CLIMAKE

ASPEN NETWORK OF DEVELOPMENT ENTREPRENEURS

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INVESTING IN THE WASTE AND CIRCULARITY SECTOR IN INDIA

E-Waste and Lithium-ion Battery Recycling Guide

ABOUT ANDE

The Aspen Network of Development Entrepreneurs (ANDE) is a global network of organizations that propel entrepreneurship in developing economies. ANDE members provide critical financial, educational, and business support services to small and growing businesses (SGBs) based on the conviction that SGBs create jobs, stimulate long-term economic growth, and produce environmental and social benefits.

As the leading global voice of the SGB sector, ANDE believes that SGBs are a powerful, yet underleveraged, tool in addressing social and environmental challenges. Since 2009, ANDE has grown into a trusted network of over 250 collaborative members that operate in nearly every developing economy. ANDE grows the body of knowledge, mobilizes resources, undertakes ecosystem support projects, and connects the institutions that support the small business entrepreneurs who build inclusive prosperity in the developing world. ANDE is part of the Aspen Institute, a global non-profit organization committed to realizing a free, just, and equitable society.

ABOUT CLIMAKE

Climake was founded in 2020 as a platform to make climate finance more accessible. Climake focuses on improving access to equity and non-dilutive capital, for startups, and to support investors to improve funding flows to the climate action, especially into emerging sectors. Climake's work focuses on 4 core areas: investment advisory for high-potential climate startups, development and adoption of innovative financing structures to mainstream climate innovations, research and knowledge sharing on climate finance trends, and advocacy with investors to focus on climate action.

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IKEA Foundation

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ABBREVIATIONS

B2B: Business-to-business

B2C: Business-to-consumer

CAGR: Compound annual growth rate

CapEx: Capital expenditure

CPCB: Central Pollution Control Board

DFI: Development finance institution

EBITDA: Earnings before interest, taxes, depreciation, and amortisation

EEE: Electrical and electronic equipment

EPR: Extended producer responsibility

EVs: Electric vehicles

FY: Financial year

GHG: Greenhouse gas

GWh: Gigawatt hour

IP: Intellectual property

LiB: Lithium-ion battery

NBFC: Non-banking financial company

PAT: Profit after tax

PCB: Printed circuit board

PE: Private equity

PLI: Production Linked Incentive

SDG: Sustainable Development Goal

SGB: Small and growing business

TPA: Tons per annum

TReDS: Trade receivables electronic discounting system

VC: Venture capital

CHAPTER 1: THE OPPORTUNITY IN E-WASTE AND LITHIUM-ION BATTERY RECYCLING

India is a significant player in the global e-waste landscape, contributing approximately 4.1 million tonnes of electronic waste (e-waste) in 2022,[1] which accounts for approximately 7% of the world's total e-waste output. In 2021, one-third[2] of India's e-waste was managed through formal and informal channels, with 80 to 90% of e-waste management operations handled by the informal sector. By 2030, India's e-waste output is expected to escalate significantly, reaching approximately 9 million tonnes (based on our estimates), which would represent about 11% of the global e-waste forecast for that year (82 million tonnes).

From 2021 to 2030, India is projected to generate a cumulative total of at least 400,000 tonnes of lithium-ion battery (LiB) waste.[3] This translates to an annual generation rate of approximately 43,000 tonnes of waste. This significant amount of waste highlights the growing demand for LiBs, driven by the rapid adoption of consumer electronics and electric vehicles (EVs). Currently, most LiB waste comes from consumer electronics. However, by 2030, EVs are expected to become the predominant source of this waste.[4]

These figures and trends underscore the pressing need for comprehensive strategies to manage and mitigate the environmental impact of LiB and e-waste. Currently, with most of India's e-waste being managed informally and less than 1%[5] recycling capacity for LiBs, there is a very high ceiling for growth driven by increased waste and the need for raw materials. The total addressable market by 2030 is estimated at US$ 11 billion, with a compound annual growth rate (CAGR) of at least 20%.

THE OPPORTUNITY

India's e-waste and LiB recycling sector offers multiple avenues to create value through innovative business models. The key opportunities range across advanced metal and rare earth extraction, integrated recycling, interim recycling for high-demand metals, second-life electronics and batteries. These cascade into specific opportunity areas across the value chain, which are summarised below (and detailed further later in this guide):

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1. International Telecommunication Union (ITU) and United Nations Institute for Training and Research (UNITAR), 2024, Global E-waste Monitor 2024, Geneva/Bonn. Retrieved from: https://ewastemonitor.info/the-global-e-waste-monitor-2024/
2. Government Of India Ministry of Environment, Forest and Climate Change, 2023, Status of E-waste in the Country. Retrieved from: https://sansad.in/getFile/annex/260/AU2426.pdf?source=pqars
3. NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, 2022, Advanced Chemistry Cell Battery Reuse and Recycling Market in India. Retrieved from: https://www.niti.gov.in/sites/default/files/2022-07/ACC-battery-reuse-and-recycling-market-in-India_Niti-Aayog_UK.pdf
4. CII Report, 2023, Retrieved from: https://www.cii.in/PressreleasesDetail.aspx?enc=6UYt9FK13Sa34a6GeomlIKlavi8RCedYYNjaH0U1+2vp3HCKU+qX9AWibtxRm9DBPuG6MrfG/0vdPv0kz3mbgw==
5. NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, 2022, Advanced Chemistry Cell Battery Reuse and Recycling Market in India. Retrieved from: https://www.niti.gov.in/sites/default/files/2022-07/ACC-battery-reuse-and-recycling-market-in-India_Niti-Aayog_UK.pdf#page=103

- High-quality recyclers are adopting low-energy, advanced technologies to extract valuable metals and rare earth elements from e-waste and LiBs, increasing both efficiency and material recovery rates.
- Combining e-waste and LiB recycling processes offers a unified approach to maximise the recovery of both precious and critical materials, creating efficiencies across operations.
- Interim facilities focusing on the recovery of ferrous and non-ferrous metals from e-waste meet the high demand for these materials, addressing a significant gap due to collection challenges.
- Refurbishing used EV batteries for secondary applications presents an eco-friendly solution, extending battery life and reducing waste. With growing EV adoption, the demand for sustainable battery lifecycle management is expected to increase, creating a scalable market for new businesses.

The above opportunities are reliant on a strengthened and effective e-waste and LiB value chain, which also provides opportunities for small and growing businesses (SGBs) that extract the highest value out of LiB and e-waste.

THE OPPORTUNITY DRIVERS

E-waste and lithium-ion battery recycling is India's second most investable waste and circularity segment, after plastics. There are four main reasons for the growth of the e-waste and LiB recycling industry in India, which is presenting growth opportunities for companies in the sector and investment opportunities for investors:

Figure 1: The four main drivers for e-waste and lithium-ion battery waste circularity (Climake analysis)

1. Domestic demand and manufacturing are increasing the generation of e-waste and LiB waste
2. Policy frameworks, through EPR, are enabling high-quality recycling
3. The need to secure high-value input raw materials is making manufacturers focus on material extraction from waste
4. Recycling is becoming increasingly formalised, improving quality and efficiency

1 Domestic demand and manufacturing are increasing the generation of e-waste and LiB waste

India's e-waste generation is driven by increasing electrical and electronic equipment (EEE) usage, with the country accounting for 3% of global EEE production.[6] Digitalisation and the rising adoption of IT-enabled products, projected to reach 920 million units annually by 2028, are key factors. The shortened lifespan of devices and e-commerce trends exacerbate e-waste. White goods demand is also rising, with sales expected to hit 480 million units by 2028. Against this growing demand, domestic EEE production has expanded, facilitated by government initiatives such as the "Make in India" scheme, factors which all make effective waste management a crucial need.

Battery replacement is required when performance drops below 70–80% of initial capacity, with used batteries often refurbished for secondary applications. Battery retirement is expected to surge to at least 6 GWh annually by 2030[7] due to increased electric vehicle (EV) adoption, up from less than 0.5 GWh in 2022. Enhanced battery technology aims to extend battery life and reduce costs but will also increase LiB waste. The rise in discarded small electronics from e-commerce further accelerates LIB waste, which is often poorly regulated, highlighting the need for stricter waste management practices.

The market for stationary and mobile batteries in India is set to triple, reaching US$ 6 billion[8] by 2030, driven by growing LiB adoption. Government policies supporting renewable energy and grid stability boost stationary LiB demand, while the EV market, with record sales of 1.2 million vehicles in 2023[9] and a projected CAGR of 22%, fuels mobile LiB growth with at least 10 million vehicles projected by 2030. More recently, India's LiB imports have surged sevenfold[10] since 2018–19, highlighting reliance on foreign raw materials. To reduce dependency, the government auctioned critical mineral reserves and introduced a US$ 2.16 billion Production Linked Incentive (PLI) scheme[11] to develop domestic battery manufacturing.

2 Policy frameworks are enabling high-quality recycling, especially through the imposition of extended producer responsibility targets

The E-Waste Management Rules 2022[12] have driven a shift from incentivising collection for recyclers to emphasising recycled product outputs for manufacturers to achieve extended producer responsibility (EPR) targets. The E-Waste Management Rules 2022 exclude micro-enterprises but cover every manufacturer, producer, refurbisher, dismantler and recycler involved in the manufacture, sale, transfer, purchase, refurbishing, dismantling, recycling and processing of over 100 different types of e-waste or electrical and electronic equipment (EEE). The applicable guidelines for e-waste incentivise the collection and recycling of a wide range of EEE, with the responsibility placed on companies through EPR.

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6. Centre for Science and Environment, 2020, E-Waste Management in India Challenges And Agenda. Retrieved from: https://www.cseindia.org/e-waste-management-in-india-10593
7. NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, 2022, Advanced Chemistry Cell Battery Reuse and Recycling Market in India. Retrieved from: https://www.niti.gov.in/sites/default/files/2022-07/ACC-battery-reuse-and-recycling-market-in-India_Niti-Aayog_UK.pdf
8. NITI Aayog, RMI, and RMI India, 2022, Need for Advanced Chemistry Cell Energy Storage in India (Part I of III). Retrieved from: https://www.niti.gov.in/sites/default/files/2022-02/Need-for-ACC-Energy-Storage-in-India.pdf
9. Autocar Professional, 2023, EV sales in India hit 1.17 million units in FY2023, charge past 100,000 for six months in a row. Retrieved from: https://www.autocarpro.in/analysis-sales/ev-sales-in-india-hit-117-million-units-in-fy2023-charge-past-100000-for-six-months-in-a-row-114543
10. The East Asia Forum, 2024, India's long road to lithium. Retrieved from: https://eastasiaforum.org/2024/01/27/indias-long-road-to-lithium/
11. Ministry of Heavy Industries, 2022, Three Companies signed Program Agreement under (PLI) Scheme for Advanced Chemistry Cell (ACC) Battery Storage. Retrieved from: https://pib.gov.in/Pressreleaseshare.aspx?PRID=1846078
12. Ministry of Environment, Forest and Climate Change, E- Waste (Management) Rules, 2022. Retrieved from: https://cpcb.nic.in/rules-6/

Table 1: Extended producer responsibility (EPR) targets for e-waste collection and recycling (E-Waste Management Rules[13])

Minimum E-waste Recycling Targets				
E-waste recycling target (by weight)	**2024–25**	**2025–26**	**2026–27**	**2027–28 ++**
Percentage of quantity of an EEE placed in the market in year Y-X, where 'X' is the average life of that product	60%	60%	70%	80%

Minimum E-waste Collection Targets for New Producers				
E-waste collection target (weight)	**2024–25**	**2025–26 ++**		
Percentage of the sales figure of financial year two years back	20%	20%		

The Battery Waste Management Rules, 2022[14] apply to producers, dealers, consumers and entities involved in the collection, segregation, transportation, refurbishment and recycling of waste batteries. They lay out EPR rules on LiB waste which mandate that 90% of discarded battery materials must be recycled and recovered by 2026. Furthermore, they specify that 20% of the recycled materials should find their way into new batteries by 2030. These guidelines for LiBs incentivise high-quality and advanced recycling for the most viable critical raw materials, as well as for other materials and components, such as plastic which will constitute a key element in recycled content obligations.

13. Ministry of Environment, Forest and Climate Change, E- Waste (Management) Rules, 2022. Retrieved from: https://cpcb.nic.in/rules-6/
14. Ministry of Environment, Forest and Climate Change, Battery Waste Management Rules, 2022. Retrieved from: https://cpcb.nic.in/rules-5/

Table 2: Extended producer responsibility (EPR) targets for LiB waste collection and recycling (Battery Waste Management Rules)

Minimum Battery Waste Collection Target (And 100% recycling/refurbishment of collected target) (% of the quantity of battery placed in the market in the 3rd, 4th, 5th or 8th preceding financial year)					
Battery waste category	**Target % context**	**2024-25**	**2025-26**	**2026-27**	**2027-28 ++**
Portable battery used in consumer electronics that are rechargeable	% of 5th preceding FY	70%	70%	70%	70%
Portable battery EXCEPT those used in consumer electronics that are rechargeable	% of 3rd preceding FY	-	50%	60%	70%
Automotive battery	% of 3rd preceding FY	70%	90%	90%	90%
Industrial battery	% of 3rd preceding FY	60%	70%	70%	70%
Electric vehicles (EV) battery of e-rickshaw (three-wheelers)	% of 3rd preceding FY	60%	70%	70%	70%
Battery waste category		**2026-27**	**2027-28**	**2028-29**	**2029-30 ++**
Electric vehicles (EV) battery of two-wheelers	% of 4th preceding FY	70%	70%	70%	70%
Battery waste category		**2029-30**	**2030-31**	**2031-32**	**2032-33 ++**
Electric vehicles (EV) battery comprising of four-wheelers	% of 8th preceding FY	70%	70%	70%	70%

Battery Type	Minimum use of the Recycled Materials out of the Total Dry Weight of a Battery (In Percentage)						
	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31 ++
Portable	0%	0%	0%	5%	10%	15%	20%
Industrial	35%	35%	40%	40%	40%	40%	40%
Automotive	35%	35%	40%	40%	40%	40%	40%
Electric vehicle	0%	0%	0%	5%	10%	15%	20%

3 The need to secure high-value input raw materials is making manufacturers focus on material extraction from waste

Domestic manufacturers need to secure their supplies of limited raw materials and have a high opportunity to access them from the e-waste and LiB recycling sector.

Manufacturing electrical and electronic equipment (EEE) relies on high-value materials like metals. Mining e-waste provides an attractive opportunity to access reliable sources of such materials, which can otherwise be scarce and hard to access. For example, gold extraction from e-waste is highly efficient compared to mining it from ore. Beyond its economic benefits, e-waste recycling reduces the need for natural resource extraction, thus aiding environmental preservation and restoration. India's thriving US$ 10 billion[15] second-hand EEE market, driven by e-commerce, supports circular economy practices, emphasises the industry's shift towards sustainable, closed-loop resource management, and likely makes the transition to circular businesses inevitable.

Similarly, manufacturing LiBs requires critical raw materials, particularly for the cathode component (which contains lithium). Although lithium only comprises about 2% of the cell composition in most LiB chemistries, it is a critical component. Its cost is highly sensitive to changes in the supply chain. Recycling to extract lithium from end-of-life batteries and/or refurbishing LiBs helps manufacturers manage their costs more reliably. Startups and technologies enabling high-quality and efficient extraction (above 90%) are key to enabling circularity in LiB raw materials like lithium.

15. Centre for Science and Environment, 2020, E-Waste Management in India Challenges And Agenda. Retrieved from: https://www.cseindia.org/e-waste-management-in-india-10593

3 Recycling is becoming increasingly formalised, improving quality and efficiency

Formal collection and recycling activities are poised to increase in India, promising a corresponding rise in the percentage of e-waste effectively recycled. However, achieving this transition requires a just and equitable approach to support informal e-waste workers, ensuring their smooth integration into formalised recycling processes. Such measures are essential not only for improving the efficiency and output quality of e-waste recycling but also for fostering the social sustainability of emerging regulations and solutions. In recent years, recycling has become more formalised in India, leading to technological advances that enable access to higher-quality recycled materials and the creation of improved outputs. However, about 67% of e-waste remains unprocessed, offering a high ceiling of opportunity for new and existing e-waste companies.

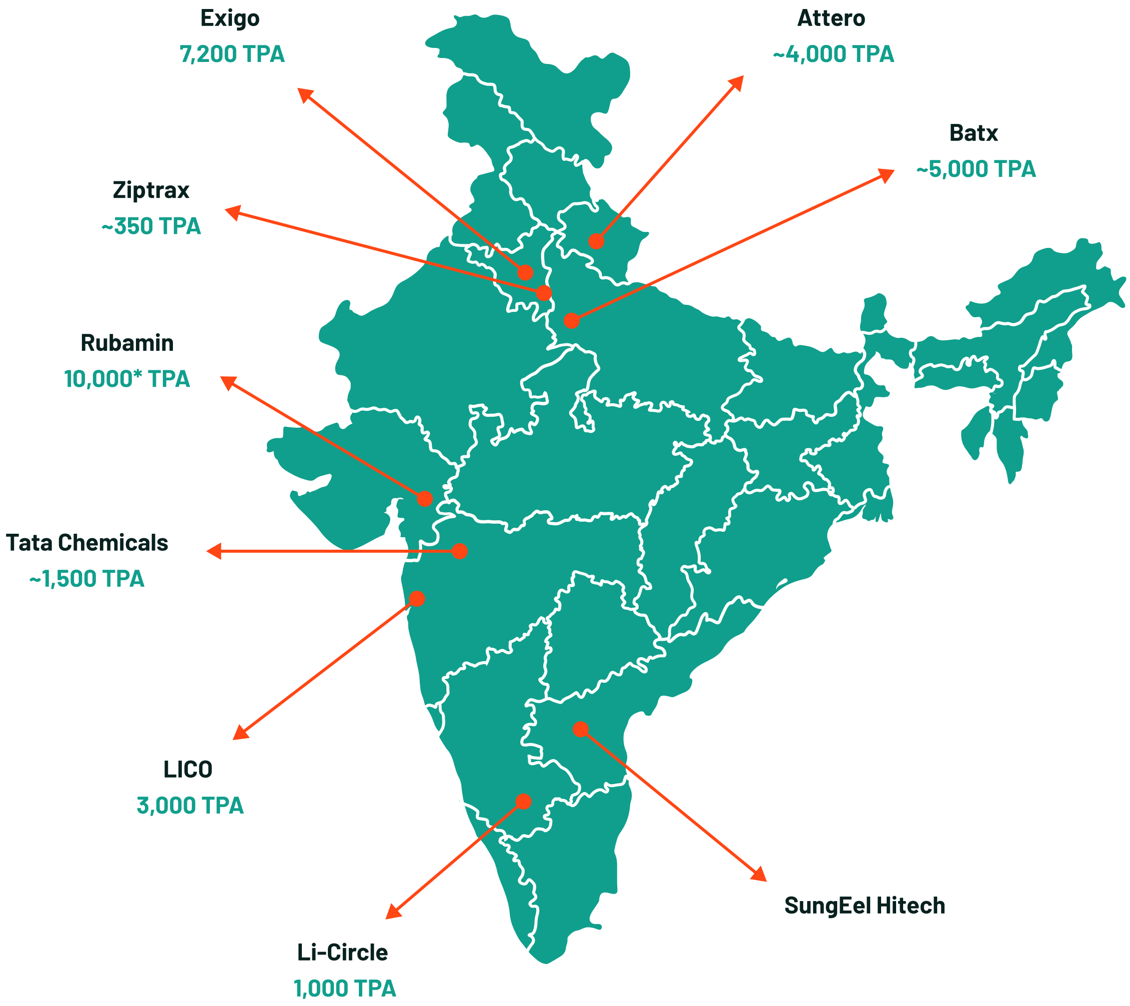
Table 3: E-waste generated and managed in India since 2019 (Source: CPCB[16])

Financial year	E-waste generation	Quantity of e-waste collected, dismantled and recycled/disposed	
	(in tonnes)	(in tonnes)	(in %)
2019–20	10,14,961.21	2,24,041.0	22.07%
2020–21	13,46,496.31	3,54,291.22	26.31%
2021–22	16,01,155.36	5,27,131.57	32.92%

The critical materials recovered are reintegrated into the manufacturing of new LIBs or other products requiring such minerals. LiB components can be directly recycled through mechanical, hydro-metallurgical, and/or pyrometallurgical methods, which are common formal recycling technologies in India. However, currently, even with increasing formal recycling, the most common recycled output remains black mass, produced by shredding and mechanical recycling.[17]

16. Central Pollution Control Board (CPCB), 2023. Retrieved from: https://sansad.in/getFile/annex/260/AU2426.pdf?source=pqars
17. Allen L., 2024, Fastmarkets, India's huge EV battery gigafactory plans could spur black mass imports and cut exports. Retrieved from: https://www.fastmarkets.com/insights/indias-ev-battery-gigafactory-plans-could-spur-black-mass-imports-and-cut-exports/

Figure 2: LiB recycling capacity of the major players (non-exhaustive) in India in 2022 in tons per annum (TPA) (Source: EV Reporter[18])



Innovative patented carbothermal recycling technology[19] offers an alternative method of recycling that reduces metals into their elemental or oxide forms and addresses the technical shortcomings of the pyrometallurgical process. Currently, India's recycling capacity is about 0.3% of the battery waste produced, but it is expected to grow beyond 50% by 2030[20] due to the increased demand for LiB applications. The drive for more high-quality outputs is creating opportunities for new technologies to be developed and scaled.

18. EV Reporter, 2024, Current LiB recycling landscape in India - leading players and commitments. Retrieved from: https://evreporter.com/current-lib-recycling-landscape-in-india-leading-players-and-commitments/
19. Zhu X.H., Li J.Y., Gong M.Q., Mo R., Luo S.Y., Yan X., Yang S., 2023, Recycling Valuable Metals from Spent Lithium-Ion Batteries Using Carbothermal Shock Method, Angewandte Chemie International Edition, 62, e202300074. Retrieved from: https://onlinelibrary.wiley.com/doi/abs/10.1002/anie.202300074
20. IBEF, 2023, Lithium-ion battery (LIB) manufacturing industry in India. Retrieved from: https://www.ibef.org/blogs/lithium-ion-battery-lib-manufacturing-industry-in-india

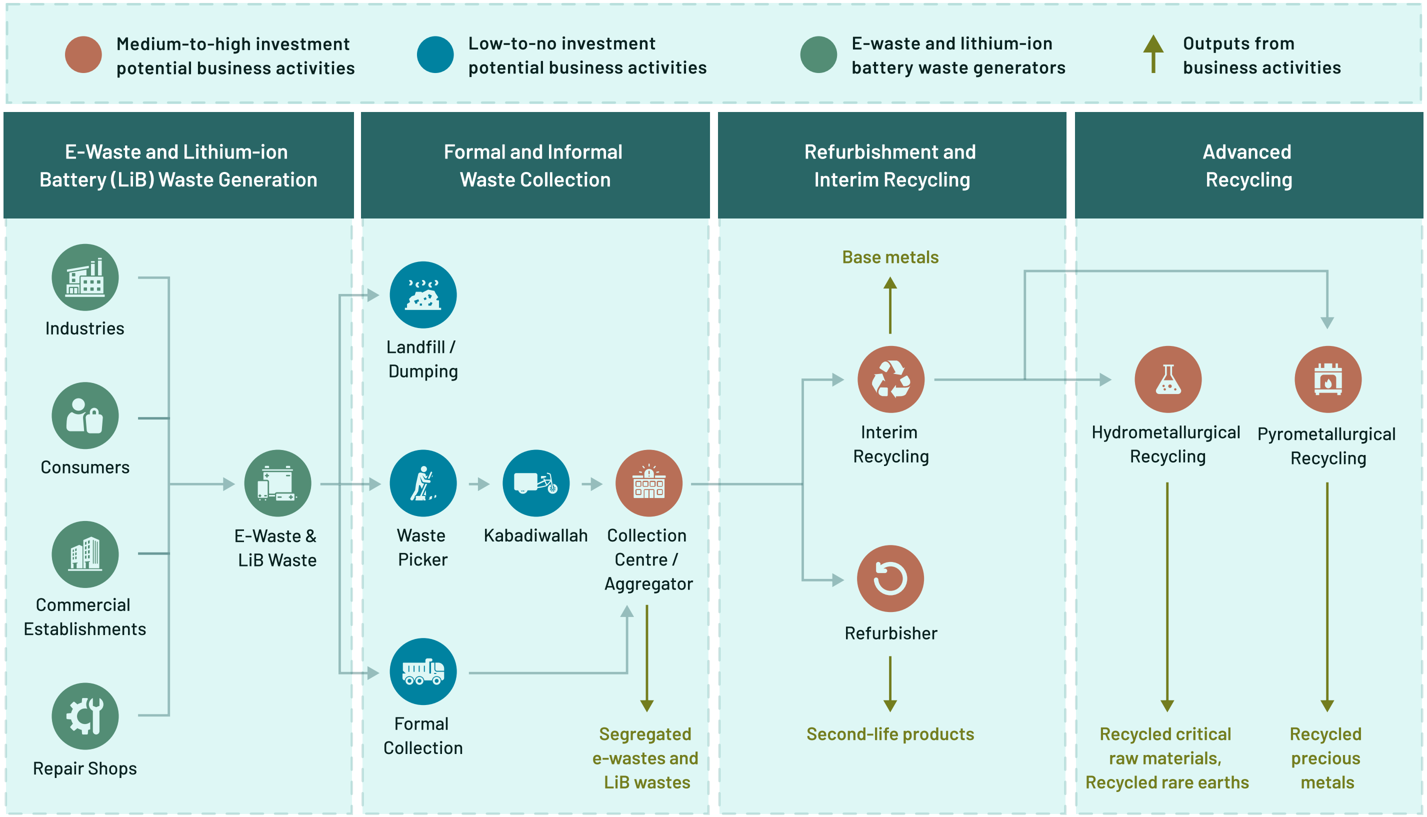
CHAPTER 2: THE CASE FOR INNOVATION IN E-WASTE AND LITHIUM-ION BATTERY RECYCLING

The E-Waste and Lithium-ion Battery Recycling Value Chain

E-waste recycling processes yield a spectrum of secondary materials, ranging from intermediate to high quality. Intermediate outputs typically include magnets, printed circuit boards (PCBs), manganese, plastic granules, copper and aluminium. High-quality secondary materials obtained through advanced recycling methodologies include precious metals such as gold, silver and palladium, rare earth metals like cadmium and neodymium, and solder recovery in the form of tin, among others. The components of LiBs present significant opportunities for separation, recovery and recycling. Key components include the casing, electrolyte, separator, anode and cathode. The cathode contains rare metals such as lithium, cobalt, manganese and nickel. Additionally, metals like copper and aluminium, along with various plastics and insulation materials like aerogels, are used throughout the battery pack.

E-waste and LiB recycling companies generally focus on the entire value chain from collection to recycling. Their growth is supported by innovations and improvements in collection logistics, material traceability, marketplaces for refurbished products, and original equipment manufacturers' advanced sorting and recycling technologies. While sourcing high-quality waste is a challenge for companies in this sector, they see value in integrated recycling as it offers more control over quality and revenue across the value chain. The e-waste and LiB collection and recycling value chain is shown below alongside the key business models and outputs generated at each stage of that chain.

Figure 3: E-waste and LiB collection and recycling value chain (Climake analysis)



The main business models that form part of the e-waste and LiB collection and recycling value chain are described below:

Collection Centres and Dismantlers

Collection centres in India aggregate, collect and dismantle electronic waste from households, commercial establishments and other waste generators. These centres then channel e-waste to refurbishers and direct dismantled components to interim metal and plastic recyclers. Currently, the informal sector dominates this space,[21] leaving limited entry points for formal players as stand-alone operators.

Formal recyclers are establishing in-house collection centres to secure a steady supply of waste materials – a trend expected to grow, as larger electric mobility batteries and electric vehicles enter the waste stream. To improve profit margins, formal businesses engage in both collection and additional value-added processes such as recycling or refurbishing. This unlocks more control over the supply chain, helping them capture value across multiple stages.

In contrast, the informal sector handles significantly larger waste volumes and operates with low margins through multi-tiered aggregation. While integrated formal operations are likely to accelerate organised recycling, supporting the formalisation of the informal sector is essential to the e-waste and LiB waste value chains.

Interim Recyclers

Interim recyclers in India specialise in extracting base metals, primarily aluminium and copper, from electronic waste. These recyclers employ pyrometallurgical smelting techniques for metal recovery and also utilise refining technologies to enhance the value of the extracted metals.

A significant portion of interim recycling operations in India is conducted by the informal sector, capitalising on relatively simple processes that do not require advanced technology. While this accessibility enables high participation from informal recyclers, it raises concerns about the quality of recycled outputs.[22]

21. Amrita Goldar, Kartik Nair, Md Sarwar Ali and Ritika Verma, Indian Council for Research on International Economic Relations, 2024. Unravelling India's E-Waste Supply Chain: A Comprehensive Analysis and Mapping of the Key Actors Involved. Retrieved from: https://icrier.org/pdf/UnravellingIndia-E-Waste.pdf

22. IFC, E-waste Roadmap 2023 for India, 2020. Retrieved from: https://greene.gov.in/wp-content/uploads/2020/12/2020120916.pdf

To improve the reliability and quality of recycled base metals entering supply chains, there is a pressing need for greater formalisation in the interim recycling sector. Such a transition would enhance the consistency of material quality, building trust among buyers and sellers.

Formal businesses prefer to integrate interim recycling processes through in-house or authorised centres. This allows robust quality control measures, ensuring recycled materials meet industry standards. Regardless of whether entities operate informally or formally, interim recyclers observe smaller profit margins compared to refurbishers and advanced recyclers. Therefore, it is important to optimise operations to sustain profitability in a competitive landscape.

Refurbishers

Electronic waste and LiB refurbishers play a crucial role in extending the lifespan of used electronic devices and batteries by specialising in repair, refurbishment and resale. The process not only mitigates electronic waste but also promotes sustainability by transforming discarded items into viable second-life products.

The robust e-commerce landscape in India has facilitated the emergence of numerous formal refurbishers specialising in EEE. These businesses leverage a buy-back or exchange model – providing customers with discounts and generating healthy profit margins due to high demand – particularly for used devices from premium brands such as Apple and Samsung. Despite the opportunities, reverse logistics is a significant pain point for refurbishers, negatively impacting operational efficiency and cost management.

The formal refurbishment of LiB is still in its infancy in India, primarily due to the limited availability of surplus used batteries. The informal second-hand market plays a pivotal role in facilitating LiB refurbishment at the aggregator level; however, transactions in this space lack reliable guarantees and pose safety risks.

To enhance safety and reliability, there is a need for the formalisation of the existing refurbishment network. SGBs operating in this segment should prioritise strategies that integrate informal players into more structured systems, ensuring quality and increasing consumer confidence in refurbished products.

Pyrometallurgical Smelters

Pyrometallurgical smelters enable the extraction of precious metals from melded components at elevated temperatures. While this technique is also employed for extracting materials from LiBs, the extraction efficiency is significantly lower compared to hydrometallurgical processes.[23]

Major private and public enterprises in India have established pyrometallurgical smelters, recognising their potential for efficient metal recovery. However, the high capital and operational costs associated with these facilities pose a barrier to entry for the informal sector.

E-waste serves as a more viable input for pyrometallurgical smelters than LiB waste due to the complexity of processing batteries and the associated lower extraction rates. The primary obstacle to scaling the pyrometallurgical smelting business for LiB recycling in India is the limited volume and quality of battery waste available for processing.[24] This constraint, along with the lower extraction efficiency, are barriers to establishing a robust LiB recycling system based on pyrometallurgical methods.

While pyrometallurgical smelting presents significant opportunities for e-waste recovery, the specific challenges associated with LiB waste processing require supply chain fixes and advanced technologies.

Hydrometallurgical Recyclers

Hydrometallurgical recyclers primarily concentrate on the extraction of materials from LiB, although recent innovations have emerged aimed at the low-energy extraction of precious metals from e-waste – a process commonly done by pyrometallurgical methods. Hydrometallurgy employs liquid mediums, like acids and leaching agents, to extract valuable metals like cobalt, lithium and nickel from black mass compounds. These materials are subsequently refined through electrorefining techniques to enhance their value.

In India, hydrometallurgical recycling is in its early stages compared to the more established pyrometallurgical smelting industry. However, the existing hydrometallurgical facilities are fully formalised and integrated within large enterprises, highlighting a more structured approach.

23. Mossali, Elena & Picone, Nicoletta & Gentilini, Luca & Rodrìguez, Olga & Perez, Juan M & Colledani, Marcello. (2020). Lithium-ion batteries towards circular economy: A literature review of opportunities and issues of recycling treatments. Journal of Environmental Management. 264. 110500. 10.1016/j.jenvman.2020.110500. Retrieved from: https://www.researchgate.net/publication/340393401_Lithium-ion_batteries_towards_circular_economy_A_literature_review_of_opportunities_and_issues_of_recycling_treatments
24. NITI Aayog, RMI, and RMI India, 2022, Need for Advanced Chemistry Cell Energy Storage in India (Part I of III). Retrieved from: https://www.niti.gov.in/sites/default/files/2022-02/Need-for-ACC-Energy-Storage-in-India.pdf

A significant barrier to the growth of hydrometallurgical recycling lies in the substantial capital investment required for technology adoption.[25] Despite its compelling value proposition of high-quality extraction, the initial costs deter potential entrants, especially new ventures. There is considerable potential for the development of homegrown hydrometallurgical technologies that can reduce adoption costs, presenting a strategic opportunity for local innovators.

While the hydrometallurgical recycling sector in India is nascent, it presents substantial opportunities for innovation and growth, particularly for SGBs looking to develop cost-effective technologies that can facilitate higher-value extraction from LiBs and e-waste.

25. Mossali, Elena & Picone, Nicoletta & Gentilini, Luca & Rodrìguez, Olga & Perez, Juan M & Colledani, Marcello. (2020). Lithium-ion batteries towards circular economy: A literature review of opportunities and issues of recycling treatments. Journal of Environmental Management. 264. 110500. 10.1016/j.jenvman.2020.110500. Retrieved from: https://www.researchgate.net/publication/340393401_Lithium-ion_batteries_towards_circular_economy_A_literature_review_of_opportunities_and_issues_of_recycling_treatments

The Current State of E-Waste and Lithium-ion Battery Recycling in India

Most e-waste recycling capability in India today focuses on the intermediate outputs, e.g., the extraction of magnets, PCBs, manganese, plastic granules, copper and aluminium. We identified less than 5 operational smelters undertaking precious metal extraction from waste PCBs, which is the highest value output in e-waste recycling.. The majority of waste PCBs in India are exported to larger capacity and more established smelters, with recyclers highlighting Europe and South Korea as key destinations for export.. Despite the regulatory frameworks in place, Indian dismantlers and recyclers currently rely heavily on exports for extracting final recycled outputs, posing a barrier to maximising the potential value of collected e-waste within the domestic market. We identified less than 5 operational smelters undertaking precious metal extraction from waste PCBs, which is the highest value output in e-waste recycling. - ones with a capacity less than 1,000 tons - where PCBs are only smelted in India. The majority of waste PCBs in India are exported to larger capacity and more established smelters, with recyclers highlighting Europe and South Korea as key destinations for export.

There is an emerging focus on extracting more of the high-quality secondary materials that include precious metals (like gold, silver and palladium), rare earths (like cadmium, neodymium, etc.) and solder recovery (like tin, etc.). This transition underscores a growing recognition of the economic and environmental benefits associated with maximising resource recovery from e-waste streams.

The repair and refurbishment of e-waste is commonly done in "mom-and-pop" (kirana) stores in neighbourhoods, particularly for small and medium EEE. Organised small and large-scale businesses in e-waste and LiB collection, refurbishment and recycling have come up mainly in the last ten years.[26] Marketplaces like Amazon, Flipkart and Cashify, among others, boost demand, especially for used mobile devices,laptops, and high value household electronics. Meanwhile, some other emerging resellers are increasing the supply and demand for second-life batteries.

Indian companies working specifically with high-quality LiB recycling are nascent. Lithium iron phosphate (LFP), nickel manganese cobalt (NMC) and lithium cobalt oxide (LCO) are expected to be the most common types of batteries recycled.[27] Recyclers are especially interested in batteries with nickel and cobalt because they are worth more. Most LiB processing output is black mass, and we have identified less than five recycling companies in India[28] with technologies to process black mass to generate high-value recycled materials that go into the LiB's cathode, such as lithium, cobalt, manganese and nickel. Black mass is used as an input for manufacturing the cathode of new batteries or in stationary storage.

26. Mandeep M, Blume VC, How Cashify Hit ₹1000 Cr Revenue: Insights from Co-founder Mandeep Manocha, 2024. Retrieved from: https://blume.vc/podcasts/pathfinders/how-cashify-hit-1000-cr-revenue-insights-from-co-founder-mandeep-manocha
27. NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, 2022, Advanced Chemistry Cell Battery Reuse and Recycling Market in India. Retrieved from: https://www.niti.gov.in/sites/default/files/2022-07/ACC-battery-reuse-and-recycling-market-in-India_Niti-Aayog_UK.pdf
28. Climake analysis

Investable Business Models for SGBs

The following three emerging areas in the e-waste and LiB recycling ecosystem could offer the potential for innovative SGBs to attract significant investment in the next decade.

1 HIGH-QUALITY, ADVANCED RECYCLING

Context and opportunity

High-quality recycling includes activities that make high-value recycled products out of precious metals, commodities and rare earths. The facilities for such recycling often need significant investments to acquire the chemical extraction or large-scale smelting technologies that they require.

There are three opportunities to drive exponential growth through advanced recycling:

- Low-energy, efficient recycling of e-waste: Pyrometallurgical recycling follows a well-established practice. Innovations offer marginal improvements in efficiency and outputs. Innovations that deliver recycling through non-energy intensive and more environmentally friendly processes are a significant opportunity.
- Recycling technologies for joint high-extraction recycling of e-waste and LiB waste: Recyclers are increasingly engaging in both e-waste and LiB recycling, but there is no unified process that maximises output efficiency; pyrometallurgy leads to low extraction rates of LiB waste and hydrometallurgy is not considered effective for precious metal extraction from e-waste.
- Recycling of rare earths from LiB and e-waste: E-waste recycling is optimised for precious metal extraction, and LiB recycling focuses on critical raw materials. Hydrometallurgical processes sometimes extract rare earths, but that is not a core focus of recycling. Focused recycling technologies could help to address the scarcity of rare earths.

All three opportunities are driven by the adoption of the right mix of technologies relevant to the type and quality of the material inputs. Advancements in these areas would help companies become more efficient, improve cash flow, scale and grow profits.

EXAMPLES OF STARTUPS IN THIS BUSINESS MODEL

Early Stage	Metastable Materials; BatX Energies
Growth Stage	Lohum; Namo eWaste; Attero

BATX ENERGIES (LITHIUM-ION BATTERY RECYCLING) - CASE STUDY

ORGANISATION SUMMARY

Year of foundation: **2020**
Number of employees: **46**
Black mass and metal extraction processing: **12,000 tonnes**
Batteries recycled: **220 million**

BatX Energies focuses on recycling lithium-ion batteries to recover critical minerals, including lithium, cobalt and nickel. Launched in 2020, the company initially developed technology to process end-of-life batteries into black mass, which it exported to specialised recyclers. Since then, BatX has advanced its technology to recover and refine these minerals directly from black mass, producing high-grade materials suitable for manufacturing new batteries. Following a successful fundraising round in December 2023, BatX is using the capital to establish a large-scale plant for critical mineral recovery.

The origins of BatX can be traced to its founders' university days in 2017 when they became interested in LiB technology, which was then emerging as a key component in India's mobility sector, aided by supportive regulations. The high costs and logistical complexities of importing LiB cells from China led them to explore sourcing used batteries domestically. Through that process, the founders gained insights into the challenges of the used-battery value chain and identified the imminent demand for LiB recycling by 2025, at a time when recycling infrastructure in India was sparse. BatX's early experience with LiB assembly has provided a strategic advantage in designing effective recycling technologies, allowing the company to extract high-value materials to industry standards.

SCALE

- **Existing revenue (FY22–23):** **US$ 3 million**
- **Break-even:** **2023**
- **EBIDTA:** **Positive**
- **PAT:** **Positive**

IMPACT

7 AFFORDABLE AND CLEAN ENERGY — Second-life batteries for solar off-grid setups – emerging impact

12 RESPONSIBLE CONSUMPTION AND PRODUCTION — 220 million batteries recycled

13 CLIMATE ACTION — 30% saving in recycling batteries

AWARDS AND RECOGNITION

- Winner in Innovation in Recycling Process and Technology (Start-up), BW BusinessWorld
- Top 15 in Asian Entrepreneurship Award 2024

FUNDING RAISED

Type of Funding	Year	Purpose	Funders / Investors
Equity	2021, 2023	Product development/growth	Zephyr Peacock, angels
Debt	2022	Working capital	Banks (collateral backed)

INVESTMENT OPPORTUNITY

Total funding raised to date	Equity: US$ 7 million Debt: US$ 2 million

BatX is looking to raise significant growth equity to expand its production capacity and further invest in research and product development. This will include technologies that improve its capabilities to refine the valuable materials extracted from waste batteries, such as lithium and cobalt. It can be expected that the company will also need to raise debt financing to fund the set-up of a new manufacturing plant with higher capacity, which will be necessary to match the expected growing demand for recycling LiB waste.

SUCCESS FACTORS

India currently lacks domestic sources of critical minerals for LiB, even as demand for lithium, cobalt and nickel is set to surge exponentially due to the rising adoption of EVs and energy storage systems. BatX's extensive experience across the LiB value chain positions it uniquely to address this market need. In addition to their technological capabilities, BatX has proactively established a supply chain for used batteries, securing a steady stream of battery waste and mitigating the supply constraints that frequently challenge recyclers in this sector.

The lithium-ion recycling industry, and BatX in particular, stands to benefit significantly from favourable policy trends, especially with the implementation of extended producer responsibility (EPR) regulations specific to LiBs. These regulations are expected to place increased targets on manufacturers and end-users to recover valuable minerals from batteries they have deployed, thus driving the demand for large-scale recycling facilities. With both operational experience and a secured input supply, BatX is well positioned to meet the projected scale of demand as regulatory pressure and industry needs converge.

2 INTERIM RECYCLING

Context and opportunity

Interim recycling facilities create recycled products from easier-to-separate commodities, such as ferrous and non-ferrous metals, for the first material extraction of e-waste. The process primarily focuses on further separation of these materials, if necessary, and smelting them into ingots for sale to manufacturers as recycled materials. Pyrometallurgy and hydrometallurgy approaches are the main technologies employed to make ingots from ferrous and non-ferrous metals.

Despite such metals being easier to recycle relative to other compounds – and having the potential to be fully recyclable if extracted properly – India's ferrous and non-ferrous recycling capacity is lagging[29]; a phenomenon that can be mainly attributed to ineffective collection of waste material. Accordingly, this segment has significant incentives and scope for growth.

EXAMPLES OF STARTUPS IN THIS BUSINESS MODEL

Early Stage	binbag
Mature Stage	KARO SAMBHAV; Ecoreco® Eco Recycling Limited

29. Rituparna N., Shivani S, Abdi S., Viral S., Rohan S., S&P Global, India's circular economy goals: Spotlight on ferrous scrap, 2024. Retrieved from: https://www.spglobal.com/commodityinsights/PlattsContent/_assets/_files/en/specialreports/metals/india-circular-economy-goals-spotlight-ferrous-scrap.pdf

BINBAG - CASE STUDY

ORGANISATION SUMMARY

Year of foundation: **2015**
Number of employees: **30**
Current e-waste processing capacity: **420 tonnes per year**
Future e-waste processing capacity: **3,000 tonnes per year**

Binbag provides specialised e-waste recycling and IT asset disposition solutions to enterprises, accelerating resource circularity by reintegrating secondary materials into the manufacturing supply chain. As a fully integrated recycling entity, Binbag partners across industries to transform discarded electronics into valuable resources.

In 2023, Binbag began establishing a 2,500-tonnes-per-annum facility in Northeastern India, aimed at increasing operational control across collection, recycling and regulatory compliance. This facility is Binbag's second recycling unit in India and strategically positions the company to expand into the EPR market, enhance its refurbishing capabilities and enter the LiB recycling sector.

Binbag's approach is particularly impactful as it is one of the few providers serving the remote regions of Northeastern India. The company has developed local expertise and networks to provide collection and interim recycling services to large consumers subject to EPR requirements. By acting as a local provider, Binbag reduces transportation costs and the carbon footprint associated with recycling, delivering a cost-effective, environmentally sustainable solution to clients.

Binbag initially launched with a B2C model, aiming to offer small generators an avenue for compliant e-waste disposal. However, the high logistical costs and limited value potential of small-scale consumer waste led Binbag to pivot to a B2B model. This shift enabled more favourable unit economics in procuring and transporting e-waste and justified investment in interim recycling infrastructure as supply scaled. Following its B2B success, Binbag reintroduced a consumer-facing arm, EcoBox, which allows individual consumers to send in e-waste. EcoBox supports Binbag's refurbishment initiatives and serves as a brand-building tool, enhancing the company's market recognition and consumer reach.

SCALE

- **Existing revenue (FY23–24): US$ 1 million**
- **Break-even: 2022**
- **Profitable**

IMPACT

12 RESPONSIBLE CONSUMPTION AND PRODUCTION — 2,000 tonnes of e-waste recycled in FY24

13 CLIMATE ACTION — 2,880 tonnes of GHG emissions avoided in FY24

AWARDS AND RECOGNITION

- Rongali Entrepreneurship Award, Government of Assam
- Urban Sanitation Award, Ministry of Housing and Urban Affairs

FUNDING RAISED

Type of Funding	Year	Purpose	Funders / Investors
Equity	2021, 2023	Product development/growth	NSRCEL-IIM Bangalore, NVCL
Debt	2022	Working capital	NBFCs

INVESTMENT OPPORTUNITY

Total funding raised to date	Equity and debt: US$ 1.1 million

Binbag, as the sole e-waste recycling player focused on Northeastern India, has successfully attracted both debt and equity capital from regional development funds and lenders. The company has effectively leveraged this funding to establish its manufacturing facilities and secure additional financing through order-based support from non-banking financial companies (NBFCs) and revenue-based lenders.

Looking towards future growth, Binbag is preparing to raise further equity to develop a robust technology platform designed to streamline e-waste disposal for brands and manufacturers, ensuring a steady supply of waste materials. This platform will also enable Binbag to partner with other interim recyclers and refurbishers with surplus capacity, allowing for an expanded, asset-light operating model to enhance regional reach and operational efficiency. In its long-term strategy, Binbag plans to enter the LiB recycling market by investing in recycling technologies that produce black mass as an intermediate output, positioning itself for further expansion in this emerging segment.

SUCCESS FACTORS

The establishment of Binbag's recycling units marks a pivotal advancement, allowing the company greater control over operational processes, margin improvement and regulatory compliance – each of which bolsters its competitive position. Notably, Binbag's second unit stands among the first recycling facilities in Northeastern India, offering both exclusivity and a foundation for regional expansion. The company's strategic entry into battery recycling aligns with global shifts towards sustainability and the circular economy, presenting a promising revenue avenue for the future. Furthermore, Binbag's development of a technology platform for brand and recycler interactions creates diverse pathways for expansion. By facilitating partnerships with other recyclers through an asset-light model, Binbag unlocks unique scaling opportunities, differentiating itself from competitors who remain limited to proprietary recycling infrastructure.

3 SECOND-LIFE BATTERIES

Context and opportunity

Refurbishers create second-life batteries and other types of refurbished EEE that re-enter the market. Refurbishment involves cleaning and repairing a product so that it can be used for the same or similar applications.

Battery retirement and replacement are typically required when the performance of a battery falls below 70–80% of its initial nameplate capacity. When a battery is replaced, the used battery can either enter a second life or be repurposed for a different use case, often being refurbished for small- or medium-scale storage applications. This process extends the battery's utility but eventually contributes to the accumulation of battery waste.

The volume of annual battery retirement from all EV segments, including rail and freight, is projected to surge, reaching at least 6 GWh per year by 2030.[30] This is a significant increase compared to less than 0.5 GWh per year in 2022. The growing adoption of EVs will inevitably lead to a corresponding rise in the number of batteries that need to be retired and managed at the end of their useful life.

EXAMPLES OF STARTUPS IN THIS BUSINESS MODEL

Early Stage	ZIPTRAX ADVANCED CLEANTECH	nunam
Growth/Mature Stage	CASHIFY	LOHUM

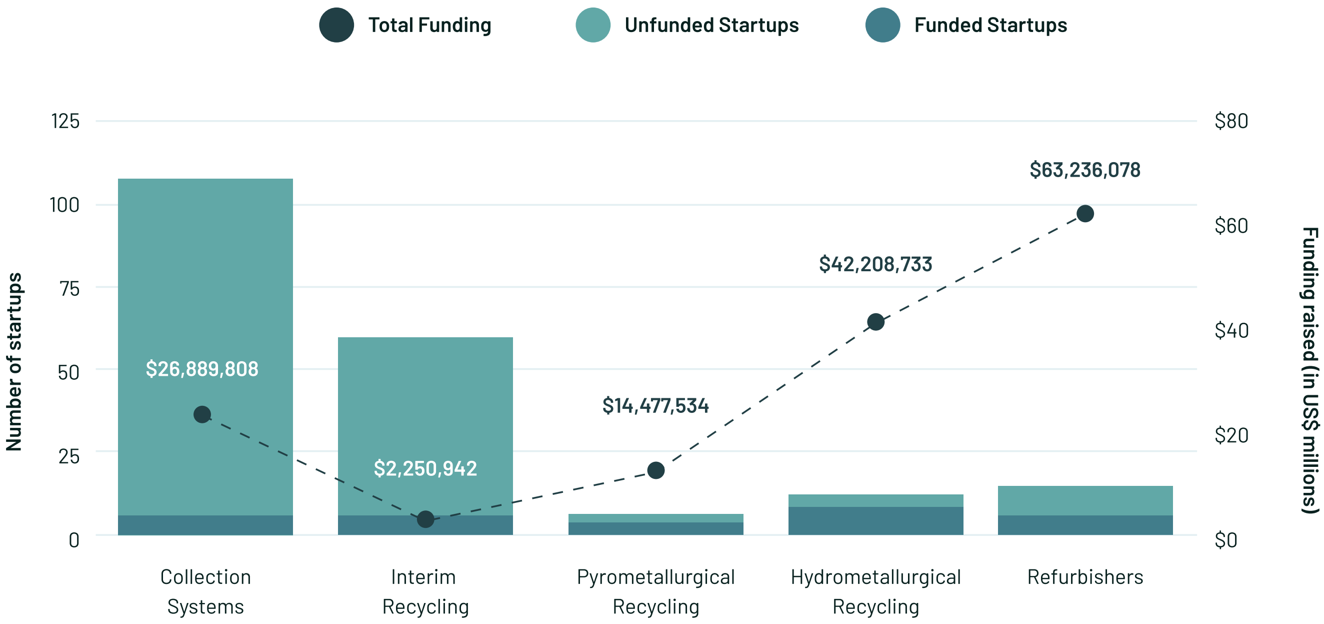
30. NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, 2022, Advanced Chemistry Cell Battery Reuse and Recycling Market in India. Retrieved from: https://www.niti.gov.in/sites/default/files/2022-07/ACC-battery-reuse-and-recycling-market-in-India_Niti-Aayog_UK.pdf

CHAPTER 3: INVESTMENT LANDSCAPE

Equity Investment Trends in E-Waste and Lithium-ion Battery Recycling

Identified Companies	Funded Startups	Total Equity Funding Raised (US$)
184	20	149.1 million

Figure 4: Startups across the five main business models in the e-waste and lithium-ion battery waste recycling and circularity value chain (Climake analysis)



The **184 startups** identified in Figure 4 are formal entities that operate across the e-waste and LiB waste value chain in fields ranging from collection and dismantling to interim recycling, creating recycled and circular outputs, and extracting raw materials through pyrometallurgical and hydrometallurgical recycling.

Collection and dismantling companies are the largest business model segment by number of entities, mainly due to lower entry barriers and the important role they play in segregating e-waste and LiB waste into components, e.g., metals, plastics, etc. Collection and dismantling companies often engage in an ancillary activity of data destruction, which is often a critical value-add to businesses and ensures data on electronic devices provided as waste are not misused. However, this is not a highly investable segment due to the lack of differentiation and low entry barriers – more than 90% of the funding in the space comes from a company where collection and dismantling is an ancillary business.

Interim recycling focuses on recycling base metals like aluminium and copper mainly through a pyrometallurgical process at a small scale and low cost relative to the smelters required for gold and precious metal extraction. This business model has some investment potential, mainly in those companies that also employ technologies for higher-quality refining and speciality uses, as well as those that look to set up large-capacity copper smelters. This form of recycling is also undertaken by large-scale aluminium and copper refining firms; however, such firms are not featured in this guide as they are large, publicly listed companies and, thus, out of the scope of this study.

Advanced e-waste recycling is primarily focused on extracting precious metals from printed circuit boards, which requires a pyrometallurgical process: the use of high-capacity smelters. This is the dominant technology for recycling in this segment as it is technologically mature. However, to make this process viable against the outputs extracted, insights from e-waste recyclers indicate that such smelters need to have an output capacity of recycled materials of at least 1,500 tonnes, which can require capital expenditure of up to US$ 8 million. This energy-intensive and emission-intensive approach also highlights the negative environmental impacts associated with this process. Although there are technologies emerging that aim to recycle through less-intensive practices, primarily through a hydrometallurgical-only route, these are still nascent and emerging, and have not reached the commercial-scale operations that pyrometallurgical approaches have achieved.

Advanced LiB recycling is primarily undertaken through hydrometallurgical practices where chemicals and aqueous solutions, along with electrolysis approaches, are used to separate and extract critical raw materials such as lithium and cobalt. This is a nascent field, giving rise to a few emerging approaches and technologies, primarily around differences in the type of solutions and extraction methods used. Considerations around minimising negative external impacts are also being adopted within this segment. As a result, early-stage investments still have a role to play in bringing hydrometallurgical recycling solutions from the lab and pilot stages to initial commercialisation. This segment has time to grow to larger-scale operations because electric vehicle batteries, which are going to provide the largest source of LiB batteries, are still nascent in volume. The current main sources of this waste are mobile phone batteries.

Refurbishers have traditionally been focused on providing second-life opportunities to electronic products. As refurbishment is normally done by semi-formal enterprises or repair shops, the quality of such products is often not standardised and can be questionable. Large e-commerce brands have also recently entered this space, working mainly with in-house teams or networks of repair shops to provide refurbished electronic products that are more affordable for customers. The refurbishers identified here are formal players, focused on providing high-quality refurbished electronics and, increasingly, LiB recycling products. Refurbished batteries, in particular, appear to present increasing opportunities. Electric vehicle batteries need to be replaced when they reach 70–80% of their overall capacity levels due to the heavy-use nature of batteries in vehicles. However, these batteries are still viable for use in energy storage applications, such as powering off-grid utilities, homes and other setups. With the increased potential of LiBs in energy storage, refurbishment will emerge as a significant opportunity area – up to 5%[31] of energy storage capacity is expected to come from refurbished batteries by 2030, with the potential to grow further.

31. NITI Aayog, RMI, and RMI India, 2022, Need for Advanced Chemistry Cell Energy Storage in India (Part III of III). Retrieved from: https://www.niti.gov.in/sites/default/files/2022-09/RMI-India-battery-report-v6-14092022.pdf

Figure 5: Stage of investments of startups across the five business models in the e-waste and lithium-ion battery waste recycling and circularity value chain by funding raised (Source: Climake analysis)

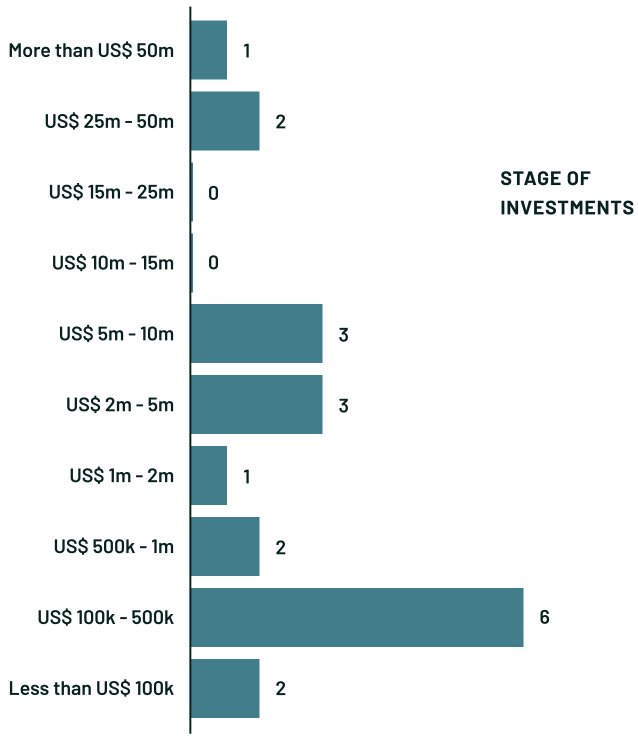
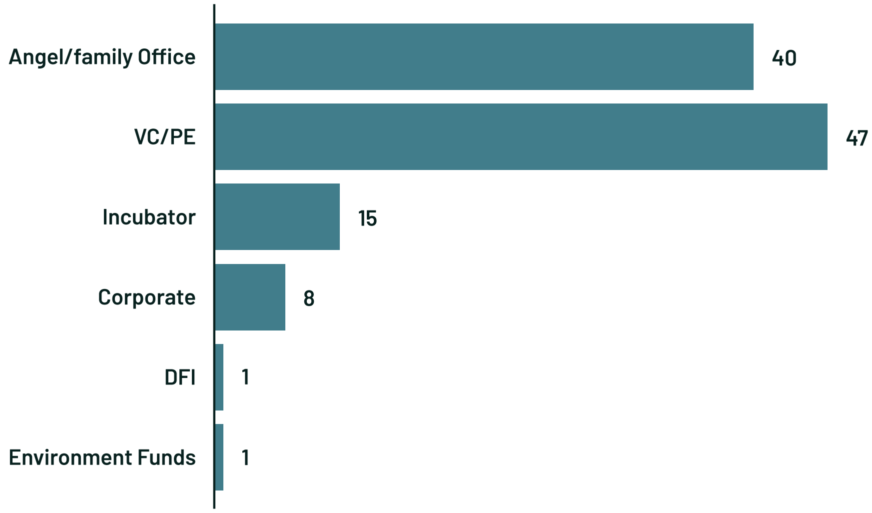


Figure 5 outlines the latest stage of funding for e-waste and LiB waste circularity startups in India. About 50% of funding was below US$ 2 million ticket sizes, which corresponds to the segment between pilot development and early traction because commercialising e-waste and lithium-ion batteries involves more capital expenditure (CapEx) than other waste segments. However, the nature of business models is diverse across these spaces. Interim recycling players can access capital if they are able to outline a path to higher-value recycling or demonstrate competitive advantages in accessing and creating waste outputs, such as geographic advantages. As these are stable, reliable business models with known technologies, the technology risk is minimal and the investment opportunities here are around backing growth. The refurbishing of LiBs is an additional investment opportunity, and this study has tracked two companies at different stages of scale accessing capital, highlighting the potential for more emerging companies to enter the space, something that will become a need given the potential for second-life batteries from electric vehicles.

The majority of hydrometallurgical and pyrometallurgical startups identified have raised capital at various stages based on their maturity. This is reflective of these segments' reliance on accessing external capital. Unfunded startups in this space have, at most, pilot facilities, having accessed grants or personal funds to reach this scale. LiB recycling is at a stage where technology competitiveness presents opportunities; this study has tracked one company that has raised over US$ 30 million – 75% of the total funding in the space. All the pyrometallurgical recycling companies identified either have a long track record in more upstream e-waste recycling activities, e.g., collections and interim recycling, or are accruing sufficient capital to further expand their activities.

Investor and Funding Landscape

Figure 6: Number of investors who have funded e-waste and LiB waste management and circularity startups by type (Source: Climake analysis)



Angels / family offices and venture capital (VC) / private equity (PE) funds overwhelmingly dominate the investor landscape in e-waste and lithium-ion battery recycling. The high participation of VC funds, especially, indicates that mainstream funds understand the opportunities present in this sector – reflected by the mainstream growth of the EV and consumer electronics spaces – and their potential to provide an alternate source of critical raw materials that will be needed to support future demand. However, the low participation of incubators and environment funds could also indicate that the high CapEx and investment needs of these sectors are out of range for these investors. DFI participation might be low, but they are taking a keen interest in the sector, and their further participation is expected, especially in providing concessional capital for setting up larger-scale facilities. Corporate investors are limited in taking early-stage bets and have not yet started investing in the segment at scale.

The roles played by each investor in supporting enterprises are summarised below:

- Incubators are primarily focused on backing advanced, high-quality e-waste and LiB recycling solutions and proofs-of-concepts. They have traditionally been the first backers of such enterprises, but angel funds have increasingly started entering that role, given the promising opportunities in this segment. In India, the majority of incubators are tied to academic institutions, but the presence of private platforms is growing and promising to provide more context-specific support.
- Angel funds and family offices come in as the first institutional investors for early-stage proofs-of-concepts. In this segment, their role is in helping to fund initial commercialisation and go-to-market. Given technology IP benefits and mainstream knowledge of the opportunities in this sector, they have often entered in roles that would traditionally be the purview of incubators.

- VC and PE funds operate in a wide space from funding initial go-to-market to making investments in the seed and growth stages based on the areas of focus of such funds. Despite often lacking the sort of clear thesis on asset-heavy investments that is needed for climate action and circularity, VC and PE participation in e-waste and LiB recycling has been more significant compared to other sectors. This can be attributed to the early-stage nature of the sector today, the exponential potential of backing the right technology, and mainstream knowledge of the sector's opportunities and expected growth as it provides an alternative raw material supply for critical business sectors requiring batteries and electronics.
- The participation of environment-focused funds has been lower than might have been anticipated, primarily because of the higher participation of VC and PE funds. Environment-focused funds traditionally come in with a willingness to take more of the risks required to meet a sector's technological needs. However, there is not a great need for such risks in the e-waste and LiB waste segment as the required technology is maturing and becoming well established.
- DFIs fund growth, but the scale of capital they can deploy means that they can have an influence on the direction and bets of earlier-stage funds, making such funds more likely to align with the DFIs' stated priorities. DFIs play a catalytic role, bringing more private finance into the sector. They often do that by offering debt or equity on concessional terms to an enterprise, which allows it to grow to a level at which it can meet the expectations of more commercial investors. DFI participation in e-waste and LiB waste management and circularity remains limited due to the nascence of the sector. However, engagement with DFIs for this research revealed that it is a high-interest sector for them.

Figure 7: Active equity investors in e-waste and lithium-ion battery waste circularity (Source: Climake analysis)

Seed Equity (< US$ 1 million)	Series A (US$ 1 -7 million)	Series B (US$ 8 - 20 million)	Series C and Beyond (US$ 20 million+)
Theia Ventures	Stellaris Venture Partners	British International Investment	Just Climate
Spectrum Impact	Circulate Capital	Morgan Stanley	Multiples
Capital-A	Sagana	gef global environment facility	TigerGlobal
Speciale Invest	KOIS Caring Finance	AsiaImpact	TPG Rise Climate
Startup Oasis	Surge	Accel	IFC International Finance Corporation
Rainmatter	Blume	nuveen	Baring Private Equity Partners
Blue Ashva Capital	Kalaari Capital		Singularity AMC
WeFounderCircle			
JITO Incubation & Innovation Foundation			

E-waste and Lithium-ion Battery Waste Circularity Businesses Also Have Significant Debt Potential

E-waste and LiB waste recycling and circularity businesses in India, particularly those in the growth stage, have demonstrated an ability to fund part of their capital needs with debt. These companies are raising three kinds of debt:

Project Finance

Advanced pyrometallurgical and hydrometallurgical recycling, in particular, require setting up capital-intensive, asset-heavy plants. Interim recycling plants also require access to capital. For companies that have raised equity and built a profitable business model, such debt financing is widely available from banks in India.

Banks, however, need companies to provide three years of profitable track record and offer collateral security beyond the project's assets. For companies who do not meet such criteria, specialised lenders, like Tata Cleantech Capital, and DFIs have expressed interest in providing non-dilutive capital to the sector. However, given the sector's nascence, active deals are yet to progress.

Working Capital

As with project finance, profitable companies that can offer collateral security and personal guarantees from their founders are able to raise credit lines from local banks to meet their working capital needs. There are several other options for those who do not qualify for bank loans:

- NBFCs offering unsecured business loans to meet the working capital requirements of young startups
- Invoice discounting offered by banks, NBFCs and multiple trade receivables electronic discounting system (TReDS) platforms
- Financing linked to orders that provides working capital to purchase raw materials and pay vendors with repayments linked to the revenue received from such orders
- Revenue-based financing for companies that have fixed monthly revenue or standard offtake contracts.

Venture Debt

While more popular with technology startups, venture debt is increasingly gaining traction in environmental and circularity sectors as well. Venture debt providers are able to complement the equity raised with a small debt component, thus increasing the runway for early-stage startups and providing an option for lower dilution in the early rounds of fundraising.

The universe of active debt investors in India's e-waste and LiB waste circularity segment is shown below.

Figure 8: Active debt lenders in e-waste and lithium-ion battery waste circularity (Source: Climake analysis)

Early Revenue (< US$ 1 million)	Early Growth (US$ 1 -7 million)	Growth (US$ 8 - 20 million)	Scale (US$ 20 million+)
Spectrum Impact, Caspian	RevX Capital, Alteria Capital	responsAbility, Northern Arc	ADB Asian Development Bank
Blue Ashva Capital, BlackSoil	BlueOrchard Impact Investment Managers, Vivriti Capital	IFC International Finance Corporation, SIDBI	British International Investment
UC Inclusive Credit, ecofy	Stride Ventures	DFC U.S. International Development Finance Corporation, Tata Capital	
	Startup lending teams of Indian and foreign banks		Local Indian Banks: Commercial Debt

Blended Finance Options for E-waste and LiB Waste Recycling

Startups in e-waste and LiB waste circularity have access to grant capital in their early product development and pilot stages, mainly through incubator-led and corporate social responsibility (CSR) programmes. Blended capital, however, has not yet been extensively adopted in this segment. There can be opportunities for this, especially in scaling promising entities at early stages, but there is no evidence yet of the sort of tailored concessional or catalytic vehicles that already exist in other segments such as plastic waste circularity.

CHAPTER 4: CONCLUSION

India generated approximately 4.1 million tonnes of electronic waste in 2022 – 7% of the world's total. That number is expected to more than double to 9 million tonnes by 2030. It is estimated that around one-third of India's e-waste is managed, and 80–90% of these operations are handled by the informal sector, which produces low-quality recycling outputs. LiB recycling is currently nascent in India, with only 1% of the required recycling capacity in place. By 2030, it is expected that the country will be generating 43,000 tonnes of LiB waste. There is increasing demand for higher-quality outputs, and the gaps in the current recycling ecosystem offer a high ceiling for new players and investment opportunities. There are four prevailing trends that will particularly incentivise the adoption of e-waste and LiB circularity solutions:

- Domestic demand and manufacturing are increasing the generation of e-waste and LiB waste.
- Policy frameworks are enabling high-quality recycling, especially through the imposition of extended producer responsibility targets.
- The need to secure high-value input raw materials is making manufacturers focus on material extraction from waste.
- Recycling is becoming increasingly formalised, improving quality and efficiency.

This study has identified 184 formal enterprises operating across five main business models in e-waste and LiB circularity: collection systems (57% of all enterprises in this field), interim recycling (32%), refurbishers (5%), hydrometallurgical recycling (4%) and pyrometallurgical recycling (2%). Each segment offers differing levels of investment opportunity and potential based on the nature of the business and the operating context. Only 4% of collection systems enterprises were able to access equity funding, in contrast to 75% of pyrometallurgical recycling startups, 71% of hydrometallurgical recycling startups and 44% of refurbishers. Businesses that can deliver and demonstrate high-quality e-waste and LiB circularity outputs are being recognised as investment opportunities.

The number of equity investments – 18 – in the e-waste and LiB waste space is smaller than other high-potential waste and circularity segments due to the relative nascence of the space and the technological complexity of the solutions. Unlike most other segments, technology risks are largely addressed, although some opportunities still abound in increasing extraction rates or making more efficient approaches that are less energy intensive.. However, even if technology risks are addressed, enterprises need to access significant funding to invest in CapEx that makes operations relevant at scale. 50% of the equity investments have been below US$ 1 million at the early stages of technology validation and initial commercialisation.

However, due to the sector's high potential, early-stage VC and angel investors account for the largest share of investors in the e-waste and LiB waste stream. Unlike other waste segments, incubators – which normally have a significant role if the majority of investments are at an early stage – have a limited role. That is because the sector is somewhat derisked by being tied to the success of the consumer electronics and electric mobility sectors; both sectors that are well established with mainstream investor participation, and where manufacturers have highlighted the need for recycling as a key source of critical raw materials. Despite the current low participation of private equity funds and DFIs, conversations with these investors show that they have significant interest in this sector if the right investment opportunities arise. These investors are already actively looking for deals in the e-waste and LiB waste recycling sector.

Debt investors will play a key role in enabling enterprises to set up recycling plants, which have significant CapEx demands, especially for hydrometallurgical and pyrometallurgical recycling facilities. Enterprises currently require project finance to set up scaled facilities as many high-quality recyclers and refurbishers are seeing growth potential that needs to be funded. Blended finance and grant-based concessional financing structures are mainly present in the early stages of an enterprise's lifecycle, primarily focusing on supporting technology validation, but more concessional capital at growth stages can be expected as this sector grows and more investors participate.

RESEARCH METHODOLOGY

The insights and conclusions of this guide were informed by data gathered from primary and secondary sources. The insights also leveraged the extensive work that Climake has already undertaken in the waste management and circularity sector.

DATA COLLECTION

1 Secondary Public Source Analysis

The first phase involved a thorough review of publicly available secondary sources: academic literature, industry publications and reports, government reports and statistics, news articles and press releases, and open-access databases and repositories.

2 Access to Proprietary Databases

We also accessed proprietary databases containing specialised and detailed information relating to startups, funding and investors, The main database leveraged for this was Tracxn. Access to these databases allowed us to obtain up-to-date market data and gather detailed company and investor-specific information.

3 Primary Research

To gather sector-specific feedback, we engaged in primary research with key stakeholders: startup founders, investors and experts in waste management and circularity. This primary research was undertaken as part of targeted and ongoing engagements with stakeholders. A total of five interviews were conducted with the following:

- Three founders of funded entities in the following core business models:
  - High-quality lithium-ion battery recycling
  - High-quality lithium-ion battery recycling and second-life batteries
  - Interim recycling and refurbishing
- Two funds with a defined thesis in e-waste and LiB recycling.

DATA ANALYSIS AND SYNTHESIS

The data collected from all sources were systematically analysed and synthesised. This process involved:

- Conducting content analysis to identify insights, conclusions, trends and forecasts
- Using data visualisation approaches to represent quantitative findings
- Validating assumptions and identifying discrepancies by cross-referencing information from different sources.

LIMITATIONS

While efforts were made to ensure comprehensive and accurate data collection, some limitations should be noted:

- Accurate data on key metrics such as waste quantities and recycling rates are poorly documented in India and vary significantly across waste streams. Our research aimed to validate all data points identified by identifying multiple sources, if available, validating with primary interviewees and leveraging our extant knowledge of the sector.

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