stories/umicore-introduces-new-generation-li-ion-battery-recycling-technologies-and-announces-award
[41] Source: Benchmarch minerals website: https://www.benchmarkminerals.com/membership/bmw-teams-up-with-huayou-to-recycle-batteries/
[42] Source: Bloomberg, May 2022, "Korean Battery Recycler Plans Share Sale as EV Demand Surges" https://www.bloomberg.com/news/articles/2022-05-08/korean-battery-recycler-plans-share-sale-as-ev-demand-surges
[43] Ibid.

battery recycling capacity with a new hydrometallurgical plan in Harjavalta (Finland).[45] Lithium-ion batteries are disassembled and treated through a mechanical process at Fortum's plant in Ikaalinen, after which the battery's black mass is collected and then taken to Harjavalta for hydrometallurgical processing.[46]

- Other than its partnerships with Li-Cycle and BritishVolt, **Glencore** has created the Circular Electronics Partnership and is a founding member of the Global Battery Alliance[47] , which is developing a sustainable battery value chain. Glencore sees battery recycling as a strict necessity to ensure the availability of raw materials and secure its own future metals business. To that end, Glencore is building relationships across the entire battery value chain.

- **Li-Cycle's** investment strategy aims for at least 100,000 tonnes of annual LiB equivalent processing capacity by its 'Spokes' (equivalent to approximately 20 GWh of LiBs) and a centralized network of at least 220,000 tonnes of annual LiB equivalent Hub processing capacity (equivalent to approximately 44 GWh of LiB) by 2025.[48] In the near to medium term, the company expects its expansion efforts to focus on North America and Europe but is also exploring investments in the Asia Pacific. Li-Cycle is partnering with multiple customers in each region, forming supply and off-take arrangements. The operating models remain anchored around its Hub in Rochester, US (currently recycling 90,000 t/a of LiB equivalent), and Spokes for collection/processing in other locations as well as countries (which will add up to a total capacity of 65,000T).[49] A partnership was announced on 5th May 2022 that sees Glencore taking a 10% equity stake in Li-Cycle.[50] Glencore will help sell the by-products from the Hubs and brings a broader international reach to serve the demand.

Interest in LiB Recycling and Research: Leading firms are continuing to invest heavily in R&D:

- Some leading companies, such as Duesenfeld[51] , are investing heavily in R&D to develop efficient and environmentally friendly recycling processes. Duesenfeld has developed an innovative process chain combining mechanical processing and hydrometallurgy, eliminating high-temperature processes and achieving a high material recovery rate for LiBs[52].
- Sustainability leaders in the metals and mining sector, such as Boliden[53] are active in several industry for a related to the circular economy. While the company

[44] Source: Fortum website: https://www.fortum.com/media/2021/03/four-fortum-projects-shortlisted-eu-innovation-funding-low-carbon-technologies
[45] Source: Fortum website: https://www.fortum.com/media/2021/06/fortum-makes-new-harjavalta-recycling-plant-investment-expand-its-battery-recycling-capacity
[46] Ibid.
[47] Source: Glencore website: https://www.glencore.com/media-and-insights/news/Glencore-joins-World-Economic-Forum-s-Global-Battery-Alliance
[48] Source: Li-Cycle website : https://investors.li-cycle.com/news/news-details/2022/Li-Cycle-Holdings-Corp.-Reports-Financial-Results-for-Fourth-Quarter-and-Full-Year-2021-Significant-Progress-in-Advancing-Spoke-and-Hub-Network-Strategy/default.aspx
[49] Ibid.
[50] Source: Glencore website : https://www.glencore.com/media-and-insights/news/glencore-and-li-cycle-announce-innovative-partnership-to-advance-circularity-in-battery-raw-material-supply-chains
[51] Duesenfeld website: https://www.duesenfeld.com/research.html
[52] Duesenfelf website: https://www.duesenfeld.com/recycling_en.html

has one of Europe's largest facilities for recycling lead-acid batteries[54] , it has no activity or announced plans for LiB recycling. However, Boliden is undertaking research on LiB pre-treatment in a partnership with Swerim, Northvolt, Stena Metall, uRecycle, Volvo and RISE IVF,[55] suggesting emerging interest in the sector.

2.3. International recycler interview insights

Corporate strategies and priorities are evolving in the rapidly growing battery recycling and reuse business. To understand the drivers of decision-making and potential insights for India, we undertook interviews and engaged with a total of ten firms as listed in the preceding section. These interviews are centered around technology, economics, regulations, their determining practices and business models, with corresponding investment choices.

2.3.1. Perceptions on technology

Battery recycling is growing in significance and the technological focus is changing. Companies are jostling for positions to take advantage of market trends. Thus far, however, recycling operations have focused on batteries from consumer electronics, laptops, small batteries, and LiB manufacturing scraps.

In the whole process of cell manufacture, which normally includes more than 50 steps[56] , about 10-15% of batteries become non-conforming products[57] and they are collected and recycled together with spent LiBs. But batteries from EVs and other large-scale stationary uses have for the most part did not reach their end of life yet. Therefore, no significant recycling of such larger battery packs exists yet in any country at scale.

The recycling process can be broadly classified into pre-processing and mechanical, hydrometallurgical, and pyro-metallurgical methods. Pre-processing is any process that does not alter the structure of the LiB cells, e.g., sorting by battery type from mixed waste. Mechanical processing involves the use of different techniques to liberate, classify, and concentrate materials without altering their chemistry. These techniques operate based on relative differences in the physical properties of materials, for instance, density, shape, and size, and they

[53] Source: Boliden website: https://www.boliden.com/sustainability/our-responsibilities/circular_economy
[54] Source: Boliden website: https://www.boliden.com/sustainability/case-studies/secondary-material-recycling-and-synergies
[55] Source: Swerim, June 2020, "Simulator for pretreatment of lithium-ion batteries" https://www.swerim.se/en/news/simulator-for-pretreatment-of-lithium-ion-batteries
[56] Source: Medium, June 2021 "Battery Manufacturing Basics from CATL's Cell Production Line (Part 1)" https://medium.com/batterybits/battery-manufacturing-basics-from-catls-cell-production-line-part-1-d6bb6aa0b499
[57] Source: MTB Recycling website: https://www.mtb-recycling.fr/en/lithium-ion-batteries-and-its-recycling-issues/#:~:text=Until%20today%2C%20the%20only%20option%20was%20smelting%20and,scrap%20rate%20to%20be%20ap-proximately%2010%25%20for%20gigafactories

generally occur before stages involving chemical reactions. After mechanical processing, the material obtained is refined by hydrometallurgy, pyrometallurgy, or a mixture of both. Pyrometallurgy refers to operations at elevated temperatures where redox reactions are activated to smelt and purify valuable metals. Hydrometallurgy involves the leaching of valuable elements from a solid matrix and their subsequent precipitation through modification of solvent-phase chemistry.

Recycling technologies vary with recyclers' histories and capacities. Small and medium-sized firms prefer mechanical plus hydrometallurgical processes, while long-established companies take advantage of hydro–pyrometallurgical processes to obtain high-end products. This reflects that mechanical and hydrometallurgical processes demand less investment and fewer emission control facilities than pyrometallurgical processes. Moreover, the pyrometallurgical process is energy intensive and not suitable for the recovery of non-metallic materials. According to interviewed firms, customers also prefer hydrometallurgy based on the belief that the process creates lower greenhouse gas emissions. Therefore, **mechanical treatment followed by hydrometallurgy is preferred by the majority of the recycling industry.**

A recent GIZ and Deloitte report (2022)[58] shows that **Indian players are choosing to focus on hydro.** While pyro technologies incur lower capital costs, hydro was found to generate greater energy savings for LiB recycling.[59] Hydrometallurgy is used by all interviewed Chinese recyclers due to favourable costs and as a means to obtain the final valuable products from the black mass. But as noted above, some large international companies employ hybrid models using hydro and pyro processes to obtain high-end products. In addition, some firms are creating a portfolio of options, wishing to have access to all technologies to be able to cater to any local market preferences. This is underpinned by a corporate desire to be able to be a leading processor of black mass and primary metals that can complement their overall business of mined products. However, **according to at least one interviewed firm, the global preference for hydro has led to an overcapacity relative to the currently available black mass. Excess capacity may be a sign of exuberance, but it also reflects the need to oversize facilities in anticipation of market growth,** given lead teams for permitting and construction.

[58] GIZ, Deloitte (2022), International review on Recycling Ecosystem of Electric Vehicle Batteries https://greenmobility-library.org/public/index.php/single-resource/VVlwYzEwdzZUWmNjVDdRQnl0L0JOZz09

[59] Ibid

Interviewed firms highlighted that mechanical processing is needed to create black mass by crushing and dissolving batteries. One interviewed firm said that it operates a licencing model through which its patented technology is made available to other firms, mostly battery manufacturers and EV makers. The process involves discharging batteries, shredding them, and drying them below 50°C, which avoids toxic gas emissions (and hence avoids the need for gas scrubbing, exhaust gas treatment, etc). Such advanced processes contrast with the **lack of regulation over mechanical recycling processes in India, which interviewed global recyclers raised as an important risk and concern for investors. Informal sector mechanical recycling in India is seen by global recyclers as a dangerous and environmentally damaging practice,** leading to the release of hazardous materials in the process of mechanical breaking, insufficient prior discharge, at times burning of batteries, and poor handling. This extends to the risk of transport of semi-processed batteries across India to recyclers who purchase them on the open market for further processing and shipment of black mass to their plants outside India.

In the recycling market, soft package batteries have a higher price than hard package batteries (such as those from EVs) due to the different casing materials[60].

The former is mostly Aluminium and the latter is steel – and they need to be recycled separately to maintain the purity of sorted products. Aside from packing materials, concentrations of nickel, cobalt, manganese, and lithium are pricing factors, and they also have impacts on extraction efficiency. Nowadays cell manufacturers tend to add a small number of nonferrous metals, like aluminium and magnesium to improve the energy density and lower production cost, thus rendering the complexity of extraction and purification. **Overall, interviewed firms expect that LFP batteries are going to be the dominant chemistry and have found a niche in transportation, especially in India. In Western countries, the most prominent battery is NMC, except in public transportation.**

Identifying the battery type and manufacturer as well as assessing compositions of valuable materials are essential for recycling. This underscores the importance of initiatives such as "battery passports" as proposed in Europe that seek to ensure transparent data sharing (see Section 2.3.3.). Recyclers globally, and led by Chinese firms, are currently investing in R&D on auto-dismantling, reuse, and recycling as it is anticipated that EV battery packs will require significant investments to handle much larger size batteries across the dismantling and processing stages (also see Section 3.2.3).

60 Pricing is from Shanghai Metals Market, https://www.metal.com/price/New%20Energy/Used-Lithium-ion-Battery

2.3.2. Global practices and business models for battery recycling

Technological change and inherent capabilities are shaping the investment choices of international battery recyclers – both for expansions of existing operations and new country entry. Rapid market growth has led to exuberance, where competition has intensified and scale matters. Therefore, the likelihood is high that the battery recycling sector will see consolidation through a wave of mergers and acquisitions.

All recyclers we interviewed anticipate LiB recycling to grow rapidly in Asia and Europe in particular. The policy is the key driver for this. China has been among the first countries to incentivise EV deployment at scale, making it also the likely first country to recycle EV batteries. Key players started setting up operations in the country in 2017 with Government subsidies. Today, 90% of global metal processing capacity is concentrated in China, according to the firms we interviewed. China recycles all its black mass and battery scrap in-country. Meanwhile, the European market is catching up, with strong EV sales since around 2020. Given the average warranties and life expectancies of EV batteries, large quantities of batteries should become available for recycling in both China and Europe around the same time. Other countries, including India, will create a significant supply of end-of-life batteries, thereafter, given a later start of mass electric mobility deployment.

The **Faraday Institution ReLiB project** is working to identify the policies and regulations that would create the economic conditions required to optimise the reuse and recycling of lithium-ion batteries from EVs[61] . The project aims to **enhance the overall efficiency of the supply chain and ensure that the UK has the facilities required for safe, economic and environmentally sound management** of the materials contained in lithium-ion batteries. The project also establishes that through direct targeting of fast, efficient dismantling processes boosting productivity and safety within the waste and recycling sector, it is possible provide high-purity and high-value recovered material streams, maximising the environmental gains of the transition to EVs.

The strategy of the project is depicted in the figure below

Life Cycle Analysis:
Techno-economic assessment of each recycling route to identify optimum management systems

Economic Assessment:
An assessment of the relative engineering and economic gains for various 2nd life applications

Segregation:
The development of recycling technologies to segregate and purify the different materials

Systems:
Fully autonomous gateway testing and robotic sorting techniques and development of systems

Characterisation:
Of active materials from cells near, and at EoL and recycled materials recovered from used batteries

[61] Faraday Institution ReLiB project, 2023 https://relib.org.uk/

Recently, **REBLEND** was selected as one of the Round 5 Faraday Battery Challenge projects to receive funding. This seeks to further **develop three processes to directly recover valuable cathode active materials** (CAM) from production scrap and end of life automotive and consumer batteries for reuse in automotive batteries. It combines novel delamination, magnetic, electrostatic and membrane separation techniques, developed as part of the **Faraday Institution's ReLiB project.**

Battery recycling business models are geared at present around the recycling of waste from consumer appliances and scrap from battery manufacturing, given the current state of the market. But this is changing rapidly. The first set of batteries from 2-wheelers (electric scooters) and 3-wheelers is beginning to near their end of life.[62] The recyclers we interviewed expect that the first wave of EV batteries at scale will be LFP batteries from buses. NMC batteries from passenger vehicles will follow around 2027/2028, given typical 7 to 8-year warranties for such batteries. However, the actual life expectancy of EV batteries is significantly longer (at least 12-15 years and potential life of up to 25 years, according to interviewees). This implies a trajectory of exponential growth: a slow ramp-up followed by a surge in batteries available for recycling over the coming decade. But there is significant uncertainty over the pace as innovations around battery chemistry and the novelty of large-scale electric mobility mean that the actual performance and life expectancy of batteries in different operating environments (including hot and humid conditions such as in India) have yet to be proven.

[62] Melin, H.E., (2018), The lithium-ion battery end-of-life market - A baseline study for the Global Battery Alliance, World Economic Forum. https://www3.weforum.org/docs/GBA_EOL_baseline_Circular_Energy_Storage.pdf

The recycling capabilities and facilities of leading companies are evolving alongside the pace of market change. As described in Section 2.3.1 above, not all recyclers currently have technology that allows the processing of all types of batteries. For example, one company cannot yet recycle LFPs. Another company's current smelters are not compatible with the leaching technology that is required for the recovery of EV batteries. Similarly, another company has not yet invested specifically in EV battery recycling. Some of the firms we interviewed highlighted in addition scepticism about the actual recovery rate and environmental footprint of EV battery recycling. Zero carbon emissions and 99% recovery rates are not achievable for most recyclers with current technologies and cost structures.

Interviewed firms confirmed that the scale of battery recycling operations is key. Line of sight to sufficient market size (and hence securing a strong position in the EV market) is driving investment choices – including countries for investment. Partnerships along the battery value chain are one element of this. Where new recycling plants or technologies are to be deployed, the lead time is between two and five years for permitting and construction, according to interviewees. This is shaping firm strategies. One company operates a "spoke and hub network", where local spokes focus on the collection of waste or pre-processed materials that are then shipped to a central hub. Another company similarly ships all globally sourced materials to its central plant. Companies also have local dismantling operations in emerging markets (that are often an extension of their existing recycling plants for consumer appliance batteries), but then ship these metals to their own central plants for recycling and end-user sales. Chinese recyclers largely have operations in China only at present but are interested in exploring opportunities abroad.

India is seen as a nascent and relatively immature market. Partnerships with EV and or battery manufacturers (OEMs) are seen as important by most of the interviewed international recyclers.

The key to this is to ensure access to raw materials of sufficient scale to warrant entry and/or expansion of existing plants.

Which scale is required exactly for profitability hinges on detailed feasibility studies, the general implied market entry strategy as illustrated above appears to be one of the initial small-scale local operations with exports to centralised facilities. Local dismantling only operations can be profitable with capacity below 2,000 t/a, while recyclers told us that 10,000-30,000 t/a scale is required for new plants focused on stationary storage recycling only, and a minimum of 50,000 t/a for plants focusing on EV battery recycling only (with a figure over 100,000 t/a cited by one player for profitable refining). **It also implies that initial investments by international recyclers would be in the pre-processing stages such as dismantling, while investments into hydro or other processing facilities would become commercially viable only if access to raw**

materials can be ensured – be it through local partnerships or the ability to create an India hub for recycling spent LiBs from neighbouring countries. The most likely result of this is a gradual scaling up of operations by international recyclers.

In addition, the reuse of batteries provides a business opportunity that can be highly profitable – but of lesser scale for most firms. EVs and other batteries that are not fully degraded after their warranty period may be suitable for refurbishing and reuse, particularly for stationary applications. For Chinese recyclers, reuse represents 50 to 70% of their operations (vs. recycling). The overall reuse rate is a function of whether batteries are typically returned in good condition after testing their performance. Firms also cited that the profitability of the reuse business is high, while recycling is less cost-effective – albeit these economics are changing due to the surging price of minerals for new battery manufacturing. For Chinese firms, this focus on reuse is also a consequence of government policy. China's regulations currently do not allow for the import of complete batteries for reuse and recycling. However, the country has allowed consumer appliances to be imported for reconditioning and reuse. Consequently, a large number of batteries have been shipped as part of the equipment to China for processing.[63] European and US firms, meanwhile, find less scale in battery reuse. According to one European interviewee, the condition of batteries available to them is poor, such that despite its higher profitability, reuse accounts for just 1-2% of their overall battery processing operations with the remainder in need of recycling. Moreover, a barrier to scaling up battery reuse is that cells of the same or similar type are needed, which is difficult to achieve. Nonetheless, **the profitability of battery reuse businesses has a key implication – widespread battery reuse will delay the need for battery recycling. This creates uncertainty for recyclers in setting up new operations.**

Alongside established recycling and reuse companies, new players and start-ups are entering the market and are experimenting with new technologies – often backed by venture capital firms or venturing arms of miners, EV manufacturers, etc. The challenges for such firms are the high up-front capital costs of facilities and ongoing operating costs unless the scale is achieved. However, **these firms are increasing the amount of overall competition within the battery recycling sector. This is impacting margins, and winners will be firms that can keep operating expenditures low, have access to global battery and resource supply chains, and reach scale with a good trade-off between capital investment and recovery rate.** Some companies are responding to this through a business model focused on recovering not only the high-value metals like nickel and cobalt but the lower-value components too. A strategy pursued by other interviewed firms is to form partnerships with a range of different recyclers, providing simultaneously an injection of capital (as an investor) and a route to market (as an off-taker of refined minerals). Such strategy is aligned with a belief in localisation of operations – both for access to battery waste and

[63] Melin, H.E. (2019), State-of-the-art in reuse and recycling of lithium-ion batteries – A research review for the Swedish Energy Agency http://www.energimyndigheten.se/globalassets/forskning--innovation/overgripande/state-of-the-art-in-reuse-and-recycling-of-lithium-ion-batteries-2019.pdf

because of government pressure to reduce dependency on a small number of countries for critical minerals. The roles of miners, recyclers, cell manufacturers, and EV manufacturers are thus becoming blurred, i.e. recycling is stretching upstream and downstream. The other **likely consequence of compressed margins is market consolidation of the industry through mergers and acquisitions.**

2.3.3. Perceptions on regulatory issues from international firms

Interviewed firms reported that the ease of doing business and the presence of regulations enabling safe and environmentally friendly recycling operations are key factors driving the appetite for investment in each of the countries they invest in the battery. For instance, **the low levels of policies and regulations enforcement (including the extended producer responsibility (EPR)) in India are key barriers to entry.** India's EPR for e-waste from circuit boards (in place since 2016) is seen as a very useful policy, but enforcement by the Ministry of Environment and Central Pollution Board is a big challenge. **The Indian e-waste market is still controlled by 90% by the informal sector[64] , which stops companies from keeping control over the way batteries are recycled.** The informal sector trades and dismantles batteries in a non-environmentally friendly way and sells the components back to the manufacturers.

Global recyclers operating in China and Europe talked about the challenges of enforcing EPR regulation even in China, a country that has a mature battery recycling market. The Government of China introduced a new EPR in 2018 in a context where the country was expected to produce around 170,000 metric tons of lithium-ion in 2018. This new EPR requires EV manufacturers to be responsible for establishing facilities to collect and recycle old batteries[65] . The main challenge comes from the outsourcing of battery

[64] Source: RLG Impact, March 2021: "Formalizing India's Informal Electronic Waste Sector" https://rev-log.com/us/rlg-impact-series-formalizing-indias-informal-electronic-waste-sector/#:~:text=The%20Indian%20e%2Dwaste%20market,e%2Dwaste%20to%20be%20processed.

[65] Source: Reuters, February 2018: "China puts responsibility for battery recycling on makers of electric vehicles" https://www.reuters.com/article/us-china-batteries-recycling/china-puts-responsibility-for-battery-recycling-on-makers-of-electric-vehicles-idUSKCN1GA0MG

processing by OEMs to external players who may not respect regulations. While China has created a "white list" of battery recycling companies, several batteries are recycled on the informal market. Chinese firms report that local collection of battery waste and EPR scheme enforcement are the main barriers they face in their current operations, because of the geographic spread of operations. The cost of building a comprehensive collection network is immense. Most used batteries lie within the private market and without strong enforcement of government rules and incentives to align, build and operate the collection network with the needs of the industry leaders. The government and industry players are jointly working on the collection network.

Battery traceability is at the centre of regulatory discussions in the EU and among interviewed firms.

It is centred around the concept of "battery passports", which are "a digital representation of a battery that contains information about all applicable lifecycle requirements of a sustainable battery, making it easier to identify and track batteries throughout their lifecycle."[66] Battery passports could support transparent data sharing on battery chemistries, and the origin and performance of used batteries. They could also help countries harmonise their regulatory actions on the transboundary movement of spent lithium-ion batteries.[67] At present, no mandatory or harmonised labelling system currently exists in the EU to provide information on the chemical. The due diligence and compliance systems currently only focus on primary production, not on used batteries. There is growing evidence that primarily produced materials enter the market as "recycled" materials (therefore not subject to regulation on primary products) in some countries that have a high melting capacity.

Interviewed firms confirmed that recycling black mass is technologically more demanding than dismantling and initial processing of batteries. Regulations need to adapt to increasing trade and transportation of black mass to recyclers who are equipped to recycle it. Compared to LiBs, a black mass is easier to transport, but risks remain and some countries classify it as dangerous goods / hazardous waste, which in turn is likely to slow down opportunities around a circular economy. China revised its regulation in 2021 to allow imports of black mass[68] , which will change the dynamics of the transboundary movements of batteries and materials and enable China to consolidate its regional position as a battery recycling hub. The Basel Convention to control the transboundary movements of hazardous wastes and their disposal (1989) started to address electronic waste issues since 2002, including illegal traffic to developing countries. However,

66 International Energy Agency (2021) World Energy Outlook Special Report: The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf

67 Source: WEF (2020), cited in Ibid.

68 Source : Circular Economy Storage online, April 2021: "New standard for crude nickel cobalt hydroxide facilitates Chinese import of battery waste": https://www.circularenergystorage-online.com/post/new-standard-for-nickel-cobalt-hydroxide-facilitates-chinese-import-of-battery-waste

the convention is a non-binding waste disposal guideline and will need to be broadened and adapted to the rise of transborder movements to avoid becoming obsolete.[69] One of the interviewed firms specifically referred to legal permission to ship LiBs to India as a crucial factor for investing in India. The question for investors is whether India can become a hub with regional facilities for South Asian and Southeast Asian countries. The policy will need to be flexible in dealing with two potentially competing business models – a centralised national model where India is a hub and the alternative where India remains a spoke for dismantling / early-stage processing and sending components to centralised locations elsewhere in the world.

[69] The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted on 22 March 1989 by the Conference of Plenipotentiaries in Basel, Switzerland, in response to a public outcry following the discovery, in the 1980s, in Africa and other parts of the developing world of deposits of toxic wastes imported from abroad. Source:http://www.basel.int/TheConvention/Overview/tabid/1271/Default.aspx

Chapter 3

Global perspective on regulations, risks and emerging market

Our interviews with leading international recyclers confirmed that the growing market and evolving regulations are key determinants of corporate investment strategies. In support of deriving recommendations for India, we reviewed the wider literature.

Section 3.1 provides a brief overview of key dynamics in global regulations on battery recycling and reuse. Section 3.2 reviews the implications of technology opportunities and risks. Section 3.4 focuses on additional aspects governing the economics of battery recycling.

3.1. Regulations governing reuse and recycling

There is no single benchmark regulation that could serve as a blueprint for India. Regulatory frameworks vary significantly from country to country to cater for the specific dynamics of the domestic battery manufacturing and recycling markets. This section doesn't serve as a comprehensive review of policies and regulations, but rather provides an indicative overview.

In Europe and North America – while the home of several recycling hubs – the volumes of LiBs processed are still fairly low, because batteries are not at the end of their life yet. Moreover, there is active trade of battery waste to China for reuse and countries such as South Korea for processing. This is accompanied by a trend towards increasing pre-processing of batteries in the countries where they are collected, including in India, for more efficient and safer transportation. High safety precautions due to fire hazards for LiB recycling create substantial hurdles to economic recycling practices. Standards on LiB recycling processes and reuse, especially the early stages (pre-processing and dismantling) are a major issue even in China where the recycling and reuse practices are the most mature[70]. Below is a brief synopsis of selected key international battery regulations and standards, particularly around EPR obligations that are shaping company strategies.

3.1.1. USA

The USA does not have federal laws and regulations specifically for EV battery recycling. Only universal laws and regulations govern the overall recycling of used batteries. LiBs are considered harmful and governed under the Standards for Universal Waste Management as "hazardous waste". There are no specific targets for LiB collection, and collection is voluntary (done by the call2recycle initiative). The EPR

70 Research Study on Reuse and Recycling of Batteries Employed in Electric Vehicles: The Technical, Environmental, Economic, Energy and Cost Implications of Reusing and Recycling EV Batteries EV Battery Reuse and Recycling, Project report by Kelleher Environmental for Energy API (September 2019) https://www.api.org/~/media/Files/Oil-and-Natural-Gas/Fuels/Kelleher%20Final%20EV%20Battery%20Reuse%20and%20Recycling%20Report%20to%20API%2018Sept2019%20edits%2018Dec2019.pdf

legislation is only present in some states and remains unclear for LiBs. A battery passport may be a viable alternative[71]. **A LiB Advisory Group** (formed of public agencies and private companies, including some of the firms we interviewed as part of this study) was set up in 2019 to support and advise the design of LiB disposal regulations, especially for EVs.

A key policy within the US is **California's Rechargeable Battery Recycling Act (2006),** which prohibits the disposal of all household batteries in landfills and requests that retailers collect or accept to take back rechargeable batteries for recycling, at no cost to consumers. The Act provides a location for consumers to recycle rechargeable batteries.

3.1.2. Asia Pacific excluding India

Asia is at the forefront of battery recycling. Over 20 companies are involved in China and at least 6 in South Korea. Their feedstock originates both from domestic batteries and imports.

China:

After benefitting from a government-led subsidies and incentives system, the Government of China started to reduce their support in 2012. This system supported a nascent recycling industry and helped attract businesses, train people and pool investments in recycling. Recycling is a hot area in China and attracts investment from domestic companies in particular. However, Chinese recyclers are now calling on policymakers to keep supporting the industry to reduce operational costs in China. In 2017, China released draft regulations holding automobile manufacturers accountable for the recovery of new energy vehicle batteries.

Since 2018, China has set up additional EPR measures to encourage battery producers and EV manufacturers to establish collection and recycling activities, beyond manufacturing only. Technical guidelines encourage the standardisation of battery design, production and verification, as well as repairing and repackaging for second-life utilisation.

China does not have any specific regulation on LiBs. There is a catalogue of e-waste product recycling (2015), which does not set any collection targets. The EPR legislation does not apply to LiBs. After closing its borders to waste imports, China reallowed in 2021 the imports of black mass[72] to facilitate access to primary materials such as crude nickel-cobalt hydroxide for the processing of waste batteries.

Japan:

Japan does not have laws and regulations specifically for EV battery recycling. Only universal laws and regulations govern the overall recycling of used batteries. The Promotion of Effective Utilization of Resources Act (1991, revised in 2000) encourages business operators to collect and recycle products where recycling is possible. **A collection target was set to 30% for LiBs.** The collection is organised through collection centres and through the Japan Portable Rechargeable

[71] GIZ, Deloitte (2022), International review on Recycling Ecosystem of Electric Vehicle Batteries https://greenmobility-library.org/public/index.php/single-resource/VVlwYzEwdzZUWmNjVDdRQnI0L0JOZz09

[72] Source: Circular Economy Storage online, April 2021, "New standard for crude nickel cobalt hydroxide facilitates Chinese import of battery waste": https://www.circularenergystorage-online.com/post/new-standard-for-nickel-cobalt-hydroxide-facilitates-chinese-import-of-battery-waste

Battery Recycling Center (JBRC) for member manufacturers of small rechargeable batteries.

An effective EPR system allows recyclers to cover up to 80% of their costs. To boost the EV industry, including battery reuse, the government and automotive sector are collaborating on the collection and testing of used batteries to maximise reuse. Batteries are viewed as a key strategic pillar for the evolution of the automotive industry and to achieve the Green Growth Strategy[73].

South Korea:

An **EPR** policy was adopted in 2003 for the collection and recycling of four battery types: Mercury, Nickel-Cadmium (NiCd), silver oxide and primary lithium batteries. In 2008, Aqueous Aluminium-Ion (MnAl) and Nickel Metal Hydride (NiMH) were also included. The policy states EPR mandatory targets for recycling and actual recycling rates are calculated by the Ministry of Environment annually to check on the policy's achievements.

Australia:

In Australia, there is no specific regulation for battery recycling or collection. An EPR legislation is in place, and collection is covered by a voluntary collection initiative (the Australian Battery Recycling Initiative, or ABRI).

3.1.3. European Union

The EU's current regulatory framework comprises (specifically) the 2006 Batteries Directive and (more generally) the Waste Framework Directive, the Industrial Emissions Directive and chemicals legislation. Current issues with the EU regulatory framework are:

- The 2006 Batteries Directive targeted 65% in terms of weight for Lead Acid batteries, 75% of Nickel–Cadmium batteries, and 50% for "other batteries" including Lithium-Ion batteries, but the directive has only boosted the collection of profitable battery types. This is problematic, given that recycling technologies are rather capital-intensive and require significant economies of scale[74] .

- The Batteries Directive is also not well equipped to keep pace with new technological developments. An example is LiBs, which are becoming the most important battery chemistry in the market but are not specifically covered by the Directive, which discourages recycling of these batteries and is a barrier to the development of high-quality recycling processes.

The implementation of the EU Directive has been uneven and the levels of batteries collected and recycled are sub-optimal. The EU has therefore set some priority actions on battery recycling, which focus on recovering mineral resources, on mining issues, how to stimulate the market and foster the e-mobility sector, and on initiatives

[73] International Energy Agency (2021), Global EV Outlook 2021 https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf

[74] Halleux, V., (2022), New EU regulatory framework for batteries: Setting sustainability requirements European Parliamentary Research Service https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf

to boost battery manufacturing, recycling and reuse. New measures have been set up to improve recycling and collection. A new Battery Regulation proposal envisioned a 70% recycling efficiency for Li-ion batteries by 2030, plus specific recovery rates of 95% for cobalt, nickel and copper and 70% for lithium.[75] A new EU directive, issued on the 10th March 2022 for manufacturers, introduced certificates and labels for the calculation of manufacturers' carbon footprint to incentivise them further.

This is supported by the EU EPR, which transfers funds from consumers to recyclers. This so far covers up to 50% of the recycling costs. Using this principle, the European Commission has put into place innovative measures to maximise collection levels centred around:

- ***A recycled content declaration requirement*** would apply from 1 January 2027 to industrial batteries, EV batteries and automotive batteries containing cobalt, lead, lithium or nickel in active materials.

- ***Mandatory minimum levels of recycled content set for 2030 and 2035*** (i.e. 12 % cobalt, 85 % lead, 4 % lithium and 4 % nickel as of 1 January 2030, increasing to 20 % cobalt, 10 % lithium and 12 % nickel from 1 January 2035, the share for lead being unchanged).

It is important to note that Germany has a different EPR system, where consumers do not pay towards the EPR financing system but rather battery producers pay an advance deposit ahead of manufacturing.

After verification that environmental and EPR regulation was respected throughout the manufacturing process, companies claim their money back. Companies can also contact an insurance policy to recover their deposit in case of non-compliance. The EPR system in Germany relies on an audit and certification system for battery manufacturers, where they sign a contract with recyclers who get the EPR funds from manufacturers. **China is trying to follow the German pattern of EPR since the Government has started reducing central subsidies to recyclers.** The Chinese government sees the German EPR system as better adapted to the geographic spread of the manufacturing and recycling industry in China, where it has proven challenging to enforce EPR regulation centrally and efficiently.

75 International Energy Agency (2021), Global EV Outlook 2021 https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf BRI(2021)689337_EN.pdf

3.2. Reuse and recycling technology: Risks and opportunities

Technology is a key distinguishing feature of international recycling companies – with each stage of battery EOL management presenting its own opportunities and risks for investors. At a high level, these stages divide into second-life applications and LiB recycling. We review the opportunities and risks associated with each of these stages.

Technologies for recycling such as pyro and hydro metallurgy for recycling EV batteries are at a mature stage with a global recycling capacity of more than 100,000 t/a. However, recycling EOL EV batteries that have about 80% capacity still left after retirement may lead to an inefficient value chain of batteries as this will lead to waste of resources and energy. **The second-life application of EV batteries is essential for establishing an efficient circular economy of EV batteries. But the testing of batteries is a nascent technology and is critical for the beginning of the EV battery reuse process.**

3.2.1. Secondary use of batteries

The second-life options of batteries will help to improve the EV's overall economic efficiency, as the overall costs can be shared between the primary and secondary users.

There are different routes of secondary use of batteries for different applications as summarised in Table 6.

Table 6: Potential second life uses of batteries

	Reconditioning	Refurbishing	Repurposing	Reuse
Description	Reconditioning is an improvement of the life of a pack that is still eligible for the EV application by identifying and replacing the cells with poor performance	Refurbishing involves the identification of good battery modules from the EoL batteries and packing them into a new battery pack for further use	Repurposing involves the use of EOL EV batteries that still has enough capacity to be used in other stationary storage applications without any change to the battery packs	Reuse involves the use of the individual battery cells from EOL battery packs that are not suitable for EV applications but are suitable for other small applications
Applications	Same EV application	Same or other small EV application	Grid-connected storage, commercial distributed energy storage	Consumer electronic applications like mobile phones

Source: GIZ (2022), Battery Ecosystem: A Global Overview, Gap Analysis in an Indian context, and Way Forward for Ecosystem Development https://greenmobility-library.org/public/index.php/single-resource/ZjJhdmkybHhBZERZMER1KzNueUM0UT09

Opportunity for secondary battery use investment:

There is a growing automotive industry interest to involve in participating in extending the life of batteries through second-life applications to help reduce the cost of batteries and thus make the EVs affordable for end-users. There are several instances of collaborations between automobile companies with battery storage developers to develop batteries for second-life applications – and collaborations with battery recyclers to facilitate this loop as described in the preceding sections. This will also improve the EoL battery collection efficiency for the second-life battery application developers. This presents an opportunity for investing in the second-life application development for EoL EV batteries. Some of such initiatives by automotive industry players include:

- Nissan's partnership with Sumitomo Corporation to reuse battery packs from the Nissan Leaf for stationary distributed and utility-scale storage systems.[76]

- Renault's Advanced Battery Storage Program. This collaboration involves several partners in the energy sector and is expected to result in a 70 MW / 60 MWh used EV battery installation for grid-scale battery storage in Europe.[77]

- BMW's consortium with recycling firm Umicore and battery manufacturer Northvolt to improve the life cycle of batteries by repurposing the EoL batteries for home storage applications.[78]

Risks of battery second life investment:

Despite this promising opportunity, there are still several unclear technical and economic risks that may hinder the second-use option of EV batteries. Many factors that are affecting its feasibility are:

- **Availability of reliable data on battery ageing:** There is uncertainty in the availability of data on how the batteries have performed in their first life as EV batteries. Therefore, battery repurposing companies and the potential end users of second-life applications of batteries lack the knowledge of how batteries have performed and in which conditions. As the second life of the batteries depends on their use in its first life, this will increase the risk for the battery repurposing company that buys the EoL batteries.[79]

- **Cost of repurposing and competition with new, more advanced, and cheaper batteries:** There is still uncertainty in the cost of repurposing. Some applications where batteries can be directly reused will have low cost, however, some applications would need dismantling and repurposing parts of batteries which might increase the repurposing cost. For second-life markets to thrive, the cost of the battery, plus this processing fee, must be lower than the expected revenue to attract financial backing. While second-life batteries are expected to be cheaper than other forms of energy storage, second-life batteries will have to compete with less-expensive versions of current lithium-ion batteries, plus other chemistries like flow batteries.[80] As highlighted in Section 2.3.2 above, the recyclers we interviewed confirmed that the battery reuse business can be highly profitable relative to recycling, but a practical challenge is the availability of sufficient quantities of batteries suitable for second-life reconditioning.

- **Liability for quality of refabricated/ repurposed battery:** If a second-life battery resulted in damages to an EV or stationary application, then the question of liability arises. Currently, regulations and standards regarding liability for second-life batteries are unclear and may discourage automakers from allowing their batteries to be used outside of the vehicle, other than for recycling.[81]

[76] https://global.nissanstories.com/en/releases/4r
[77] https://events.renaultgroup.com/en/2022/01/27/stationary-energy-battery-storage-three-new-projects-in-europe/
[78] https://www.umicore.com/en/newsroom/news/bmw-group-northvolt-and-umicore-join-forces-to-develop-sustainable-life-cycle-loop-for-batteries/#:~:text=The%20BMW%20Group%2C%20Northvolt%20and,for%20electrified%20vehicles%20in%20Europe.
[79] UCLA, Berkeley Law report (2014) Reuse and Repower: How to Save Money and Clean the Grid with Second-Life Electric Vehicle Batteries https://www.law.berkeley.edu/files/ccelp/Reuse_and_Repower_--_Web_Copy.pdf
[80] Ibid.
[81] Ibid.

3.2.2. Testing of battery pack and module

Determination of battery condition is key in EoL EV battery management. For reuse/ repurpose of the batteries, companies must test the condition and performance at the building blocks level of the battery i.e., each module and cell level if required.

The testing of batteries for determining their condition will involve measurement of important battery parameters like its State of Health (SoH)[82] , State of Safety (SoS)[83] and Remaining Useful Life (RUL)[84] prediction. The generic process of testing batteries involves taking decisions at different stages of breaking the battery and testing to put the battery in the best suitable application. Figure 15. illustrates the process of determining applications.

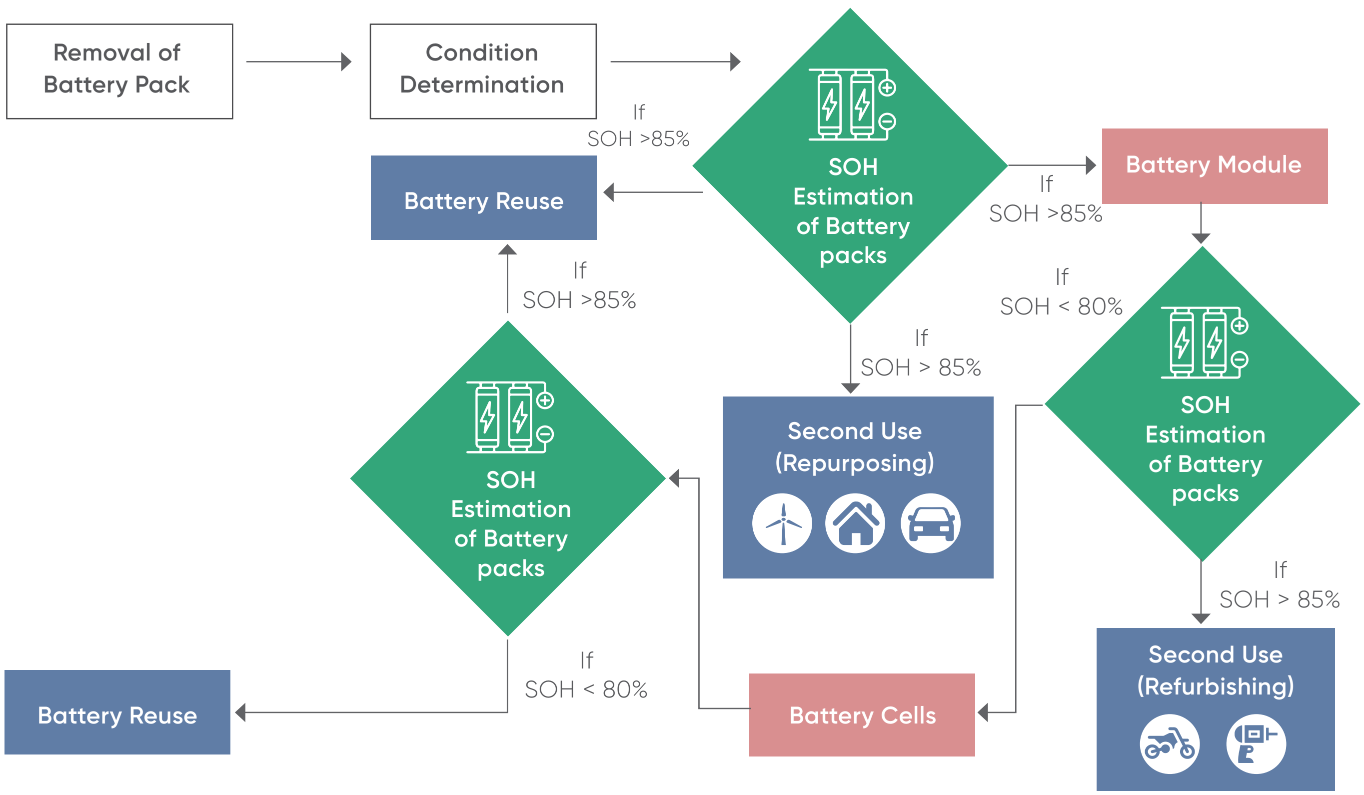


Figure 15: Flow chart for decision making on secondary life application of battery

Source: GIZ (2022), Battery Ecosystem: A Global Overview, Gap Analysis in Indian context, and Way Forward for Ecosystem Development, https://greenmobility-library.org/public/index.php/single-resource/ZjJhdmkybHhBZERZMER1KzNueUM0UT09

[82] State of health (SoH) is a figure of merit of the condition of a battery (or a cell, or a battery pack), compared to its ideal conditions. The units of SoH are percent points.
[83] State of Safety (SoS) represents the condition when the battery is in danger to use in the vehicles, and it can be estimated by several means, such as its thermal runaway, current, voltage, state-of-charge (SoC), and SoH
[84] The lithium-ion battery Remaining Useful Life (RUL) is defined as the remaining number of charge-discharge cycles of the battery with a specific output capacity

Opportunity if battery condition can be determined:

As standards are being developed worldwide for EoL battery testing, this provides an opportunity for reusing instead of recycling the batteries right after the first life. China has recently issued technical guidelines[85] to test the performance of batteries destined for reuse. This opens the scope for use of the EoL batteries in a range of applications and drives the efficient circular economy for the batteries.

Risks associated with battery testing:

- **Long testing times:** The major challenge of performance testing is that the test duration can be excessive and last for several hours. Current testing standards for capacity measurement of Li-ion cells (i.e., IEC-62660 and ISO-12405) would require at least a test duration of around 10 hours. Such a long test duration when considering large volume testing in a reverse logistics scenario, coupled with the expected rise in EV sales volumes, would be prohibitive for several vehicle manufacturers and specialist suppliers to apply circular economy principles within their businesses.[86]

- **No promising testing methods:** The methods for estimation of the parameters for battery condition determination (SoH, SoS and RUL) include empirical estimation, model-driven estimation and data-driven (machine learning) approaches.[87] Each of these methods has its own advantages and disadvantages and are still in research. Figure 16 illustrates these testing methods. Table 7 discusses their advantages and disadvantages.

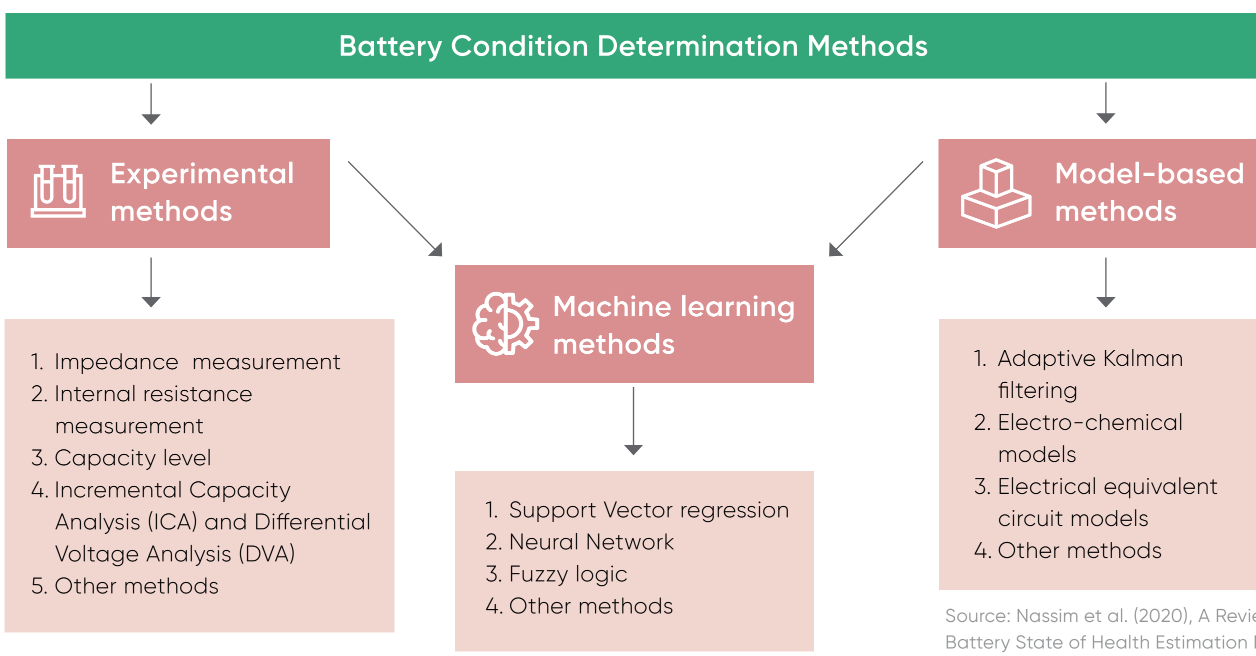


Figure 16: Battery condition determination methods classification

Source: Nassim et al. (2020), A Review of Battery State of Health Estimation Methods: Hybrid Electric Vehicle Challenges, https://www.mdpi.com/2032-6653/11/4/66/pdf?version=1602836129

[85] Standard GB/T 34015-2017 issued in 2017 by the Ministry of Industry and Information Technology (MIIT)
[86] https://www.sae.org/publications/technical-papers/content/2017-01-1277/
[87] https://hal.archives-ouvertes.fr/hal-02993901/document

Table 7: Battery testing methods, advantages, drawbacks and limitations

Method	Advantages	Drawbacks and limitations
Experimental methods: These are based on measurements that are done in laboratories to understand and evaluate the battery ageing behaviour	• High accuracy • Low computational effort	• Require specific equipment to be conducted • Most of the time the measurements are time-consuming
Model based methods: These methods use the equivalent electro-chemical and electric circuit models that describe the battery behaviour considering various battery condition indicators	• Require a simple structure. • Provide a relatively accurate and robust estimation. • Provide fast processing and easy implementation.	• Require experimental pre-validation in the development phase of the process. • Rely heavily on the model used in terms of accuracy and computational time.
Machine learning methods: These methods represent a combination of experimental and model-based ones. In fact, they use training data, measurements and models in the learning process to estimate the battery SOH	• Provide a high accuracy estimation. • Provide an easy implementation process.	• Rely heavily on the quality of the training data used and the operating conditions and battery types considered for these data. • Rely on the model used in terms of accuracy and computational time.

No standard design of battery: The current issue with testing the battery modules from various manufacturers is the fact that there are various designs and no harmonization between the various designs. There are different module and cell designs in the market, for example, Tesla Model S has cylindrical cells, Nissan Leaf has pouch cells and Mitsubishi i-MiEV has prismatic cells. The different form factor and chemistry makes the testing process challenging. Further, there is no standardization of the Battery Management System for EV batteries.

3.2.3. Automated dismantling of EV batteries

Dismantling of batteries involves breaking the battery into cells that can be further reused for various applications or crushed into a fine powder called black mass which can be fed to the recycling process. Automation of this process could accelerate the practical and economic feasibility of battery recycling and reuse at scale.

Opportunities for automated battery dismantling:

Presently most of the dismantling happens manually. However, EV batteries for 4-wheelers, trucks and buses are larger than what the recycling industry has traditionally catered for. It will be more challenging and riskier to dismantle them manually. This presents the case for implementing an automated dismantling of EV batteries.

Chinese companies who are actively involved in recycling have engaged in R&D for the dismantling stage as a critical step of pre-processing before recycling can happen. Successful automation would enhance both profitability and the technical feasibility of recycling and reusing LiBs at the scale that will be required to manage the volume of batteries reaching their EOL over the coming decade.

Risks associated with automated dismantling processes:

- **Processes to deal with chemicals used for battery cooling** require additional safety procedures to deal with polluting coolants. This is less easily automated.

- **Lack of standard battery designs** creates additional challenges for automated processes to detect components, separate them effectively and manage to dismantle them safely. Labelling and battery passports are potential solutions.

3.2.4. Battery recycling: recovery of high-value metals

Recycling is the final step of end-of-life battery management, focused on the recovery of high-value metals. While a profitable business, technological challenges persist that affect the economics of operations.

Opportunities for battery recycling technology:

- **Mechanical recycling remains a key technology that many global recyclers are involved in.** The process involves removing the outer case of the batteries, electronics, plastic separators and copper cables, and the remaining cells are crushed into a black mass. The resultant black mass contains high-value critical cathode metals and is processed for further extraction.

- **Hydrometallurgical and pyrometallurgical processes are well-established recycling technologies for recovering critical metals.** These are the processes that interviewed international recyclers are focused on. **A direct recycling[88] process is an emerging technology,** which is expected to recover critical metals more economical compared to the other two technologies

Risks associated with recycling processes:

- **Changing battery chemistries present technical and economic challenges:** Because of depleting resources, increasing costs and geopolitical issues with the sourcing of critical metals, battery manufacturers are looking to reduce the use of such metals by developing battery chemistries like sodium-ion, LFP and low cobalt NMC chemistries. These batteries hence contain fewer high-value minerals. This will affect particularly the profitability of capital-intensive hydro and pyrometallurgical recycling processes.[89]

- **Contamination of chemical process with changes in battery chemistry in case of hydro:** Shifts to lower critical metal and advanced new battery chemistries will severely affect the metal recovery efficiency of the process like hydrometallurgy. The hydrometallurgical process involves the chemical leaching of batteries. The new chemistries of advanced batteries would create unwanted chemical compounds during the chemical leaching process and contaminate the recycling process.[90]

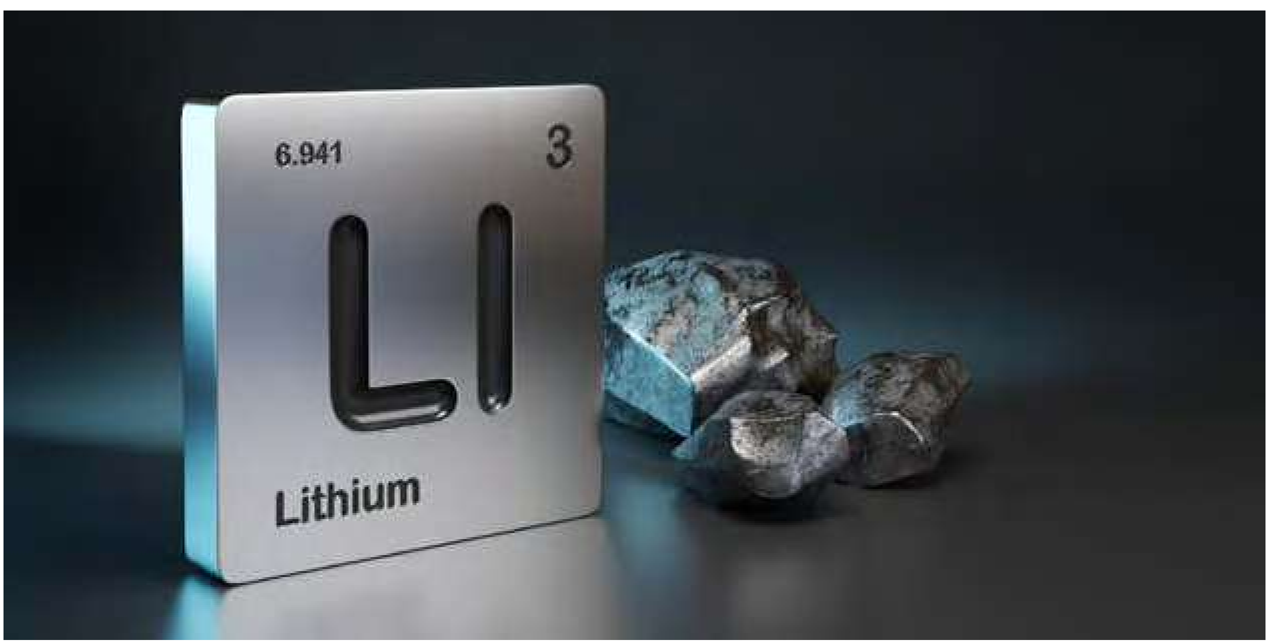
- **Higher recycling capacity for profitable processing of black mass:** The estimated break-even point for the critical metal recovery process is 17,000 t/a for pyrometallurgy and 7,000 t/a for hydrometallurgical plants.[91] The high capital intensity of these processes combined with highly competitive price offerings for black mass from some of the established recyclers (e.g. from China and South Korea) will pose a risk for battery recyclers in other regions of the world.

[88] Direct recycling is an emerging process, offering improved recycling efficiency, as it does not break down the cathode into elements, but instead retains the material crystal structure and regenerates the cathode material
[89] Lander, L. et al (2021), "Financial viability of electric vehicle lithium-ion battery recycling", iScience, Volume 24, Issue 7, 2021, 102787, ISSN 2589-0042, https://doi.org/10.1016/j.isci.2021.102787
[90] Sojka, R., (2020), "Comparative study of Li-ion battery recycling processes", ACCUREC Recycling GmbH, September 2020, page 3 https://accurec.de/wp-content/uploads/2021/04/Accurec-Comparative-study.pdf
[91] Ibid

- **Costly process for extraction of Lithium:** Most of the current recycling processes based on hydro and pyrometallurgical technologies are not able to recover the lithium from the batteries.[92] The extraction of lithium has not been economical historically. To make the recycling process profitable, it is essential to develop technologies to extract high-value Lithium which are still under the development/research stage.
- **There are social and environmental risks associated with recycling,** which are discussed in Section 3.4.3 below.

3.3. Relevant standards

A range of international standards exists for EOL battery management in individual countries. Companies operating in these countries or wishing to do business with these countries are obliged to comply. However, these standards themselves are evolving in response to technology and market trends. This creates uncertainty for recyclers. A detailed discussion of each standard is beyond the scope of this paper and the reader is referred to comprehensive discussions in, for example, European Commission, Joint Research Centre (2018).[93] A list of current standards is provided in table below. These provide an indicative overview of some of the standards currently in place. **Importantly, India lacks any such national standards at present.**



[92] Yan, T. et al (2020), "High-efficiency method for recycling lithium from spent LiFePO4 cathode", Nanotechnology Reviews, vol. 9, no. 1, 2020, pp. 1586-1593. https://doi.org/10.1515/ntrev-2020-0119
[93] European Commission, Joint Research Centre (2018), Ruiz, V., Di Persio, F., Standards for the performance and durability assessment of electric vehicle batteries: possible performance criteria for an Ecodesign Regulation, Publications Office, 2018, https://data.europa.eu/doi/10.2760/24743

Table 8: Global end of life battery management standards

Stage of EOL battery management	Standard	Country	Scope
Testing	GB/T 34015-2017	China	Test of residual capacity
	GB/T 33598.3-2021 Part-3	China	Specification for discharging
	GB/T 34015.3-2021 Part-3	China	Echelon using requirement
	GB/T 34015.4-2021 Part-4	China	Labels for echelon used battery products
	JIS C8715-1-2012 Part-1	Japan	Tests and requirements of performance
	JIS C8715-2-2012 Part-2	Japan	Tests and requirements of safety
	EN IEC 62660-2:2019	EU/ Global	Test procedures to observe the reliability and abuse behaviour of secondary lithium-ion cells and cell blocks
Battery manufacturing / usage / disposal	PAS 7061	UK	Safe and environmentally-conscious handling of battery packs and modules
Automated dismantling	GB/T 33598-2017	China	Dismantling Specification
	QC/T 1156—2021	Japan	Specification for secondary cell dismantling
Reuse / recycling	Technical code in drafting	China	Three technical codes and one regulation are at preparation or amendment stage: 1. Technical code of carbon emission accounting for EV battery reuse enterprises; 2. Amendment of regulation governing reuse and recycling of EV battery; 3. Technical code of the list of hazardous wastes (HW) generated in EV battery production; 4. Collection network and facility construction for EV batteries
	SAE J2997 (WIP)	USA	Standards for a testing and identity regimen to define batteries for variable safe reuse

3.4. Changing outlook: economics, emissions and social factors

3.4.1. Global lessons on the economics of LiB recycling and reuse

The preceding sections have demonstrated the viability of both LiB recycling and reuse. The wider literature identifies additional considerations for the profitability of such businesses. Battery recycling has typically been geared towards recovering cobalt, nickel and copper, which have been considered most valuable. Batteries from consumer electronics (the bulk of EOL batteries today) are LCO with 17% cobalt content, rendering them profitable to recycle. In addition, with strong commodity prices and efficient processes, most batteries with little to no cobalt (NCA, LFP and LMO) are profitable to recycle if received as cells.[94] However, EV batteries are more complex and assembled in modules and packs (see Sections 3.2.3 and 4.2.4 above), making disassembly costly. Transportation of batteries to specialist facilities may also be required. **The combination of the costs of transport, disassembly and processing (a function of labour, general expenses, electricity, water, etc) is the reason why the estimated profitability of EV battery recycling varies significantly across locations as highlighted in Figure 17**

Importantly, the economics are not static. In our interviews with recyclers, firms unanimously expressed their expectation of high profitability of EV battery recycling, given their industry-leading efficient processes, price expectations, and policy incentives. EPR schemes place an obligation on producers to ensure recycling and, e.g., in the EU, cover a significant proportion of recycling costs as highlighted in Section 3.1. Overall policy promotion of electric mobility and renewable energy is contributing to rising battery demand. An expectation of scarcity of critical minerals for battery manufacturing implies a forward view of enhanced recycling profitability.

For example, traditionally, lithium has not been recovered from batteries at scale, because it has not been deemed cost-competitive compared with primary supplies.[95] It is similarly possible for other materials that new mining may currently be more cost-effective for manufacturers than recycling in the absence of any support schemes.

[94] Melin, H.E., (2018), The lithium-ion battery end-of-life market - A baseline study for the Global Battery Alliance, World Economic Forum. https://www3.weforum.org/docs/GBA_EOL_baseline_Circular_Energy_Storage.pdf
[95] Halleux, V., (2022), New EU regulatory framework for batteries: Setting sustainability requirements European Parliamentary Research Service https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/689337/EPRS_BRI(2021)689337_EN.pdf

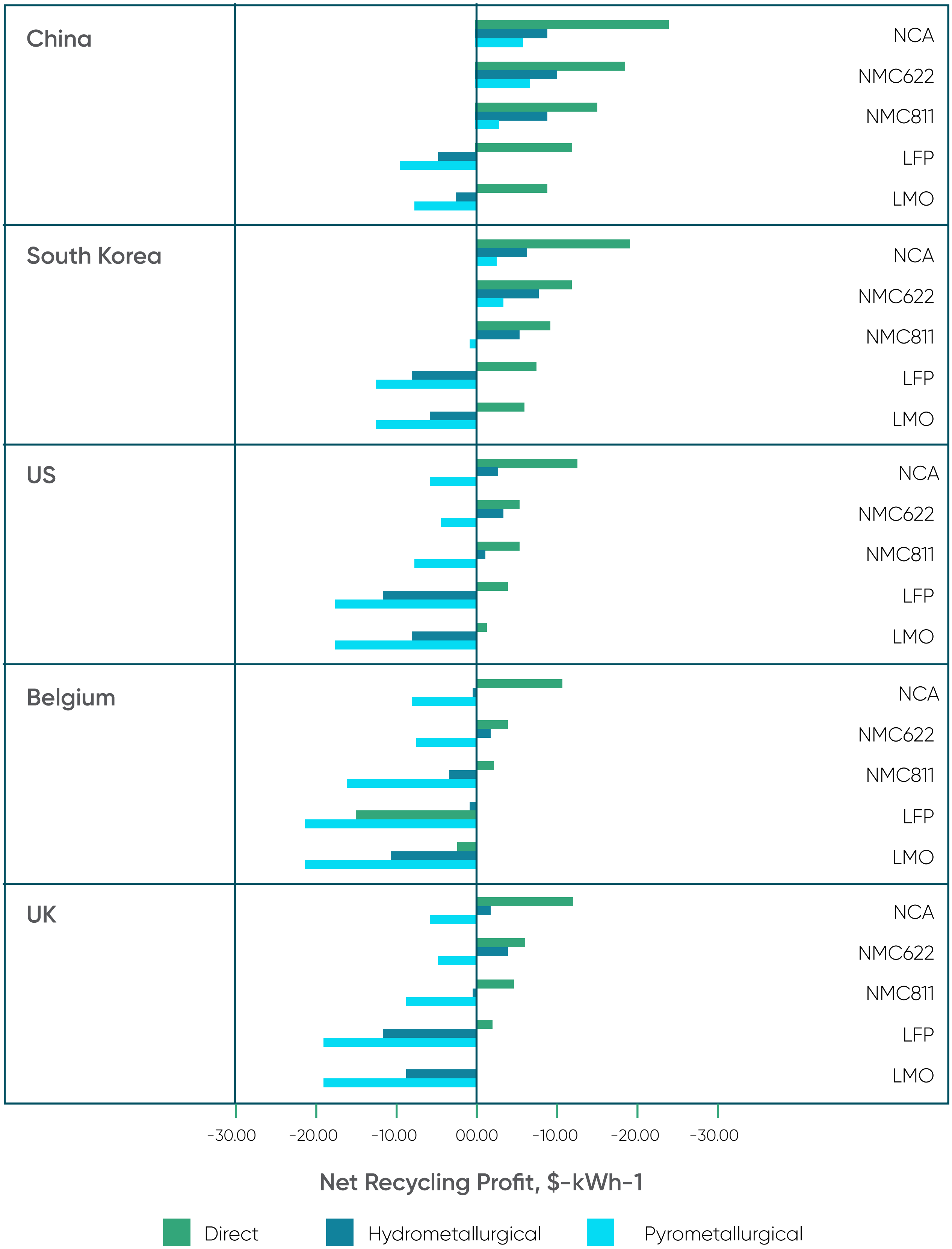


Figure 17: Estimated EV battery recycling profits by country, technology and type

Source: Lander, L. et al (2021)
Note: Bars pointing to the left indicate a net loss; bars pointing to the right are a net profit.

The expected supply-demand gap of high-value metals (cobalt, lithium, nickel) will make recycling and reuse indispensable over time. For example, lithium has frequently not been recovered from batteries at scale, because it has not been deemed cost-competitive compared with primary supplies.[96] But higher market prices for materials have already changed this, according to international recyclers we interviewed. Moreover, while EV battery reuse or 'second life' has so far been seen as more profitable, higher market prices for metals will incentive users to send batteries for recycling rather than for reuse due to more immediate recovery of these metals.[97] In addition, the challenge of re-engineering batteries for reuse and the potential safety liability of OEMs for such second-life applications are disincentives. This combines with expected reductions in battery production costs. According to a Global Battery Alliance study[98] , second-life batteries are currently traded for between \$60 and \$300 per kWh, depending on the market and application. These prices are set to fall in line with the general market to \$43 per kWh in 2030, primarily due to falling new battery prices. That value would be similar to what materials in batteries are worth today. Therefore, 'used batteries which still contain cobalt might be diverted to recycling as recyclers might pay the same or a higher price for the batteries.'[99] In other words, **the overall economics will shift away from battery reuse towards recycling instead** because "the regulation of and investment into the collection and material recovery incentivize the development and wide-spread application of high-quality recycling processes currently in early-stage development. This raises recovery rates across all major markets."[100]

3.4.2. Life cycle assessments and carbon footprint certifications

Environmental policy is a key driver of the viability of battery recycling and reuse as described in previous sections, but not all recycling processes currently deployed bring large environmental gains. Processes with low recovery rates may deliver limited benefits to the circular economy of batteries, some recycling processes generate substantial GHG and pollutants[101] and – where not regulated – informal sector mechanical dismantling processing may cause safety as well as environmental risks.

Emerging new regulations globally are creating compliance challenges. Life cycle assessment (LCA) is a methodology used to assess the environmental impacts of products or systems and is becoming an increasing requirement in several jurisdictions as a way to measure carbon footprint for battery manufacturers and recyclers. A typical LCA of a battery for electric vehicles covers all life cycle stages from mineral sourcing, processing, cell and module production, battery assembly, distribution and use to final recycling and end-of-life disposal. The primary use of an LCA is for producers to identify areas for improvement and also to measure the carbon footprint of batteries to get a certification. LCA methodologies typically push for a model where valuable materials extracted through recycling go back to manufacturers. Such a circular model would reduce the overall carbon footprint of batteries significantly.

[96] Ibid
[97] HMelin, H.E., (2018), The lithium-ion battery end-of-life market - A baseline study for the Global Battery Alliance, World Economic Forum. https://www3.weforum.org/docs/GBA_EOL_baseline_Circular_Energy_Storage.pdf
[98] Ibid
[99] Ibid
[100] Research Study on Reuse and Recycling of Batteries Employed in Electric Vehicles: The Technical, Environmental, Economic, Energy and Cost Implications of Reusing and Recycling EV Batteries EV Battery Reuse and Recycling, Project report by Kelleher Environmental for Energy API (September 2019) https://www.api.org/~/media/Files/Oil-and-Natural-Gas/Fuels/Kelleher%20Final%20EV%20Battery%20Reuse%20and%20Recycling%20Report%20to%20API%2018Sept2019%20edits%2018Dec2019.pdf
[100] Ibid

Battery recyclers will increasingly have to demonstrate the existence of an LCA certificate to their partners and clients. Recyclers who are also suppliers of raw materials for battery manufacturers will have to show LCA / carbon footprint certification to national authorities in the country where the battery is sold or exported (this is compulsory for exports to the EU). Specialist third-party companies provide LCA services and these are frequently used by small manufacturers, while large battery manufacturers have in-house teams dedicated to LCA to ensure compliance with global regulations.

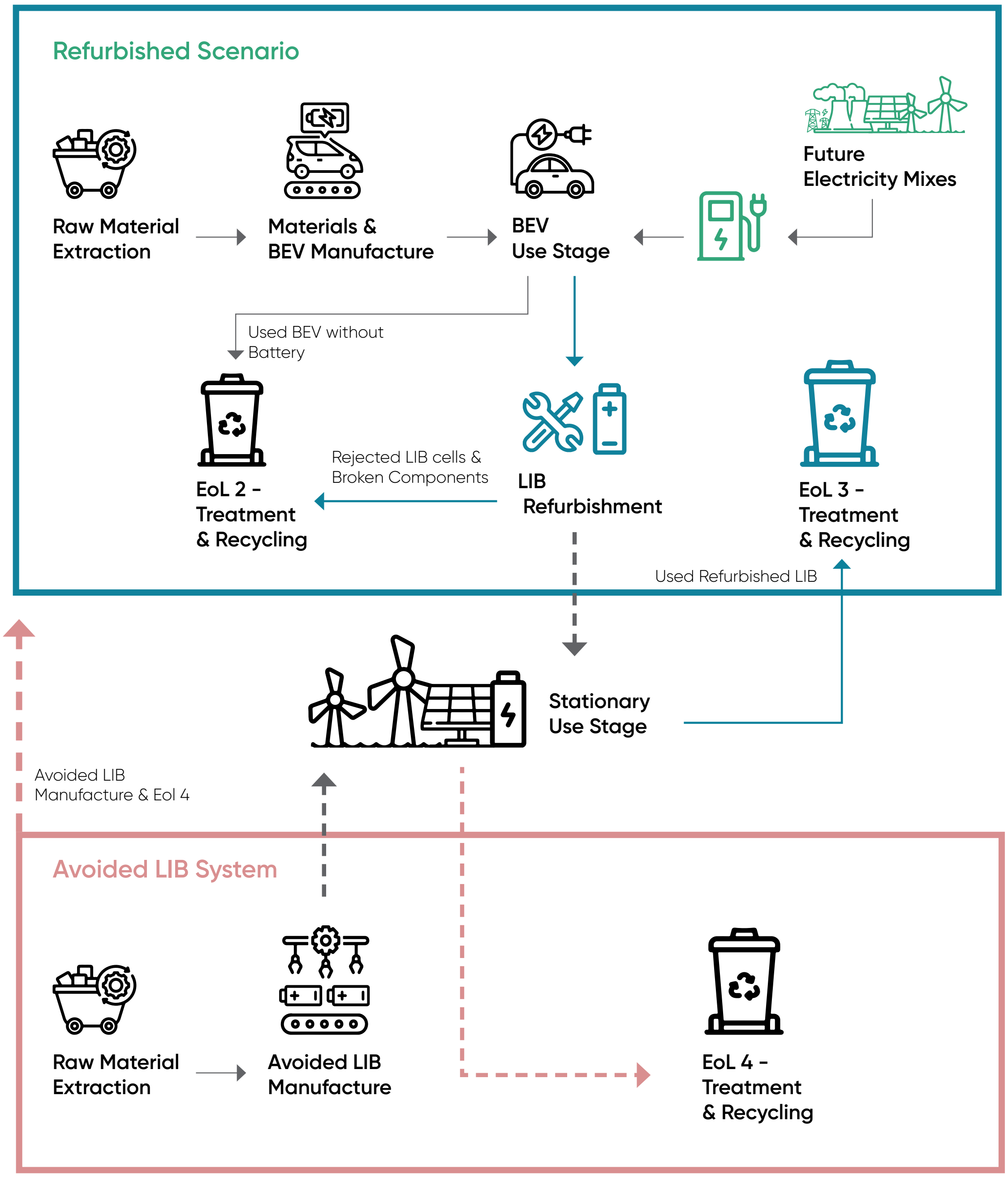


Figure 18: Example of life cycle assessment scenario analysis technology and type

Source: Koroma, M. S. et al (2022)[102]

[102] Koroma, M., S., et al (2022), "Life cycle assessment of battery electric vehicles: Implications of future electricity mix and different battery end-of-life management", Science of The Total Environment, Volume 831, 2022, 154859, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2022.154859.

LCA is increasingly being incorporated into EPR and Circular Economy (CE) guidelines:

- **The draft EU batteries regulation (10th March 2022)**[103] introduced a requirement by 2023 for battery manufacturers to include a carbon footprint declaration in the technical documentation of batteries (above 2 kWh), leading to the implementation of 'carbon footprint performance classes.' The implication is that it would become necessary for all of the players in the lifecycle of EV batteries to conduct an internal LCA to obtain a carbon footprint certificate (CE mark/certificate). Furthermore, repurposed (second life) batteries might be considered as new products- these will need to comply with product requirements when they are placed on the market. Harmonised rules for calculating carbon footprint for batteries have not been developed.

- **In South Africa,** as part of EPR requirements, producers might be required to carry out LCA for batteries.[104]

- **China** has established a national platform for EV battery monitoring and tracing, which includes three modules: *Vehicle Management Module, Recycling Management Module,* and *Local Authority Monitoring Module.* This platform provided life cycle management of EV batteries and started operation on 1st August 2018.

LCA is becoming central in the sector. Manufacturers and recyclers should position themselves to build up sustainable business models or risk falling out of compliance. There could be global implications of such certification requirements. For instance, the EU regulation also establishes a 'battery passport' to digitally track key metrics across the battery value chain. This means that batteries (including second life) placed in the EU market will need to abide by certification rules and also set up battery passports.

3.4.3 Social considerations, informal sector and transparency

Compliance and transparency entail additional dimensions that are likely to become of growing importance in the LiB recycling and reuse market. This includes aspects such as social considerations, the role of the informal sector and overall accountability for processes along the recycling and reuse value chain. As part of this study, we discussed these factors with international recyclers, experts on corporate responsibility and a representative from the OECD (see Annex C for details).

The role of the informal sector or unregulated recycling businesses

Battery recycling – especially at the early stages – like much of waste management more broadly, is frequently conducted by the informal sector or small unregulated businesses. This is the case in India, where battery separation, dismantling as well as the processing of battery scraps are often

[103] Proposal for a Regulation Of The European Parliament And Of The Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020PC0798

[104] GIZ, Deloitte (2022), International review on Recycling Ecosystem of Electric Vehicle Batteries https://greenmobility-library.org/public/index.php/single-resource/VVlwYzEwdzZUWmNjVDdRQnI0L0JOZz09

undertaken by the informal sector with limited oversight over health, safety and environmental (HSE) standards. Aside from unsafe work practices with negative social impact, such informal sector processing leads to lacking clarity over what happens to residual by-products from these initial battery recycling stages. Interviewees highlighted in addition that the informal sector similarly manages the transport of batteries – both at the initial collection stage and for the resale of recovered waste on the open market. For some international recyclers active in India, open market purchase of pre-processed battery waste is the only way of obtaining access to sufficient battery mass at present in India. They perceive this as a significant risk to investment, with battery passport and LCA regulations set to amplify the challenge over time. A route to direct access to battery waste that, therefore, bypasses informal sector intermediaries, is a core part of the strategy of international recyclers as they scale up their operations in new markets.

The informal sector may have cost advantages while creating liability challenges for OEMs. According to a report by Kelleher Environmental, "amateur operators with low safety and environmental standards will take apart a Tesla battery, test and sell the cells separately for $5 to $6/cell. In theory, if 80% of the cells are in good condition, these amateurs could make $15,000 from a used Tesla battery. These operators are of significant concern to Panasonic [the manufacturer of Tesla batteries] because of the risk and liability associated with the distribution of cells without proper standards and management." [105]

Formalisation, standardisation and regulation of the battery collection and early processing stages thus offer significant opportunities for enhancing local social impacts through better HSE practices, while simultaneously improving the investment climate for international recyclers.

Transparency and traceability along the battery value chain

Transparency and traceability of recycled materials are concerns for all metals, including those from batteries. This commences at the mining stage, where cobalt is increasingly being seen within the category of so-called 'conflict minerals' as e.g. three-quarters of global production comes from the Democratic Republic of Congo[106], where practices at artisanal and small-scale mines (ASM) and armed conflicts remain concerns. While knowledge of the country of origin exists at the mining and, hence, most likely also at the original battery manufacturing stage, this is no longer certain after battery reuse or recycling. There are two reasons for this.

There is no clear definition of what 'recycled' means when referring to batteries. A strict definition might classify recycled batteries as those consisting of 100% of post-original consumption materials. However, in practice, a recycled or refurbished battery may consist of a blend of recovered and newly mined components. This may extend to the level of individual metals, e.g cobalt. This issue is already the case for other metals, most notably gold, where ASM gold is entering the market under the disguise of a 'recycled'

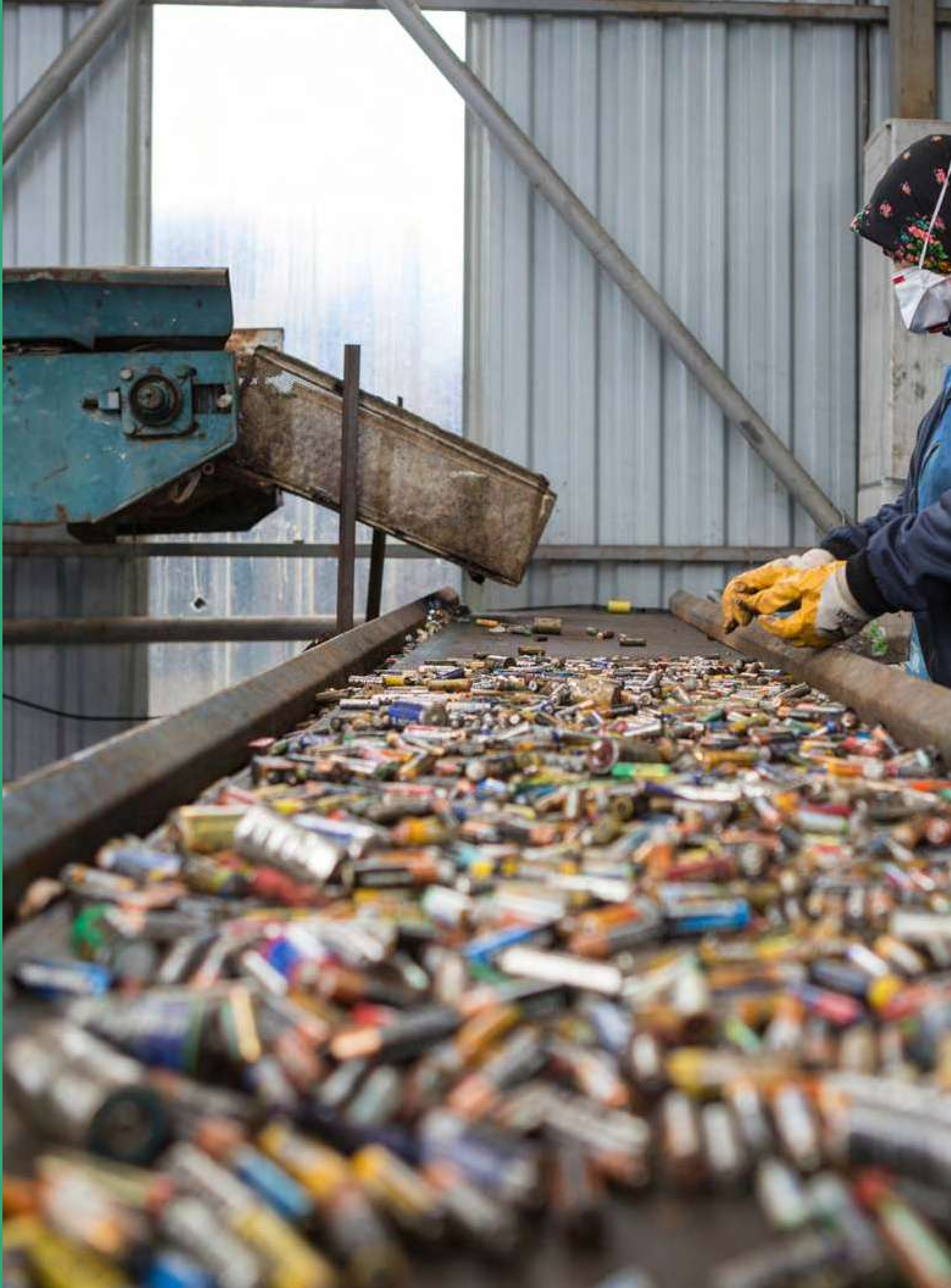
[105] Research Study on Reuse and Recycling of Batteries Employed in Electric Vehicles: The Technical, Environmental, Economic, Energy and Cost Implications of Reusing and Recycling EV Batteries EV Battery Reuse and Recycling, Project report by Kelleher Environmental for Energy API (September 2019) https://www.api.org/~/media/Files/Oil-and-Natural-Gas/Fuels/Kelleher%20Final%20EV%20Battery%20Reuse%20and%20Recycling%20Report%20to%20API%2018Sept2019%20edits%2018Dec2019.pdf
[106] USGS (2021). Mineral Commodity Summaries. Cobalt. United States Geological Survey, 2021. https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-cobalt.pdf

material via countries or companies with less strong responsible sourcing requirements by melting and binding it to other metals.[107] Recognition of the issue and discussion of enhanced standards for due diligence on metals overall was the theme of the 15th OECD Forum on Responsible Mineral Supply Chains that took place from 2 to 6 May 2022.

International trade in battery waste compounds the issue of transparency and traceability of components. Corporate strategies pursued by leading international recyclers are anchored around the principle of obtaining battery waste from source countries, where they are pre-processed and then exported as black mass to centralised hubs for final processing. While proposed 'battery passports' seek to track the origin of components, the potential role of intermediaries (as well as informal sector actors) within the different stages complicates the tracking of components. Another example of this is the trade of batteries with China. While battery waste import is prohibited in China, the import of batteries within defunct appliances for refurbishment reuse is not. Yet it is difficult to distinguish at the border which purpose battery waste will serve in reality. This extends to international statistics on the battery waste trade, which is only just emerging globally. A forthcoming OECD study on the topic notes that international statistics i) do not distinguish between quantities for reuse or recycling, and ii) do not track the original source of metals and potential re-export.[108] Such 'rule of origin' criteria to determine the national source of a product begin to matter, however, as batteries constitute a significant part of the value of EVs and, therefore, may impact on excise and duties charged on them.

[107] Dietsche, Evelyn (2022), private verbal communication in interview to authors of this study, 11 May 2022.
[108] Rubinova, S. (2022), OECD, private verbal communication in interview to authors of this study, 11 May 2022.
[109] Source: Reuters, May 2021: "Glencore, Umicore to trace battery cobalt with blockchain technology" https://www.reuters.com/business/energy/glencore-umicore-trace-battery-cobalt-with-blockchain-technology-2021-05-20/
[110] Dietsche, Evelyn (2022), private verbal communication in interview to authors of this study, 11 May 2022.

Battery passport and to some extent LCA certification processes will help enhance transparency and traceability. They will, however, encounter the limitations outlined above. Innovative solutions may exist and, for example, Glencore and Umicore are piloting at present the tracing of battery cobalt with blockchain technology.[109] Alternative solutions may emerge, with options floated in other domains of the circular economy including extensions of EPR regulations. Such an option could include that miners retain property rights of metals even after the end-of-life products. In other words, this would resemble a model whereby mined outputs are leased rather than sold to producers.[110] Such an approach would, however, have to be accompanied by tracing technology such as blockchain that remains to be proven economically viable at scale.



Chapter 4

Conclusions and recommendations for India to attract international investors and boost domestic recycling ecosystem

Our review of the literature and interviews with stakeholders identified that battery recycling is not a choice, but a necessity to ensure the global availability of critical minerals required for the low carbon energy transition. India can become a key part of this and attract international LiBs recyclers to invest in the country. In the sections below, we have highlighted the challenges and barriers faced by existing domestic recyclers in India, along with the risk and opportunities of investing in India as perceived by international recyclers.

4.1. Challenges and barriers highlighted by domestic recyclers

Li-ion battery recycling is a multistep process, which requires proper logistics to procure scrap batteries, capital-intensive plant setup, and additional technologies and cell chemistries that are feasible for long-term business. Below are some of the key challenges highlighted during several rounds of consultation with key recyclers in India.

Policy and Regulatory

- **Lack of waste handling regulations, standards, and certifications:** Li-ion batteries are considered hazardous since they have corrosive, flammable, toxic, and explosive characteristics. Most of the collection of batteries is through informal mechanisms hence it lacks standards for collection and transportation. This may pose a great risk of any mishap.

- **Lack of schematics and standardization of batteries for recycling and healthy recovery of batteries:** Manufacturers do not provide explained diagrams of battery systems/ packs, disassembly sequences, type and number of fastening techniques, tools required, number of cells, and necessary warnings, etc. Such information can help in ensuring the healthy recovery of materials and the safety of end-of-life and waste battery handlers.

- **Import restriction on used Li-ion batteries:** The import restrictions on the used/scrap lithium-ion batteries are a hindrance for recyclers who can expand their base not only in India but also in catering to international markets.

- **Bigger focus on recycling:** The draft policy on waste management rules focuses on battery recycling but misses out on the reuse of batteries, which is an important aspect of achieving a circular economy from batteries coming from the EV sector. Although the draft is yet to be officially notified.

Collection

- **Dominance of the unorganized sector:** Due to the lack of ease of disposal via the organized channel of battery disposal, consumers rely heavily on the unorganized sector.
- **Price discovery:** The prices of scrap batteries vary from region to region due to the presence and dominance of local scrap dealers. Causing uncertainty in the long-term supply of batteries to recyclers.

Market Offtake and Operations

- **Non-segregation of scrap batteries:** The used batteries come in different lots through scrap dealers, it becomes a time-consuming process for recyclers to segregate them based on different chemistries and compositions.
- **Lack of battery manufacturing from recycled minerals/metals:** The recycled minerals and metals from the recycled process are majorly used in industries like aviation, pharmaceuticals, ceramics, cement, etc. It lacks circularity for not being utilized in new battery manufacturing.
- **Labs for quicker testing:** The number of labs for validation of heterogeneous materials of different batteries is very less and it takes too much time to get the final report.
- **Competing with new batteries:** Advances in technology have led to significant enhancement of new battery performance and a decline in battery prices. Although the cost of second-life repurposed batteries is much lower than the cost of new batteries in the current scenario, in the long run, the battery prices will decline further. Hence, new-tech batteries could potentially be a competitor for repurposed batteries.
- **Economic Feasibility:** The economic value of recycling batteries is primarily dependent on the battery chemistry (assuming full recovery efficiency). Although LFP is one of the most extensively used battery chemistry, the margins involved in LFP recycling are not very appealing to recyclers due to the lower economic value and high recycling costs. Furthermore, LFP does not contain any valuable metals except lithium, which is present in a very small quantity. Therefore, recyclers must tailor their processes to boost plant productivity and the ability to process a wide range of battery chemistries.

Others

- **Capacity Building:**
  In the absence of any manufacturing facilities for Li-ion battery production in the country, the manpower has limited skillsets to be deployed in upcoming facilities and would require time and effort to learn new skills.

- **Variety of battery packs:**
  A wide variety of battery pack designs and interconnect technologies make the disassembly process complex, time-consuming, and cost-intensive. Dissimilarity in battery design and configuration creates a problem in the establishment of standard recycling units.

- **Carbon footprints:**
  The recycling process of LiB units itself involves several carbon-emitting activities, starting with the emissions resulting from collecting and transporting batteries to the recycling process, which itself requires a considerable amount of electricity and thermal energy.

4.2. International recyclers' perspective on risk and challenges in investing in India

International battery recyclers are interested in exploring and/or scaling up investments in India as they see the country as a nascent and promising market. However, they require a greater understanding of the specific market opportunities. Of the interviewed recyclers, only one firm has an existing battery recycling business in India that it is in the process of upgrading. However, some of the interviewed recyclers are keeping an eye on how the recycling landscape is evolving in India- they either have existing businesses in parallel sectors (such as charging) or have dedicated policy advocacy teams focused on finding suitable partners in India.

The lack of familiarity with the Indian market is a barrier for investors who do not yet have partners in India or operating experience in the country. Some of the interviewed firms had limited knowledge of existing initiatives India has taken to accelerate the manufacturing and deployment of batteries, while others understand that the FAME I programme[111] did not achieve to boost individual EV sales as much as expected. FAME II allocated USD 1.4 billion over 3 years, to boost the manufacturing of 1.6 million hybrid and electric vehicles, with a strong share of the incentives dedicated to buses (41%),

[111] The Faster Adoption and Manufacturing of Electric and Hybrid Vehicles in India (FAME) scheme was set up by the Government of India in 2015 to reduce pollution caused by diesel and petrol operated vehicles and to promote electric or hybrid vehicles. Phase I (2015-2019) was followed by a new investment of Rs. 10,000 Crore (2019-2022). 86% of FAME II has been allocated for Demand Incentive so as to create demand for xEVs in the country. This phase aims to generate demand by way of supporting 7000 e-Buses, 5 lakh e-3 Wheelers, 55000 e-4 Wheeler Passenger Cars (including Strong Hybrid) and 10 lakh e-2 Wheelers. Source: India Ministry of Heavy Industries

3-wheelers (29%) and 2-wheelers (23%). However, only 3% of the allocated funds had actually been used by 2021, for a total of just 30 000 vehicles (with Covid being a contributing reason for low demand). This suggests a slow uptake of EVs on the domestic market and significant acceleration will be required to reach both the programme targets and national targets of 30% EV sales by 2030. As 2- and 3-wheelers (NMC batteries) are seen as the core of the Indian market for now, it is anticipated that these batteries will be the first ones to reach their end-of-life and present the predominant opportunity for recyclers in 2030. Meanwhile, initiatives such as India's announced Production Linked Incentive (PLI) Scheme for Advanced Chemistry Cell (ACC) Battery Storage can provide additional opportunities for recyclers to manage manufacturing scraps as a domestic value chain emerges.[112]

Potential international investors seek an enhanced understanding of Government of India policies related to EVs, battery manufacturing, and EOL regulation. Regulatory gaps for LiB recycling represent a key risk for investors. India does not currently have any policy structure or mechanism for recycling LiBs and the demand for a second use. Since 2019, a recycling policy for LiBs is in the drafting phase, in which the recyclers are given Standard Operating Procedures (SOPs). This strategy also places responsibility on battery manufacturers to recover used batteries under the EPR requirements.[113]

The preferred market entry strategy among potential international LiB recycling investors would be a joint venture (JV) with a local partner. This is seen as providing local expertise and, most importantly, access to battery waste. Given the early stage of the Indian market, international recyclers require confidence in the ability to secure sufficient volumes of EOL batteries. There is no unanimous view over which type of local partner would be preferable and some international investors are deliberately agnostic. Partnerships with local recyclers are seen as securing a share in the market immediately. However, all interviewed international firms highlighted the benefits of forging a partnership with an Indian battery or EV manufacturer as a way of being directly a part of the growing market in high-quality batteries and helping to close the loop as EPR regulations come into force over time. A European firm emphasised that a condition for partnership would be that the company is strong and demonstrates a good value system in support of compliance and sustainability regulations. A separate and particular way of market entry is technology licensing, which would require an Indian entity to purchase access to such technology to manage its environmental obligations.

The scale of the current Indian LiB market is insufficient for international investors to set up large-scale operations within the country now. However, interviewed firms observe a shift of the global battery supply chain model towards localisation and regional hubs across the world. India could become such a hub for South Asia.

[112] For detail on PLI ACC scheme: https://pib.gov.in/PressReleasePage.aspx?PRID=1809037#:~:text=The%20Government%20approved%20the%20Production,outlay%20of%20%E2%82%B9%2018%2C100%20crore

[113] Deepti, D., et al (2022) "Economic Analysis of Lithium Ion Battery Recycling in India", Wireless Personal Communications. 10.1007/s11277-022-09512-5. https://www.researchgate.net/publication/357887808_Economic_Analysis_of_Lithium_Ion_Battery_Recycling_in_India

Firms explicitly operate a model whereby local centres gather and pre-process battery waste for shipment to large-scale hubs. The objective is that local centres or 'spokes' are located as close to the customer as possible, whereas 'hubs' need economies of scale. For dismantling or mechanical processes, such local centres are seen as economically viable at less than 5,000 tons per year capacity, with international investors seemingly envisaging a potential scale of at least 10,000 tons per year in India. Interviewed firms highlighted that a standalone hydro facility within India would require recycling at least 20,000-40,000 tons per year of batteries, which the Indian market could not supply alone over the medium-term. One Chinese recycler thus expressed interest in combining a potential Indian recycling plant with its already existing Indonesian business. One North American recycler is exploring the option to set up a regional hub for South Asia based in India, which could then attain up to 300,000 tons/year in capacity over time. But initial investments are likely to be on a smaller scale, and the realisation of the regional hub scale would be highly contingent on the Government of India's policy related to the battery waste trade.

Battery collection and pre-processing are seen as major operational risks for recycling in India.

Interviewed recyclers recommend that local pollution boards' monitoring is crucial to ensure the collection of used batteries in safe conditions. International firms expressed particular concern over the prevalent role of informal sector recyclers in India with unsafe working dismantling and transport practices, causing potential liabilities for any purchases of battery waste on the open market. Of course, the risk appetite of individual firms varies, but potential new investors in India see greater governance and reputational risk than firms already operating in India.

The economics of recycling and reuse in India relative to other countries will determine where international firms invest.

Recycling is highly sensitive to the costs of transport, disassembly, and processing (a function of labour, general expenses, electricity, water, etc.). **Market participants also expect that battery recycling will become more economically favourable than battery reuse due to changes in battery chemistries and recycling technologies, while also providing greater scale.**

The global battery recycling market may be entering the phase of consolidation, where dominant global players will emerge, and start-up specialists are displaced and/or purchased. This presents both an opportunity and risk to India's recycling sector as niche operators may cease to exist. The openness of India to international investment will determine the exposure of India's own battery recyclers to global competition and pressures.

4.3. Recommendations to improve attractiveness for investment and domestic recycling ecosystem

In order to improve the battery recycling network, it is necessary to have a robust battery recycling and disposable ecosystem in the country. **India can attract international investment into battery recycling and reuse.** The experiences in the EU and China may serve as guides for specific policies, while we draw on the global literature and our domestic and international firm interviews to highlight key **recommendations to improve India's attractiveness to investments,** following are some key recommendations:

- **Ensuring effective implementation of the EPR scheme:**
  Effective implementation of the Extended Producer Responsibility (EPR) defined by the government under Battery Waste Management rules, 2022 must be ensured to control the growing pollution from battery waste. It involves that all the EV manufacturers must abide by the EPR targets set under the new rules and allow second use of these batteries before they are handed over for disposal to some authenticated recycler. For making EPR effective, consumers may be charged a small battery fee. Additionally, incentivizing in form of a rebate can be provided to consumers to return end-of-life EV batteries to the appropriate collection agent to ensure compliance.

- **Subsidies for attracting investments:**
  To promote increased participation of start-ups, support in the form of grants should be extended to recyclers for land, machinery, and other infrastructural requirements. Open calls for standards and allowing anybody to apply for such grants will result in a larger return and greater recovery.

- **Incentives for LFP recycling:**
  LFP is one of the most extensively used battery chemistry and huge volumes of it end up in the recycling market. However, due to the lower economic value and high recycling costs, LFP recycling does not offer recyclers highly attractive margins. Therefore, incentives in the form of viability gap funding can be offered to make LFP recycling profitable. Additionally, including some of the cost of LFP recycling in the battery's production cost can also assist in making LFP recycling economically viable.

- **Facilitating the establishment of LiB recycling plants in India:**
  Recycling is highly sensitive to the costs of transport, disassembly, and processing (a function of labour, general expenses, electricity, water, etc). Government support schemes are key to unlocking investment in countries that already have large recycling and reuse centres. The state government should focus on attracting investments through streamlined policies and procedures with a focus on single window clearance, resolving land acquisition issues, developing trunk infrastructure, manufacturing clusters, and cheap and uninterrupted power supply. Support

from the central government may also be sought through the central coordination cell to reduce bottlenecks.

- **Providing tax exemption:**
  The establishment of a battery recycling program will create cost implications. Policies for establishing a comprehensive incentive system such as incentives for establishing tax holidays and income tax deductions for the establishment of lithium-ion battery recycling plants in India have to be framed.

Battery recycling can be made economically feasible by relaxing import restrictions on scrap metals, black mass and waiving the duties on special lab equipment required for recycling can make the market appealing.

- **PLI scheme for recycling:**
  Apart from non-fiscal incentives from states, a production linked incentive can also be introduced by the Government of India in line with the ACC PLI scheme given to cell manufacturers. This will not only help the domestic recyclers but also serve the cell manufacturers selected under the ACC PLI scheme. Several parameters which can be considered for evaluation could be:
  - Cell chemistry (or the minerals and metals being recovered)
  - Recovery efficiency of minerals and metals recycled
  - Domestic utilization of recovered minerals/metals should be more than 60% within India, and preferably to cell manufacturers

- **Develop legislation for adequate storage and disposal of used LiBs** to improve immediate health, safety, and environmental benefits and will increase regulatory certainty for domestic and international investors. Specifically, in India, in the upcoming battery management rules, the Central Pollution Control Board (CPB) must explicitly state the responsibilities of corporates and the repercussions of the inability to meet the same. The disposal of batteries in landfills should be made illegal and an effective mechanism should be developed for batteries to undergo proper disposal through recyclers.

- **Formalisation of recyclers and waste traders, and/or obligations for battery recyclers to sell manufacturing scraps to formal sector recyclers.** This will realise significant HSE benefits and increase the feedstock available to large-scale investors. In India, so far, the unorganized sectors have been playing an important role in the collection and recycling of different batteries. A proper framework would streamline the process of battery collection and segregation as well as prevent recycling in the unorganized sector where proper safety considerations are often ignored. To streamline and channel waste effectively, there is an urgent need to digitize waste management in the country.

- **Tie-ups for setting up collection channels:**
  Several informal sector players can be leveraged to establish proper battery collection channels. For example, Exigo has tie-ups with efficient logistics partners across India to transport waste in a secure and environmental-friendly way. The reverse logistics service provider for Exigo also operates collection centres

across India. Owing to such tie-ups, a formal communication channel has been established between the collection recentres of the recycler with that of the informal battery collectors. The informal collectors are made aware of the kind of batteries Exigo is looking forward to recycling and only such batteries are submitted by the informal collectors for recycling

- **Mandating specific recovery rates:** There is no provision as of now regarding the amount of material recovery that is expected from the batteries. Fixing specific recovery rates will encourage more participation from the formal sector while helping in the development of a healthy supply of raw materials for battery manufacturing. The recovery rates can be set as per the battery technology/ chemistry and should be suitably reviewed and updated continuously.

- **Support recycling 'spokes' within India itself,** through the creation of a network of battery collection and pre-processing spokes near major centres within the country. This can help lower transaction costs (and may also contribute to the formalisation of the sector) and support the emergence of any potential recycling hub within India over time.

- **Encouraging domestic mineral extraction from black mass:** Currently, the majority of the black mass produced from battery recycling in the country is exported to international companies. Therefore, the Indian government can encourage local players to establish facilities for mineral extraction or black mass refining in India by making provisions to reduce this export of black mass. Additionally, the minerals that will be extracted from the black mass can be utilised by either selling them to different industries like ceramic, pharma, etc. or by further purifying them to be used in cell manufacturing. Therefore, limiting the export of black mass from the nation can also aid India in satisfying its upcoming demand for batteries.

- **Clarity of regulations governing the import/export of used batteries and their components to India** for recycling. Such policy will shape whether India can become a hub with regional facilities for South Asia and South-East Asia countries.

- **Implement battery traceability and certification** as key enablers for investing in India for compliance with emerging global policies. An online gateway can be utilised to ensure battery and cell movement, similar to a battery passport system. This will make it possible to keep track of the used batteries that are up for secondary life usage.

- **Licensing and Design guidelines for the labelling of LiBs:**
Separate license for handling only LiBs, separate from electronic waste, and to help distinguish them from other types of batteries. Furthermore, LiBs should have labels on their coverage based on the recycling process to be used, making it easier to segregate them.

- **Skill development:**
The recycling hubs shall require trained manpower to scale up operations. The network of Industrial Training Institutes (ITIs) may be leveraged by introducing courses related to battery recycling processes. Courses through Skill India centres may also be updated to include battery capabilities.

- **Invest in research programmes and/or encourage the industry's R&D collaboration related to standardised battery designs that facilitate end-of-life disassembly:**
This can be a key factor to reduce the cost of pre-processing and recycling. Leading international recyclers are working on fully automated dismantling processes for improved efficiency and cost savings. **Government support can unlock collaboration between national firms and international recyclers.** Alongside automation, increasing the understanding and efficiency of the recycling process will provide flexibility to treat various battery chemistries and shapes which although will add costs in setting up the process but will increase plant productivity and recycler profits. Additionally, battery manufacturers through research and development can design batteries that makes them more recyclable. For example, bolts and nuts can be used to replace inter-cell welding while forming battery packs. Manufacturers can have their recycling subsidiaries have a better understanding of the recycling process and understand the design parameters which cause difficulties in dismantling batteries. **Manufacturers should also announce the chemistry composition of the battery properly during manufacturing to facilitate ease of recycling.**

- **R&D for efficiency improvement in the recycling process:**
The recycling process needs to be designed in such a way that it provides flexibility to treat various battery chemistries and shapes. This added flexibility may add costs in setting up the process but will increase plant productivity and recycler profits. For example, LFP is not suitable for pyrometallurgy or hydrometallurgy owing to the presence of phosphorous ions.

The operation cost could be reduced by 30% if LFPs are processed separately as they do not contain cobalt or nickel.

- **Establishing labs for faster sample checks:**
The process of obtaining the final report will be sped up by the establishment of new

labs for the validation of heterogeneous materials of various batteries as well as the determination of the purity of the recycled material. Therefore, by facilitating quicker analysis, it will be easier to determine the intended use of the recycled minerals, resulting in lower storage costs.

- **Capacity building:**
  Start-ups are invested in research in cell chemistries and require support from highly skilled technical resources to translate their work into products for recycling. The government may support the establishment of incubation centres on campuses like IITs, NITs, IIMs, etc wherein the industry may tie up with academia for practical implementation regarding extraction of raw minerals from battery waste at higher efficiencies. **Establish platforms for stakeholder consultation between the Government of India and industry players on battery-related policies and regulations:** This will help promote a shared understanding of progress on India's LiBs recycling policy, operating procedures, and obligations. It will also provide a forum to improve awareness of specific market opportunities and risks.

- **Communicate existing and considered electric mobility policies as well as an industrial policy supporting local battery and car manufacturing:**
  The line of sight to scale battery recycling operations in India is the key for international investment to be unlocked.

- **Specifying guidelines for transportation and handling of used LiBs:**
  Lithium-ion batteries are relatively popular in the marketplace due to their high energy density. If safety measures are not practised during its transportation and disposal, it may become damaged or crushed in transit or from processing and sorting equipment, creating a fire hazard explosion.

Therefore, used LiBs should be transported following strict safety protocols, indicating a need for the drafting of industry standardised transportation guidelines for its logistics handler.

4.3.1. Recommendations to boost the reuse market in India

The battery reuse industry in India is in its nascent stages and therefore will require significant improvement in the next decade in order to cater to the high volume of batteries (specifically EV batteries) reaching their end-of-life. Improvements in both the upstream and downstream activities of battery reuse would be required for the development of the reuse ecosystem. Some key recommendations for different stakeholders that can boost battery reuse in India are as follows:

- **Establishing reuse targets:**
  Batteries from EVs can be used for various secondary life applications and as such establishing reuse targets for passenger and commercial vehicles and e-buses could help meet the growing battery demand across the stationary storage sector by providing around 37 GWh of storage capacity by 2030.

- **Formalizing standards for secondary life applications:**
  The government must separately lay down the guidelines and associate standards for battery reuse in the country. They should also work with industry stakeholders to devise a methodology for certifying refurbishers, as well as metrics for assessing and guaranteeing performance standards and establishing incentives for innovative approaches for second-life applications.

- **Conducting pilot projects to encourage BESS:**
  To increase the demand for repurposed batteries and facilitate the growth of the reuse industry in the country, policies should be directed towards encouraging the use of BESS. This can be done by running pilot projects to prove its technical feasibility, thus attracting stakeholders to invest on R&D in this space.

- **Tracking battery capacity and other parameters:**

In the long term the reuse industry would benefit largely through the electronic exchange system for battery information. OEMs in the automotive and battery industries must develop diagnostic technology that can correctly track the capacity and other properties of a battery to determine its feasibility for reuse. As a result, the cost of reuse will be reduced, thereby ensuring increased adoption.

- **Subsidies:**
  : Subsidies should be made available to encourage the development of infrastructure for battery reuse. Assistance in form of funding should be provided to the reuse sector stakeholders in order to establish adequate battery handling capacity. Additionally, funding demonstration projects that reuse batteries for a variety of applications would act as a catalyst to help India's battery reuse sector and infrastructure to grow.

- **Research and Development:**
  Examining battery degradation and developing new approaches or technologies for battery reuse should be the focus of research and development going forward. As part of an industry-led approach, growth centres might be established to encourage present market players to reuse batteries. This could boost market innovation, productivity, and competitiveness. Further, research can be done to develop a better tracking algorithm using machine learning and artificial intelligence for an accurate estimation of SOC (state of charge) and SOH (state of health) of the battery.

Annexures

Annex A: Questionnaire – Global companies

GGEF - EV battery recycling and reuse study

A consortium of OPM, PwC India and leading experts is supporting NITI Aayog (Government of India) on battery recycling and reuse interventions in India. The project is funded by The Green Growth Equity Fund Technical Cooperation Facility (GGEF TCF) of the UK Foreign Commonwealth and Development Office (FCDO), which aims to catalyse private investments into Indian green infrastructure projects.

Name of the organisation: ______________________________

Address and Contact Infomation: ______________________________

The results of this survey will not be shared individually, but be used only collectively as part of a wider group to derive inferences for a study on assessment of the market and technologies for battery recycling and reuse. We assure you that your and your firm's anonymity will be maintained throughout.

A. PROFILING QUESTIONS:

1. What is your current battery recycling capacity in tons/year and which locations?

2. Do you think the LiBs recycling business will be growing dramatically over the next 5 years?

☐ Yes ☐ No

- If "Yes": In which regions/countries do you see the strongest growth?
- If "No": Why not?

3. What target group in terms of applications, are you currently catering?

☐ Stationary storage ☐ Electric vehicles
☐ Consumer electronics

4. What types of battery chemistries are you currently recycling?

☐ LEP ☐ NMC ☐ LCO
☐ Any other (please specify) ____________

5. What approximate percentage of your operations is focused on re-use of batteries rather than recycling?

6. What battery recycling technologies/ processes are you employing at your facility?

☐ Hydrometallurgy ☐ Pyrometallurgy
☐ Mechanical ☐ Hybrid ☐ Other

7. What are the factors that justify investment in battery recycling? (Pick all that apply)

☐ Market size ☐ Regulations ☐ Technology

- If "Market size": Can you share what is your current battery recycling capacity in tons/year and which locations? What are the commercial model(s) that make it worth the investment?
- If "Regulations": What are the regulations or investment laws that help or make it difficult to invest in the countries where you operate?
- If "Technology": Can you share what are the technology, technical, engineering and logistical challenges of battery recycling?

B. INDIA INVESTMENT / PIPELINE QUESTIONS:

8. What are your overall expansion plans internationally? Can you specify your plans by country and capacities?

9. Does your company currently have any research & development projects on Battery Recycling technologies in the pipeline?

10. What is your outlook for the Indian recycling market? And why?

- What opportunities do you see in entering the Indian market?
- What risks and challenges (eg cost of collection, logistics, competition, policy/regulation) do you anticipate your company could face?

11. Are you aware of the key initiatives India has taken to accelerate deployment of batteries and manufacturing of batteries? Can you summarise your understanding of them for us, please?

12. Are you interested in investment in the LiBs recycling business in India? And why?

☐ Yes ☐ No ☐ Maybe

13. If you were to enter the Indian market, which operating structure would you favour? And why?

☐ Sole proprietorship ☐ Joint venture
☐ Other: ____________________

14. Who would be your preferred partner to set up recycling facilities in India? And why?

☐ Local recycler ☐ EV manufacturer
☐ Battery manufacturer ☐ Other:________

C. ENABLING ENVIRONMENT QUESTIONS:

15. What are the regulatory challenges of battery recycling in any of the countries where you operate? Can you explain why?

☐ Battery waste management rules: Please unpack challenges about battery waste management rules and regulations

☐ EPR scheme: Please unpack challenges brought by EPR regulations

☐ Local collection: Please unpack challenges related to local collection of batteries

16. In your experience in order to be economically profitable, is there a minimum capacity a recycling facility should operate at?

☐ <5,000 tons ☐ 10,000 – 30,000 tons
☐ 30,001 – 50,000 tons ☐ >50,000 tons

17. Do you have any specific recommendation for policymakers to help attract recyclers to set up recycling facilities in India (re. Policies, Regulations, incentives, etc.)?

Annex B: Questionnaire – Domestic companies

GGEF - EV battery recycling and reuse intervention

A consortium of OPM, PwC India and leading experts is supporting NITI Aayog (Government of India) on battery recycling and reuse interventions in India. The project is funded by The Green Growth Equity Fund Technical Cooperation Facility (GGEF TCF) of the UK Foreign Commonwealth and Development Office (FCDO), which aims to catalyse private investments into Indian green infrastructure projects.

Name of the organisation: ____________________

Address and Contact Infomation: ____________________

The results of this survey will not be shared individually, but be used only collectively as part of a wider group to derive inferences for a study on assessment of the market and technologies for battery recycling and reuse. We assure you that your and your firm's anonymity will be maintained throughout.

Overarching research questions:

1. What are your current battery recycling capacity in tons/year and which locations? e-waste recycling (applied for battery recycling)

2. What types of battery chemistries are you currently recycling?

- ☐ LFP ☐ NMC ☐ LCO
  ☐ Any other,(Please elaborate)
- Any specific preference of battery chemistry? If yes, then why?

3. What target group in terms of applications, are you currently catering?

☐ Stationary storage ☐ Electric vehicles
☐ Consumer electronics

4. What could be the projected recycling volume capacity of India in tons/year by 2030?

5. What battery recycling technologies/ processes are you employing at your facility?

☐ Hydrometallurgy ☐ Pyrometallurgy
☐ Mechanical ☐ Hybrid, (Please elaborate)

6. Who would be your preferred partner to set up recycling facilities in India? And why?

☐ Local recycler ☐ EV manufacturer
☐ Battery manufacturer ☐ Other:________

7. Is there any future demand projection that you foresee to increase your recycling capacity?

- Please elaborate in terms of capacity, applications, and technology and from which segment do you see most of the demand coming from in near future?

8. What are your overall expansion plans internationally? Can you specify your plans by country and capacities?

9. Does your company currently have any research & development projects on Battery Recycling technologies in the pipeline?

10. Which state/city in India is more preferred based on policies, regulations, demand, and ease of doing business?

- What are some of the incentives that you are looking forward to from State governments regarding the setting up of battery recycling plants?
- What infrastructure facilities are needed to set up such plants?

11. Do you have any contracts with battery manufacturing players for recycling? If yes, please elaborate.

12. What percentage of recycled minerals or components are being used for secondary life applications and re-use?

- What are your views about the reuse market in India and how do you think it is going to affect the recycling market?

13. What kind of companies usually buy the recycled minerals from you?

- What is the pricing mechanism that is being followed? Is it market discovery or bipartite agreements?

14. What is the average rate at which you are buying after life/used batteries from the market (INR/ton)?

15. What according to you are the challenges and risk associated with battery recycling market in India?

- ☐ Policy and Regulatory Challenges
  ☐ Logistic Challenges ☐ Lack of awareness
  ☐ Others

16. What are the recommendations that you would suggest is needed to boost the recycling segment in India?

- What are the changes you would like to see in the draft "Battery Waste Management Rules – 2020"?

Annex B: Domestic Firms and stakeholder interviewed

Company name	Name of person interviewed / consulted	Title
Tata Chemicals	Mr. Neeraj Kohli	General Manager- Sales and Marketing
Exigo Recycling	Mr. ALN Rao	CEO
Attero Recycling	Mr. Abhinav Mathur	Advisor to the Board
Batx	Mr. Utkarsh Singh and Mr. Vikrant Singh	Co-Founders
Ziptrax	Ms. Sonia Singh	Co-Founder and CEO
Li-Circle	Mr. Santosh Kumar	Founder
Eco Tantra	Ms. Richa Devale	Director
E-waste recyclers India	Mr. Ajai Singh	Operations Manager