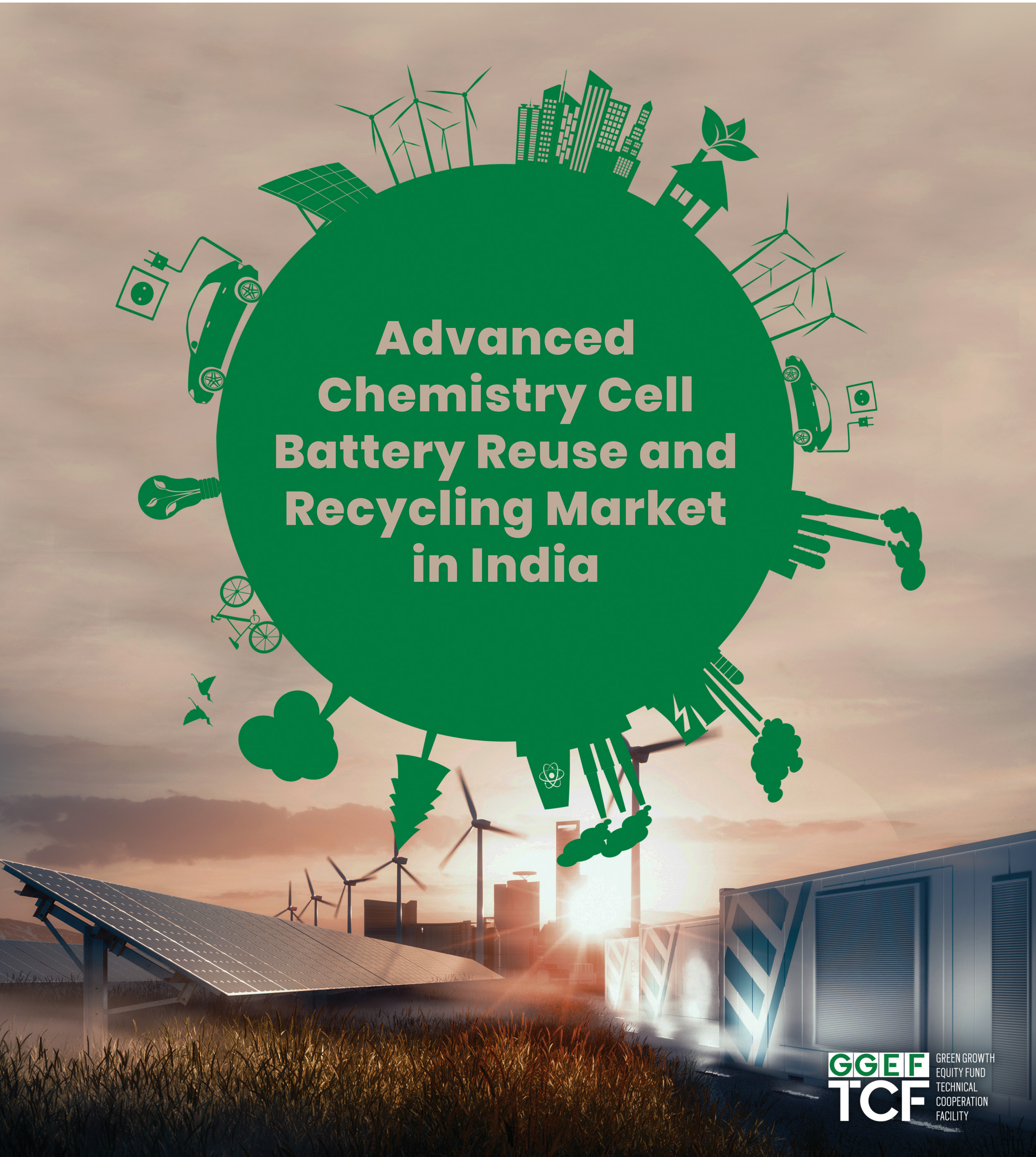
NITI Aayog

UK Government

Advanced Chemistry Cell Battery Reuse and Recycling Market in India



GGEF TCF
GREEN GROWTH EQUITY FUND TECHNICAL COOPERATION FACILITY

Authors and acknowledgements

Authors

The team for this report involved colleagues from NITI Aayog, Oxford Policy Management, pManifold and PricewaterhouseCoopers:

- **Akshay Gattu**
- **Ankit Agrawal**
- **Ankit Chatterjee**
- **Diewakarr Mittal**
- **Mohammed Subhan Khan**
- **Rahul Bagdia**
- **Randheer Singh**
- **Safa Mohsin Khan**
- **Vaibhav Singh**

Contacts:

For more information, contact ggeftcf@opml.co.uk

Acknowledgements

The authors are grateful for the guidance and support from UK Foreign, Commonwealth & Development Office (FCDO), and Phil Marker and Dhiraj Mathur from Oxford Policy Management, which helped in framing the recommendations. The team is also grateful for the guidance received from Sudhendu J. Sinha, Niti Aayog and for contributions received from:

Mr. Nitin Gupta, CEO, Attero Recycling
Mr. ALN Rao, CEO, Exigo Recycling
Mr. Atul Arya, Head Energy Systems Division, Panasonic

Suggested Citation

NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, Advanced Chemistry Cell Battery Reuse and Recycling Market in India, May 2022.

All images used are from iStock.com/Shutterstock.com unless otherwise noted.

Disclaimer: The views and opinions expressed in this document are those of the authors and do not necessarily reflect the positions of their organizations or governments. While every effort has been made to verify the data and information contained in this report, any mistakes or omissions are attributed solely to the authors and not to the organizations they represent.

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.

Table of contents

List of tables

List of figures

Executive Summary

Nations around the world are producing plans to achieve net zero by adopting disruptive low-emission and energy-efficient pathways to reduce dependence on fossil fuels. These pathways include electrification of the transport sector and having a higher share of renewable energy (RE) in the energy mix.

To accomplish this, energy storage is expected to play an important role in promoting electric mobility and stationary applications (i.e. grid storage). These applications are expected to drive the energy storage market along with existing applications like automobile starting, lighting and ignition (SLI) batteries, consumer electronics and home or commercial uninterruptible power supply (UPS) solutions.

This report undertakes analysis of the overall battery market in India, deep-diving into the relevant policies and regulations; current and estimated segment-wise market sizing; support interventions at central and state level; and the recycling potential of current and evolving battery technologies. Further, it discusses in detail the battery storage supply chain and reviews different battery storage and recycling technologies. It also identifies and elaborates key initiatives that may ease the battery manufacturing and recycling industry. The report culminates in recommendations for the government and various stakeholders to address the challenges pertaining to the battery recycling market in India in terms of the current policy and regulations, incentives and others. A coherent regulatory framework incentivising all stakeholders to participate in the recycling process will help in the development of a battery recycling ecosystem in the country and is key to move towards a more sustainable society.

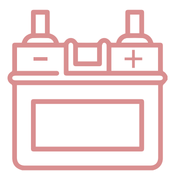
Globally, energy storage has evolved a great deal in terms of applicability, including the diverse range of advanced cell chemistries employed, to make such storage applications a reality. In India, segments like electric vehicles (EVs), stationary storage and consumer electronics are projected to be major demand drivers for the adoption of battery storage. The battery ecosystem makes a strong pitch to integrate RE into the grid; reduce crude oil imports by boosting electric mobility; transition intermittent RE into a round-the-clock supply with the phase-out of conventional power; and make India a global manufacturing hub for upcoming battery chemistries.

Globally, the combined markets of stationary and transportation energy storage are estimated to grow upto 2.5-4 TWh annually by 2030, resulting in approximately 3–4 times the current 800 gigawatt-hours by the end of this decade.

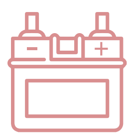
Chapter 2 of this report looks at the current value chain of batteries as well as different battery chemistries to understand the entire battery ecosystem. In addition to lithium ion batteries (LIBs), several emerging battery technologies are coming onto the market. These batteries are yet to commercialise but showcase promising features that can help them supersede the LIBs. These chemistries include solid state batteries, sodium ion, lithium sulphur, metal air and redox flow batteries. Each of these battery chemistry types is described in detail in the subsections of this chapter. Further, the chapter explores the availability and environmental aspect of the key materials used in manufacturing LIBs, such as nickel, lithium, cobalt and titanium.

The initial part of Chapter 3 provides an overview of the battery storage market in India across all sectors. Battery storage has become an issue because of the energy sector's growing technology landscape and efficient cost-cutting tactics across the supply chain. In 2020, global annual demand for batteries was around 730 GWh, which is expected to grow fourfold to reach 3,100 GWh by 2030.

Share of the total battery market in 2020



60%
Lead acid batteries (LABs)



40%
Lithium-ion battery (LIBs)

In India, the estimated cumulative stock of LIBs in 2020 was about 15 GWh. Within this, stationary applications took up a 36% share with an estimated 5.6 GWh of deployments, transportation applications a 3% share with an estimated 0.45 GWh of deployments and consumer electronics a 61% share with an estimated 9.4 GWh of deployments. To provide a comprehensive picture of the battery market in the country, the chapter presents a list of some prominent storage tenders that are in various stages of development.

The next part of Chapter 3 look at policies and regulations for battery storage in India, analysing various central and state-level policies and initiatives taken up by the respective governments to promote battery storage deployment in the country. Policy and regulatory frameworks are the biggest drivers in mobilising market penetration for the adoption of battery manufacturing technologies. A stable and long-term central policy, accompanied by state-level incentives and programmes, serves as an input for investors to use in planning and developing their entry strategy for Indian markets. The Indian government's intention is to create forward and backward linkages in manufacturing to generate a strong multiplier effect in the economy, in addition to driving export competitiveness.

The final part of Chapter 3 projects the demand for current and upcoming battery storage technologies or chemistries in India till 2030. Considering the targets set for the year 2030, and India's need for local battery manufacturing, it lays out estimated battery demand and recycling potential in battery energy storage for stakeholders to tap. Using the methodology stated in the figure and a bottom-up approach, we estimate the demand for batteries for various end use applications across all sectors till 2030.

Approach adopted for estimating the market projection of battery demand in India

Sector-based research

based on secondary data

Data validation

through reports, penetration level

Forecast model

bottom-up approach

Analysis

review of current market trends and models and individual market forecast

Cases considered

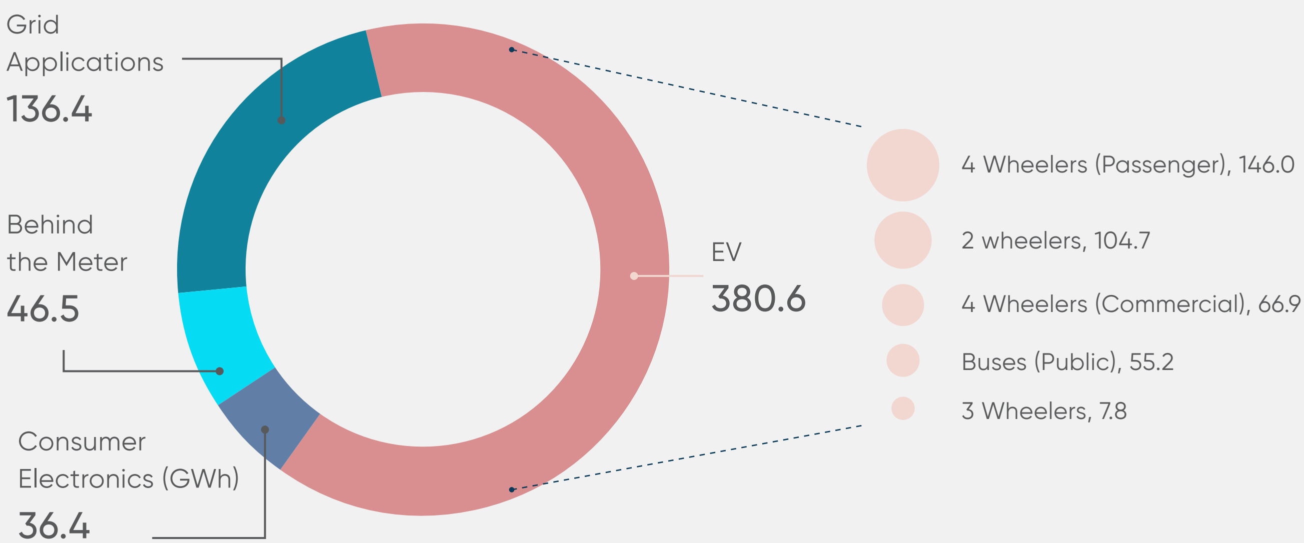
base case, conservative and optimistic

Demand

annual and cumulative based on above projections

Based on our analysis, the total cumulative potential for battery storage in India will be 600 GWh by 2030 – considering a base case scenario and with segments like EVs and consumer electronics ('behind the meter', BTM) projected to be major demand drivers for the adoption of battery storage in India.

Cumulative potential of advanced chemistry cells in India, 2021–2030 (GWh) (base case)

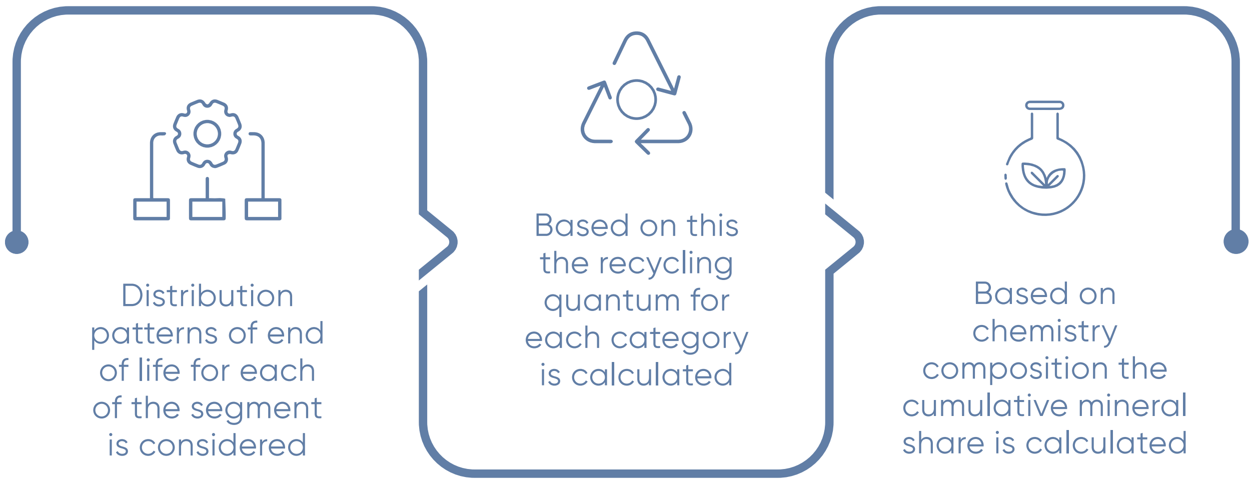


The immense battery storage potential of India has been dominated by the exponential rise of **EVs**. Domestic battery production to supply the transition to EVs represents significant market potential for the Indian economy. The demand for battery technologies is expected to increase over the next decade on the back of growing sales of EVs at a compound annual growth rate (CAGR) of ~50% over FY21–30, with two-wheelers garnering the maximum share. The total cumulative demand of batteries for electric mobility is estimated to be ~381 GWh by 2030.

Grid-scale RE penetration: The Government of India is targeting to add ~500 GW of renewable energy capacity by 2030 and as such a huge scale of RE integration with the grid is required. However, the higher the penetration of RE, the higher the need for flexibility. One flexibility option is provided by battery energy storage. Energy storage can provide the critical energy-shifting service reducing RE source curtailment.

BTM applications of batteries are connected through electricity meters for commercial, industrial and residential customers. With the reduction in the battery storage cost, new business models will emerge in BTM applications. For example, battery storage can be provided under 'energy as a service" in BTM applications for commercial and industrial consumers. This solution will be economically viable in the states that have high time-of-day tariffs during evening or night hours.

To conclude Chapter 3, the battery recycling market, and the recoverable cumulative mineral share over the next decade, is projected using a three-step approach. A number of assumptions are made with regard to battery module weight, application-wise battery replacement rates and battery damage during transportation and construction; based on these scenarios, the chapter calculates the battery recycling quantum in GWh terms both annually and cumulatively till the year 2030.

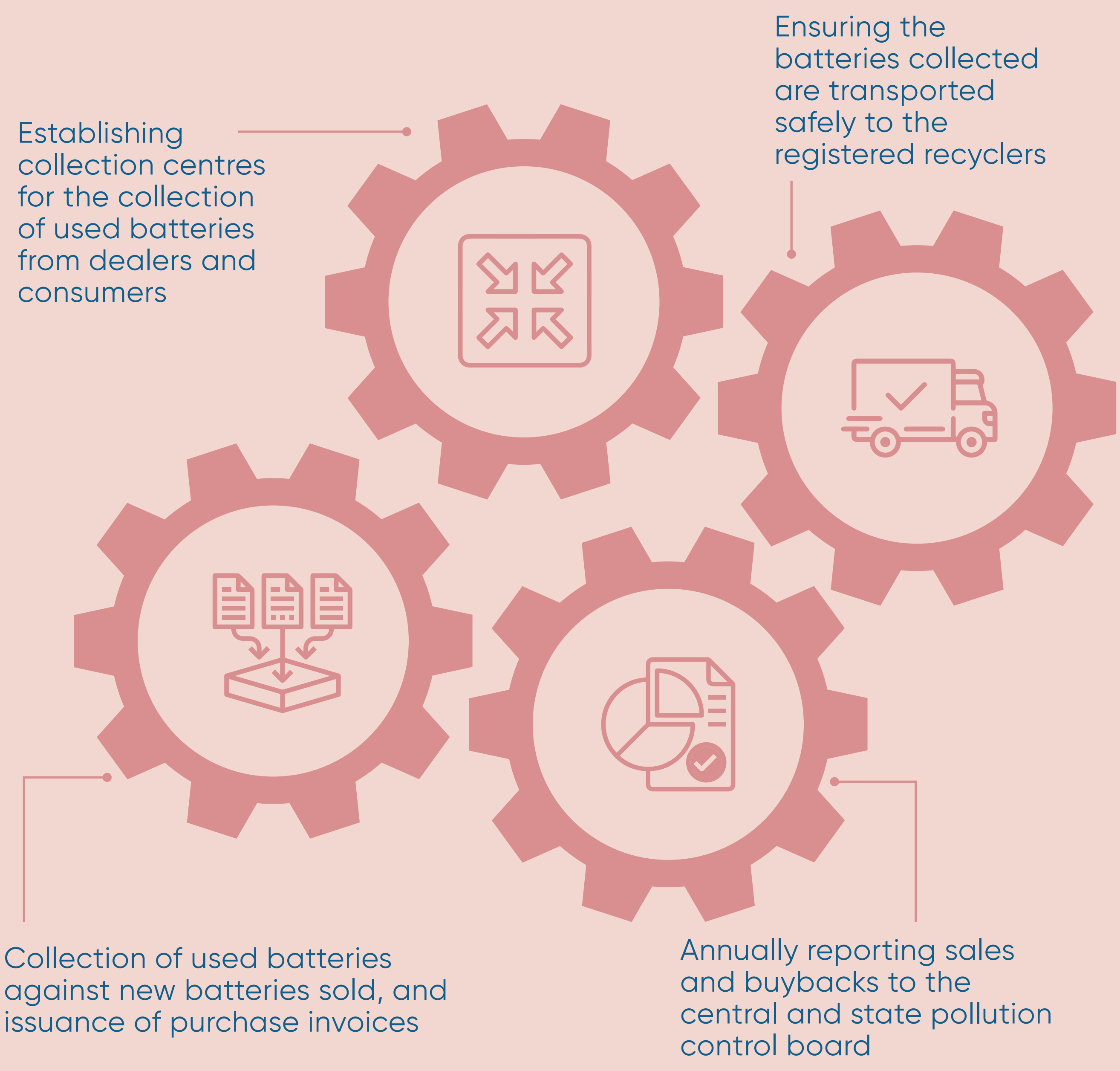


It is estimated that the cumulative potential of LIBs in India from 2021 to 2030 across all segments will be around 600 GWh (base case) and the recycling volume coming from the deployment of these batteries will be 165 GWh by 2030. Out of this, almost 106 GWh will be from the EV segment alone.

Chapter 4 explores in detail the need for battery recycling along with reuse/recycle technologies to understand the current landscape and the technologies best suited to India. LIB recycling is a multi-stage effort, and the number of processes involved is dependent on the selected recycling route, the input feedstock and the quality of the expected output product. A qualitative multi-criteria analysis is carried to compare competing recycling technologies across 5 parameters and 17 sub-parameters. The parameters include applicability of technology to different size and chemistry of battery; technology performance; market; economic viability; and process dependency and risks. In addition to this, the chapter scans the patent database to understand efforts undertaken by Indian scientists and companies.

The chapter then presents an economic assessment of battery recycling along with the key battery recycling players in India as well as globally. Indian battery recycling players seem to be following a similar strategy to those from China and South Korea – that is, focusing on hydrometallurgy. Finally, to conclude this chapter, different reuse/recycle pathways are explored, and their characteristics discussed. A comparative study is carried out of LAB and LIB recycling pathways and key learnings are identified. These include how local battery manufacturing can aid in battery recycling and the role of enforcement of regulations to avoid unsafe recycling that is hazardous to the environment, public health and worker safety.

Chapter 5 looks at the policies and regulations involved in battery recycling in India. Acknowledging the importance of battery recycling, India has come up with a few policies, including the Batteries (Management and Handling) Rules (BMHR) 2001 (applicable only to lead-acid batteries), E-Waste (Management and Handling) Rules 2011, 2016, an amended version in 2018 and finally, the draft Battery Waste Management Rules 2020. This chapter describes in detail the responsibilities of manufacturers and dealers under the draft rules, some of which can be summed up as follows:



Chapter 5 then discusses the relevance of battery regulations in India by highlighting how battery recycling will encourage the development of new business models such as trading the recycled raw materials in the exchange market or reusing aged batteries in other applications. The rapid increase in the usage of batteries in EVs and energy storage applications has generated a need to establish methods for the sustainable handling of these batteries at their end-of-life. To establish a successful domestic battery manufacturing industry, India needs to evaluate the lifecycle impact of lithium-ion batteries. This includes cultivating opportunities to implement circular economic principles for lithium-ion battery stakeholders by establishing a policy framework that promotes proper end-of-life management. Furthermore, India needs a clear and strict policy framework with strong monitoring and enforcement capabilities to prevent growth of informal markets, as well as encourage heavy investments in recycling infrastructure.

Below are some key recommendations related to addressing bottlenecks in the effective implementation of battery waste management rules and promoting battery recycling in India.

Demand Measures

- Disposal of batteries in landfills should be made illegal so that batteries can undergo proper disposal through recyclers
- A separate collection agency should be established to help in streamlining both the collection and the recycling of batteries

Policy Support

- There should be provision of a separate licence for handling lithium ion batteries separate from electronic waste to reduce the minimum requirement for entry in recycling
- The Central Pollution Control Board must explicitly state the responsibilities of corporates and the repercussions for their inability to achieve stated responsibilities

Incentivising

- A Deposit Refund System should be implemented to provide incentives to customers to return batteries
- Incentives for manufacturers to meet recycling regulations, such as green taxes, should be provided in order to enforce extended producer responsibility, thereby attaining a higher recycling rate

Financing

- Supporting start-ups in developing the recycling of battery products is a must to ensure long-term growth in energy storage
- Several research organisations can be funded to come up with commercially viable recycling processes with high recovery rates

List of abbreviations

AAS	Atomic Absorption Spectrophotometers
ACC	Advanced Chemistry Cell
AGM	Absorbent Glass Mat
Al-air	Aluminium Air
AMD	Atomic Minerals Directorate for Exploration and Research
ASSB	All Solid-State Battery
BaaS	Battery-as-a-Service
BAU	Business-as-Usual
BMHR	Batteries (Management and Handling) Rules
BMO	Bank of Montreal
BMS	Battery Management System
BMW	Bayerische Motoren Werke AG
BTM	Behind the Meter
BYD	Build Your Dreams
CAGR	Compound Annual Growth Rate
CEA	Consumer Electronics Application
COP	Conference of the Parties
CPCB	Central Pollution Control Board
CSIR	Council of Scientific and Industrial Research
DAE	Department of Atomic Energy
DC	Direct Current
DMC	Dimethyl Carbonate
DRC	Democratic Republic of Congo
DRS	Deposit Refund System
E2W	Electric Two-Wheeler
E3W	Electric Three-Wheeler
E4W	Electric Four-Wheeler
EC	Ethylene Carbonate
EDX	Energy Dispersive X-Ray Analysis
EOL	End of Life
EPR	Extended Producer Responsibility
EV	Electric Vehicle
FCDO	Foreign, Commonwealth & Development Office
FER	First Examination Report
FSP	Field Season Programme
FY	Financial Year
GEM	Green, Eco-manufacture
GGEF	Green Growth Equity Fund
GHG	Greenhouse Gas
GoI	Government of India
GSI	Geological Survey of India
ICE	Internal Combustion Engine
INR	Indian Rupee
IOT	Internet of Things
IT	Information Technology
JAC	Anhui Jianghuai Automobile
JMC	Jiangling Motors Corporation
LAB	Lead Acid Battery
LCO	Lithium Cobalt Oxide
LFP	Lithium Iron Phosphate
LG	Life's Good
Li-air	Lithium Air
LIB	Lithium Ion Battery
LiS	Lithium Sulphur
LME	London Metal Exchange
LMO	Lithium Manganese Oxide
LNO	Lithium Nickel Oxide
LTO	Lithium Titanate
MoEFCC	Ministry of Environment, Forest and Climate Change
Na-ion	Sodium Ion
NCA	Lithium Nickel Cobalt Aluminium Oxide
NiCad	Nickel-Cadmium
NiMH	Nickel Metal Hydride
NMC	Lithium Nickel Manganese Cobalt Oxide
NREL	National Renewable Energy Laboratory
OEM	Original equipment manufacturer
OPM	Oxford Policy Management
PLI	Production-Linked Incentive
PMP	Phased Manufacturing Programme

PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
RPT	Recycle Plant Technology
SA	Stationary Application
SDG	Sustainable Development Goal
SE	Solid Electrolyte
SGST	State Goods and Services Tax
SLA	Sealed Lead Acid
SLI	Starting, Lighting and Ignition
SoC	State of Charge
SoH	State of Health
SOP	Standard Operating Procedure
SPCB	State Pollution Control Board
TCF	Technical Cooperation Facility
UK	United Kingdom
UKIBC	UK India Business Council
UN	United Nations
UNFC	United Nations Framework Classification for Resources
UPS	Uninterruptible Power Supply
US	United States
UV	Ultraviolet
VRLA	Valve Regulated Lead Acid
XRD	X-Ray Powder Diffraction
Zn-air	Zinc-Air


LI-ION BATTERY
ENERGY
STORAGE

Chapter 1

Introduction to Energy Storage

Energy storage is the capture of energy produced for later use to reduce imbalances between energy demand and energy production. Battery energy storage has become prominent, with the use of rechargeable batteries in consumer electronic applications like mobile phones, laptops, tablets, etc. and automobile applications like starting, lighting and ignition (SLI) batteries.[1]

With commitments from countries all over the world to reducing greenhouse gas (GHG) emissions and attaining net zero, and as the world is moving the use of fossil fuels to renewable energy (RE) sources in the electricity and transportation sectors (which currently account for about 40% of global GHG emissions), the application of battery energy storage is starting to become popular in these sectors as well.

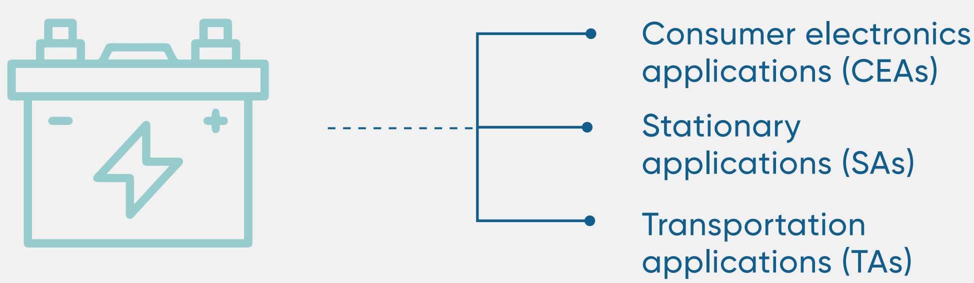
For electricity grids to operate efficiently, supply and demand must always be balanced. If one source generates less, this has to be balanced with a reduction in consumption. The same applies if a source of energy produces more: consumption has to increase. But with intermittent RE sources in the grid, the load has to be more flexible. It needs to absorb wind energy generated at night and solar energy at noon, and to reduce consumption during cloudy days, which is not practically possible. To overcome this challenge, excess energy needs to be stored for use when needed.

In addition to SLI batteries, big onboard (traction) batteries[2] are needed for EVs, which use electrical energy to run their motors. These batteries are required to store and provide energy when needed. As such, the energy storage is the need of the hour to support the penetration of RE and EVs.

Apart from decarbonising the transportation and electricity sectors, batteries also contribute directly and indirectly to achieving the UN Sustainable Development Goals (SDGs). They enable decentralised and off-grid energy solutions, help people access energy and can improve productivity, health care and livelihoods.

1.1. Overview of energy storage and applications

Based on the application, battery energy storage can be classified into three categories:



[1] SLI batteries are the rechargeable batteries used in automobiles for powering their three most important features, the starter motor used to crank or start the engine, the car's lighting and the ignition spark plug.
[2] Traction batteries are rechargeable batteries used for supplying energy to electric motors responsible for producing the required traction in an electric vehicle (EV).

CEAs include the batteries used in consumer electronics like mobile phones, tablets, laptops, cameras, etc. These rechargeable batteries are of a smaller size.

SAs include the batteries used for commercial and industrial applications like grid-connected battery energy storage for renewable integration; energy storage for telecom and data centres; and industrial logistics like forklifts, medical devices and power tools. Table 1 presents the different stationary applications.

Table 1: Stationary applications

Application sector	Application	Application description
Grid-level	Ancillary services	Provision and absorption of short bursts of power to maintain supply and demand and thus the frequency of the grid; frequency regulation and reserves.
	Distribution utility energy storage system integration	Energy storage system installed by distribution utilities to provide support to distribution networks with penetration of distributed RE sources.
	RE integration	Uptake driven by increasing system flexibility needs. Energy storage is charged during low prices and surplus supply and discharged to meet demand. Batteries can be charged from surplus RE or from assets that, along with the battery, become dispatchable.
	Transmission Deferral	Energy storage system installed at transmission network side of the electrical system to avoid augmentation of transmission infrastructure.
Behind-the-meter	Commercial and industrial energy storage for solar rooftops	Energy storage that is used to increase the rate of self- consumption of a photovoltaic system by a commercial or industrial customer.
	Uninterruptible power source	Use of batteries for uninterruptible power.
	Telecom backup power	Telecommunications towers require an uninterruptible power source and backup power and are a significant demand in the stationary sector.
	Rural electrification	Rural electrification applications like solar streetlights, solar home lighting systems.

TAs include batteries for SLI application and onboard batteries for e-mobility applications. Table 2 presents the different applications for energy storage in transportation.

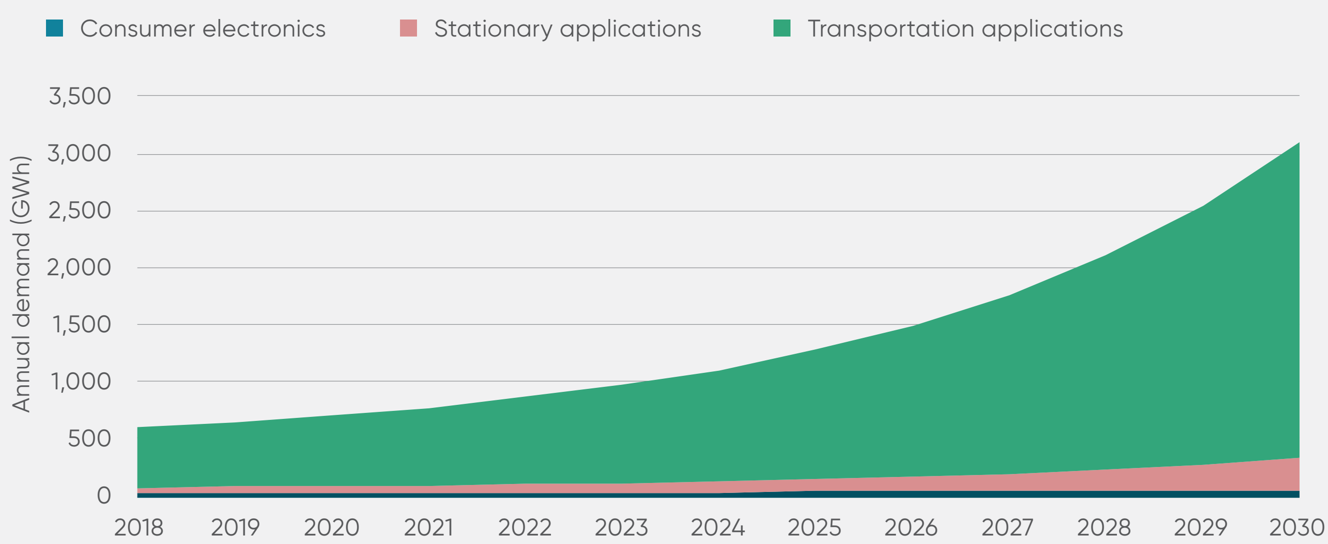
Table 2: Transportation applications

Application sector	Application
e-mobility – battery storage	Battery EV (light-duty, medium-duty and heavy-duty)
	Hybrid EV
	Plug-in hybrid EV
SLI – starting, lighting and ignition	Batteries in cars, trucks, bikes and other internal combustion motorised vehicles

1.2. Global scenario

Between 2010 and 2020, the global demand for batteries grew at a compound annual growth rate (CAGR) of 25% to reach an annual demand of about 730 GWh.[3] By 2030, the demand for batteries is expected to grow fourfold to reach an annual rate of about 3,100 GWh. This shows a growth of 16% CAGR through 2020–2030. The electrification of transportation and battery energy storage in electricity grids are expected to be the key drivers in the growth of battery demand.

Figure 1: Annual demand in the global energy storage market, 2018–2030

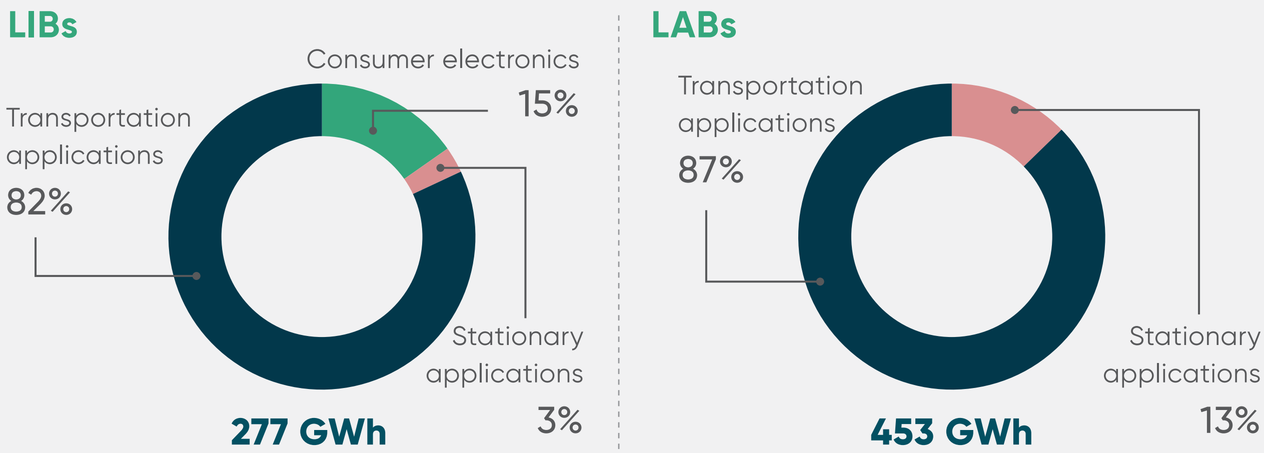


Source: WEF (2019) A Vision for a Sustainable Battery Value Chain in 2030; Authors' analysis.

[3] WEF (2019) A Vision for a Sustainable Battery Value Chain in 2030: Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation.

Globally, among the various battery technologies, lead acid batteries (LABs) and lithium ion batteries (LIBs) are the primary technologies for CEAs, SAs and TAs. Other battery technologies include nickel cadmium, nickel metal hydride, redox flow batteries, etc. In 2020, the annual demand for LABs and LIBs was about 453 GWh and 277 GWh, respectively.

Figure 2: Breakdown of LAB and LIB market by application, 2020



Source: WEF (2019) A Vision for a Sustainable Battery Value Chain in 2030; Authors' analysis.

Globally, transportation applications lead the LAB market with a close to 87% share. LABs are also prominent around the world for applications like telecom backup power and home uninterruptible power supply (UPS), which account for the remaining 13% of LAB sales.

In the early 1990s, Moli and Sony used carbon materials with a graphite structure to replace metal lithium anodes and used transition metal composite oxides such as $LiCoO_2$ as cathode.[4] This led to the commercialisation of LIBs. After commercialisation, LIBs were used widely for CEAs. In 2020, consumer electronics had an estimated 15% share in the LIB market.[5]

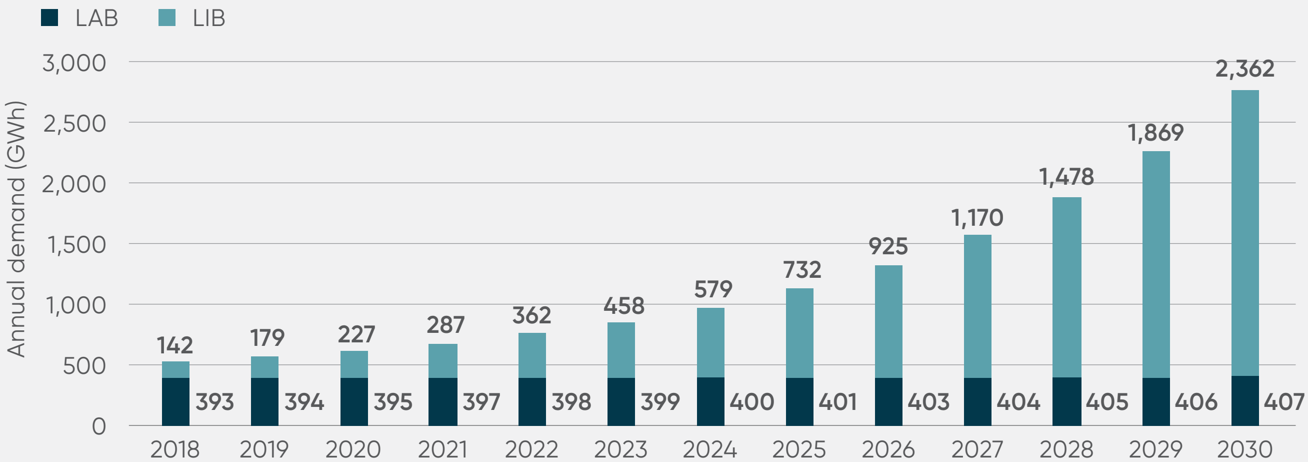
With growing innovation around battery chemistries and falling costs (a decline in price by 70% between 2010 and 2016[6]) in recent years, most analysts around the world expect LIBs to capture the majority of energy storage growth in all markets by the next decade, with the majority of deployments in stationary storage and transportation. TAs dominate the LIB market and are also the fastest-growing segment, with just ~4% of automotive sales[7] consuming an estimated 82% of LIBs in 2020.

[4] Zhou, L.F., Yang, D., Du, T., Gong, H. and Luo, W.B. (2020) The Current Process for the Recycling of Spent Lithium Ion Batteries. Frontiers in Chemistry, 3 December.
[5] WEF (2019) A Vision for a Sustainable Battery Value Chain in 2030; Authors' analysis.
[6] Bowen, T., Chernyakhovskiy, I. and Denholm, P. (2019) Grid-Scale Battery Storage: Frequently Asked Questions.
[7] Walton, R. (2021) Global EV Sales Rise 80% in 2021 as Automakers Including Ford, GM Commit to Zero Emissions: BNEF. Utility Dive, 12 November.

1.2.1. Transportation applications

In transport energy storage, SLI applications using LABs dominate annual demand for batteries, with about a 60% share in 2020. They are expected to grow slowly through 2030, following global vehicle sales. The expected annual growth rate for the period 2020–2030 is 0.3%. As EVs are expected to grow fast, on-board mobility storage deployments will likely exceed SLI for the first time in 2023.[8] Overall, TA demand is expected to grow at 26% CAGR through 2020–2030. LIBs dominate on-board mobility storage.

Figure 3: Annual demand in the global TA energy storage market, 2018–2030



Source: WEF (2019) A Vision for a Sustainable Battery Value Chain in 2030; Authors' analysis.

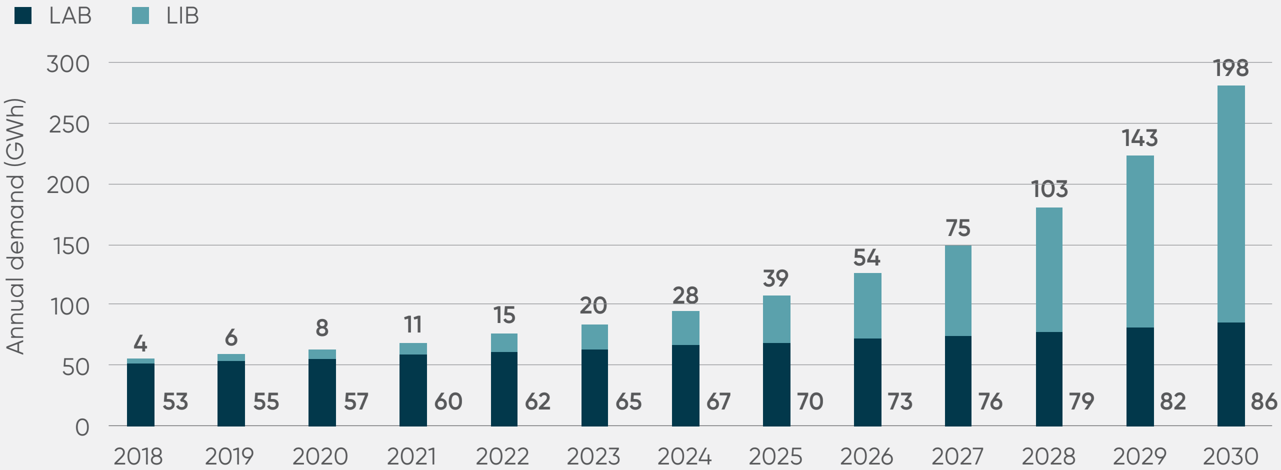
1.2.2. Stationary applications

In 2020, annual demand for SAs was about 65 GWh; this is projected to reach to about 280 GWh by 2030. Currently, industrial applications (e.g. forklifts) lead the demand for stationary energy storage. This is followed by UPS, telecom applications and data centres.[9] The industrial applications market is expected to grow at 8% CAGR through 2019–2030, while UPS and data centres will grow at 4% CAGR and telecom applications at 2% CAGR. Commercial and industrial applications are currently dominated by LABs.

However, by 2030 grid-level storage is expected to have a higher share in SAs. In 2020, the annual LIB demand for stationary energy storage was about 8 GWh; it is projected to increase to almost 200 GWh by 2030 at a CAGR of about 38%.[10] Grid-connected energy storage would be dominated by LIBs.

[8] U.S. Department of Energy (2020) Energy Storage Grand Challenge: Energy Storage Market Report.
[9] U.S. Department of Energy (2020) Energy Storage Grand Challenge
[10] WEF (2019) A Vision for a Sustainable Battery Value Chain in 2030.

Figure 4: Annual demand in the global stationary application energy storage market, 2018–2030



Source: WEF (2019) A Vision for a Sustainable Battery Value Chain in 2030; Authors' analysis.

1.3. Indian scenario

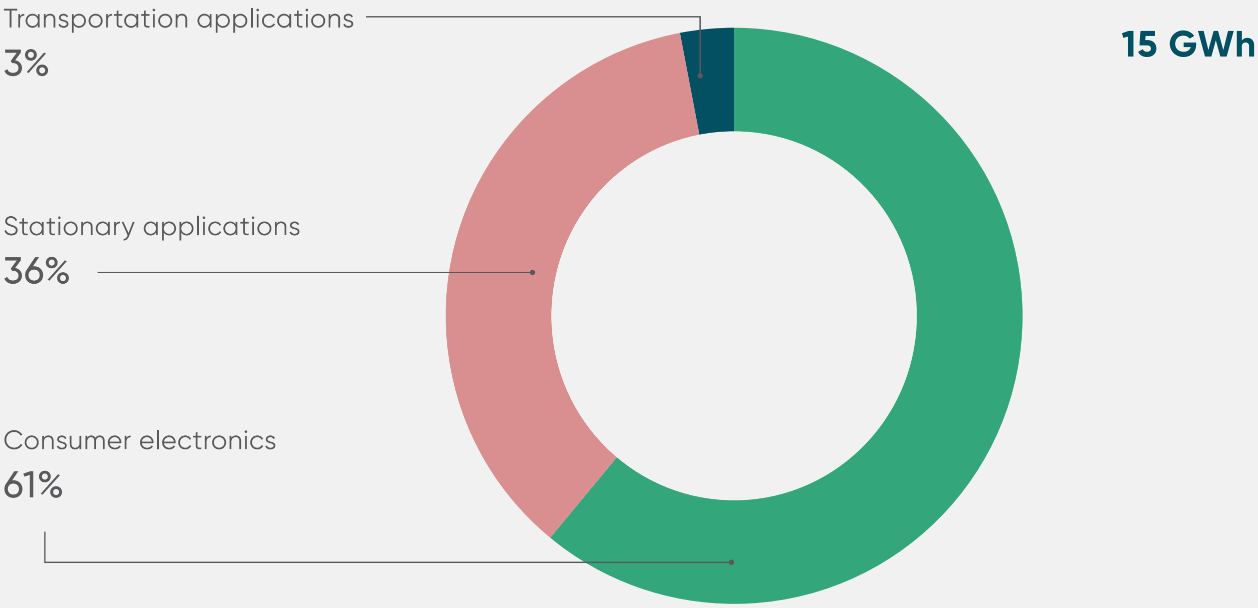
In its National Statement at the Conference of the Parties (COP) 26, the Hon. Prime Minister of India announced the 'Panchamrit', or its five commitments on climate change. The five commitments include:

1. Non-fossil fuel-based generation capacity of 500 GW by 2030
2. 50% of the country's energy requirement met from RE by 2030
3. Reduced total projected carbon emissions by 1 billion tonnes by 2030
4. Carbon intensity of the economy reduced to less than 45% by 2030
5. Country carbon-neutral and to achieve net zero emissions by 2070

In achieving the ambitious commitments, RE and transport electrification (EVs) will play an important role. To support the growth in these two markets, battery storage will also play a critical role. The growth in battery storage applications will result in the growth in LIBs and other emerging advanced chemistry cells (ACCs).

In India, the estimated cumulative stock of LIBs in 2020 was about 15 GWh. Among these, SAs had a 36% share with an estimated 5.39 GWh of deployments, TAs a 3% share with an estimated 0.45 GWh of deployments and CEAs a 61% share with an estimated 9.13 GWh of deployments.

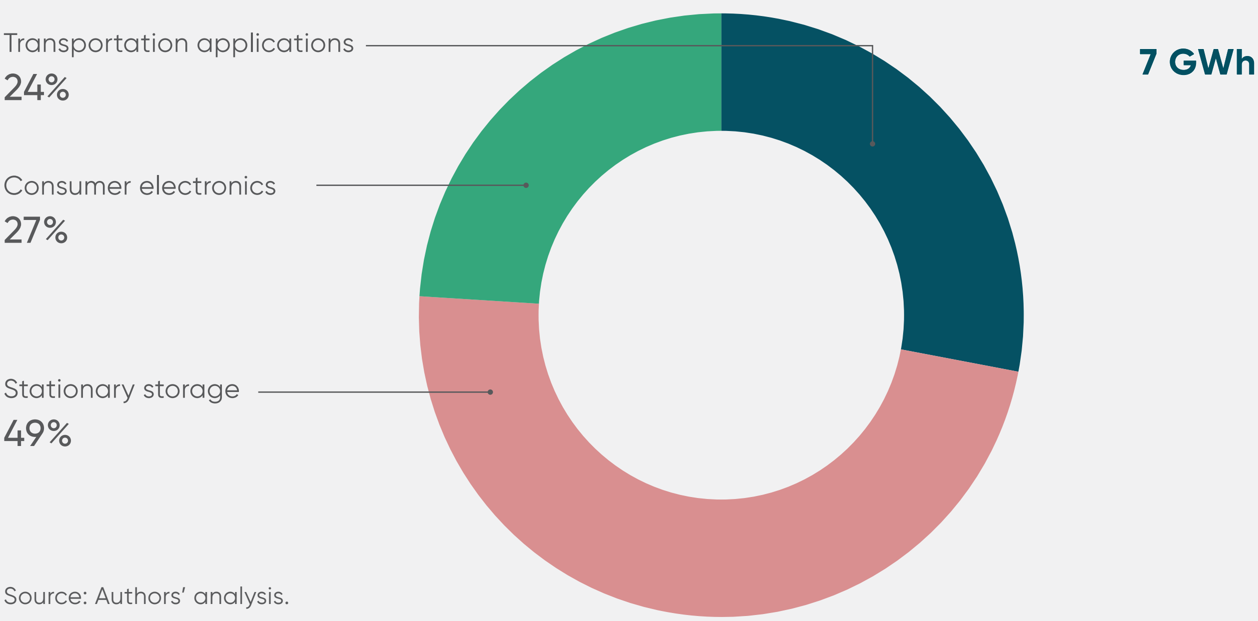
Figure 5: Cumulative stock of LIBs in India, 2020 (GWh)



Source: Authors' analysis.

For the year 2021, estimated annual demand for LIBs in the country was about 7 GWh. SAs and TAs were estimated to have 64% and 23%, respectively, with annual demand of 3.4 GWh and 1.66 GWh, respectively. CEAs are estimated to have a 27% share, with 1.9 GWh.

Figure 6: Estimated annual demand for LIBs in India, 2021 (GWh)

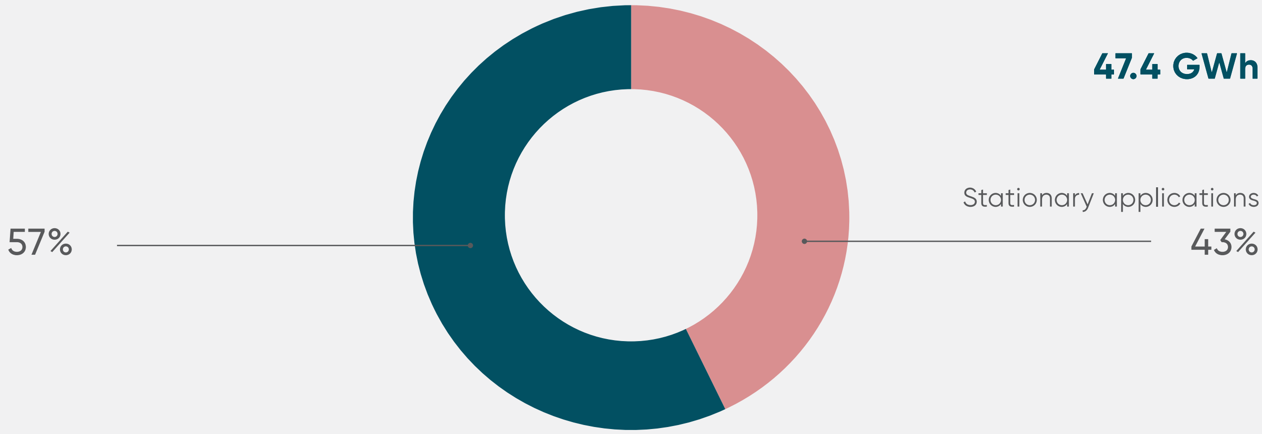


Source: Authors' analysis.

Similar to the global scenario, the LAB market currently leads the energy storage market in India as well. In 2020, the estimated Indian LAB market was about US$5.21 billion.[11] At a rate of US$110/ kWh,[12] the annual LAB market was around 47.4 GWh. The LAB market was led by the auto replacement market, with about a 35% share.

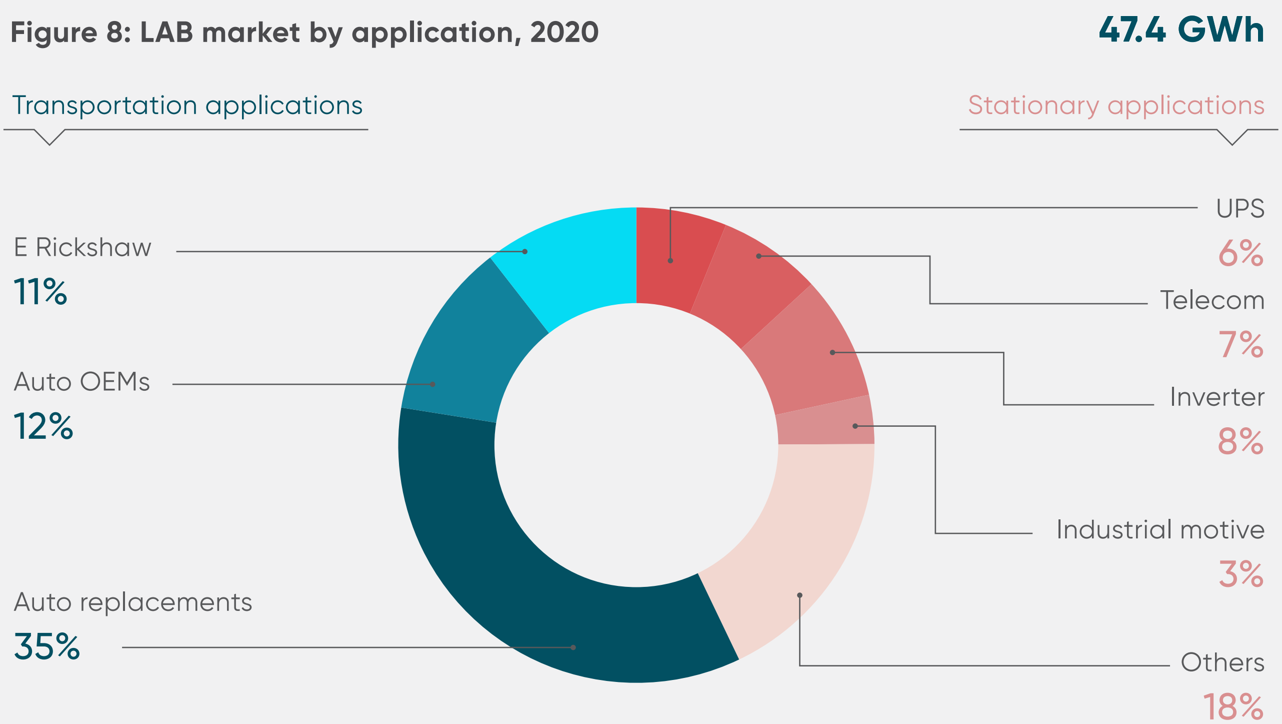
TAs and SAs have a 57% and 43% share, with 27 GWh and 20 GWh, respectively. Figure 8 presents the breakdown of the LAB market by applications.

Figure 7: Annual demand for LABs in India, 2020 (GWh)



Source: Motilal Oswal (2018), Batteries: Huge opportunities, but challenges too.

Figure 8: LAB market by application, 2020



Source: Motilal Oswal (2018), Batteries: Huge opportunities, but challenges too.

[11] Motilal Oswal (2018), Batteries: Huge opportunities, but challenges too
[12] In 2020, the LAB market in terms of value was at US$49.93 billion and in terms of volume it was at 453 GWh.

Chapter 2

Energy storage technologies and applications

2.1. Overview of battery storage technologies

As mentioned in Chapter 1, LABs are currently used widely globally. These batteries are technologically mature. They have been used since 1860 but growth in the consumer electronics market and demand for smaller batteries has led to the popularisation of nickel-cadmium (NiCad) and nickel metal hydride (NiMH) batteries. Currently, these batteries have a very small market share and are used in niche applications like cameras, some laptops and other consumer electronics. These have also been used in first-generation electric and hybrid vehicles. However commercialization of LIBs, their versatility to adapt for application in different fields and higher energy densities has made LIBs very popular. As a result of their compatibility in large-scale applications like EVs and grid-connected battery storage, these batteries are expected to come to dominate in the battery market globally.

In addition to LIBs, several other battery chemistries with comparable characteristics are also emerging. Promising batteries include all solid-state, sodium-ion, lithium sulphur, zinc air batteries and lithium air batteries.

This section covers different battery chemistries, from matured LABs to emerging new chemistries with a focus on different LIB chemistries.

2.1.1. Lead acid batteries

LABs have been in use for stationary applications since their discovery. As the automobile sector has grown, these batteries have also been widely used for SLI applications. The use of LABs is popular because of their mature technology, low cost and ruggedness compared with other battery technologies.

A typical LAB consists of a negative electrode or anode made of spongy or porous lead to facilitate the formation and dissolution of lead. The positive electrode or cathode consists of lead oxide. These electrodes are immersed in an electrolytic solution of sulfuric acid and water. To separate the electrodes, a chemically permeable membrane called a separator is used. This separator provides both chemical and electrical isolation between the electrodes. LABs store energy by means of a reversible chemical reaction, $PbO_2 + Pb + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_2O$. The full discharge theoretically results in both electrodes being covered with lead sulphate and water.[13]

This use of a wet electrolyte in LABs means these are generally categorised as wet flooded batteries that need frequent maintenance. These batteries also confront challenges in terms of transportation and are classified as a 'dangerous good'.[14] Low depth of discharge of these batteries also

[13] C.B.Honsberg and S.G.Bowden, "Photovoltaics Education Website," www.pveducation.org, 2019. https://www.pveducation.org/pvcdrom/batteries/lead-acid-batteries
[14] Concordia University (2016), Lead acid batteries https://www.concordia.ca/content/dam/concordia/services/safety/docs/EHS-DOC-146_LeadAcidBatteries.pdf

means these batteries are not very suitable for certain applications like grid-connected storage. A better version of these batteries, addressing these challenges, is represented by sealed lead acid (SLA) batteries or valve regulated lead acid (VRLA) batteries. In these variants of LABs, the wet electrolyte is replaced by a gel type or wet electrolyte trapped in a separator, which makes these batteries low maintenance and easy to transport and install. The different variants of VRLA batteries are absorbent glass mat (AGM) and gel batteries.

However, LABs are heavy and bulky. They also do not cycle well to meet some of the demanding new application needs. As the use of consumer electronics has increased, battery technologies like NiCad and NiMH batteries have been discovered; these are lighter and have more life with a deep cycle.

2.1.2. Nickel-cadmium batteries

NiCad batteries have become popular because of their availability in all sizes and the fact that they can be moved around easily. The nickel in the battery acts as the positive electrode while the cadmium is the negative electrode. These electrodes are separated by a layer made up of KOH or NaOH. The chemical reaction involved in the battery is $2NiOOH + Cd + 2H_2O \leftrightarrow 2Ni(OH)_2 + Cd(OH)_2$.

Like flooded LABs, large-sized NiCad batteries have to be maintained periodically. As such, they are the battery of choice for smaller applications like cameras and other portable devices.

However, the use of these batteries has been restricted because of environmental concerns related to cadmium. Many countries, including the US, have banned cadmium recycling. In India, use of cadmium in electrical and electronic appliances is restricted under the Reduction of Hazardous Substances (RoHS) provisions of the E-Waste Management Rules 2011 and the 2016 amendment.[15]

2.1.3. Nickel metal hydride batteries

To address the issues arising from the environmental effects of cadmium, NiMH batteries have become an alternative solution for portable applications. These batteries have a similar construction to that of NiCad except the Cd anode is replaced by the hydrogen absorbing metal alloys (mainly the Ti and Ni compounds such as $Ti_2Ni+TiNi$).

The NiMH batteries have been widely used in consumer electronics. In addition, several first-generation hybrid and electric vehicle models have used NiMH batteries.

NiMH battery technology have not been considered for large stationary applications because of the high cost of nickel. NiMH batteries also have a high self-discharge rate and generally take a long time to charge compared with LIBs, which makes them unsuitable for modern EVs.[16]

[15] Implementation Guidelines for E-Waste (Management) Rules, 2016

[16] Moorthi, M. (n.d.) Lithium Titanate Based Batteries for High Rate and High Cycle Life Applications.

2.1.4. Lithium-ion batteries

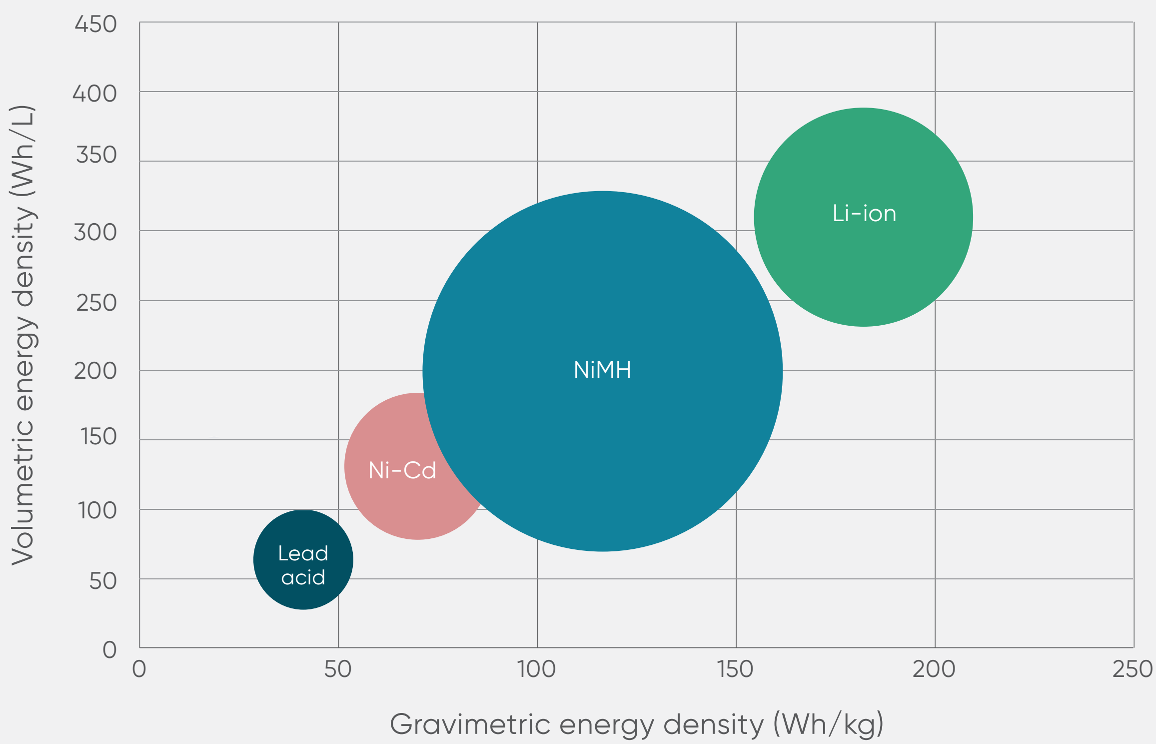
Compared with LABs, NiCad and NiMH batteries, LIBs are proven to be superior, with higher volumetric and gravimetric energy densities. LIBs batteries are lighter and smaller compared with same capacity batteries of other battery chemistries. LIBs do not have a defined unique chemistry like LABs or NiCad and NiMH batteries. They have several different possible combinations, providing several possibilities for a variety of application requirements.

Like any other battery chemistries, a LIB cell has three main components: a positive electrode (cathode), a negative electrode (anode) and a separator. Various cathode and anode materials provide flexibility to design batteries for specific application needs.

The battery's electrical and performance characteristics, including voltage, capacity, energy density, rate and thermal capability, and cycle life, will change under different options for materials for the anode, cathode, electrolyte and separator.

The different LIB chemistries on the market based on cathode chemistries with graphite as an anode include lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminium oxide (NCA) and lithium iron phosphate (LFP). A LIB variant in which the graphite anode is replaced with lithium titanate oxide (LTO) has also been developed that uses either an NMC, an LMO or an LFP cathode.[17]

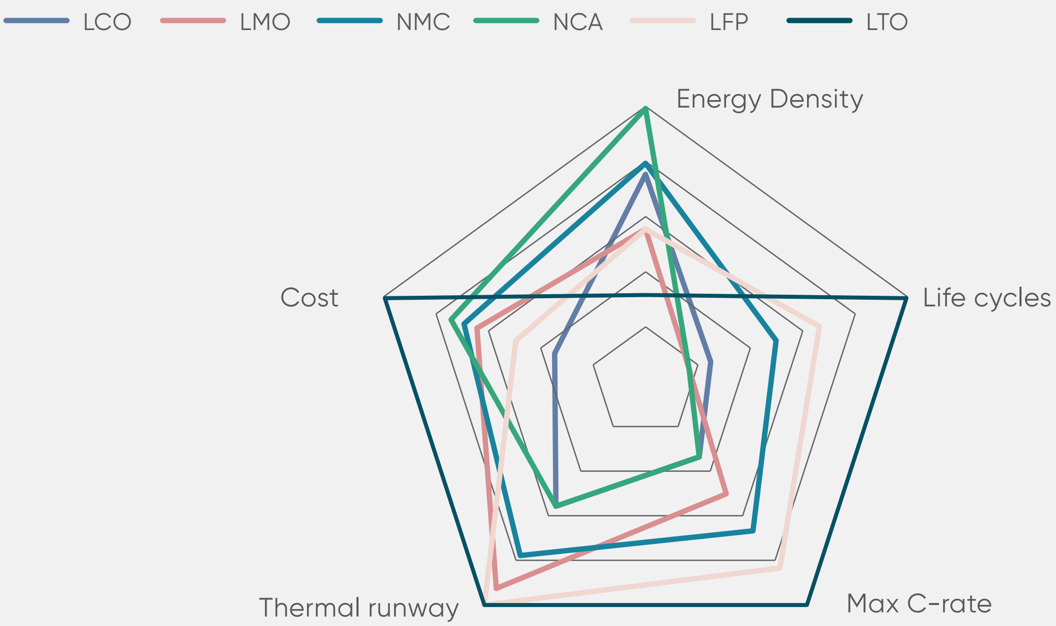
Figure 9: Volumetric and gravimetric energy densities of different batteries



Source: Authors' analysis, multiple sources

[17] NEI Corporation, Lithium Titanate Based Batteries for High Rate and High Cycle Life Applications

Figure 10: Radar map of different LIB chemistries



Source: Authors' analysis, multiple sources

All the above LIB chemistries have their own advantages and disadvantages, which are covered in more detail subsequently in this section. The radar map in Figure 10 shows a comparison of different LIB chemistries against key specifications of batteries such as energy density, life cycle, max allowable C-rate, thermal runaway and cost. These key parameters decide the suitability of the batteries to various applications.

Table 3 presents the trends of these parameters in different LIB chemistries.

Table 3: Battery specification of different LIB chemistries

Battery specification	Trend
Energy density	NCA > NMC > LCO > LMO > LFP > LTO
Life cycles	LTO > LFP > NMC > LCO > LMO > NCA
Max C-rate	LTO > LFP > NMC > LMO > NCA > LCO
Thermal runaway	LTO > LFP > LMO > NMC > NCA > LCO
Cost	LCO* < LFP < LMO < NMC < NCA < LTO

*LCO of smaller capacities for consumer electronics application.

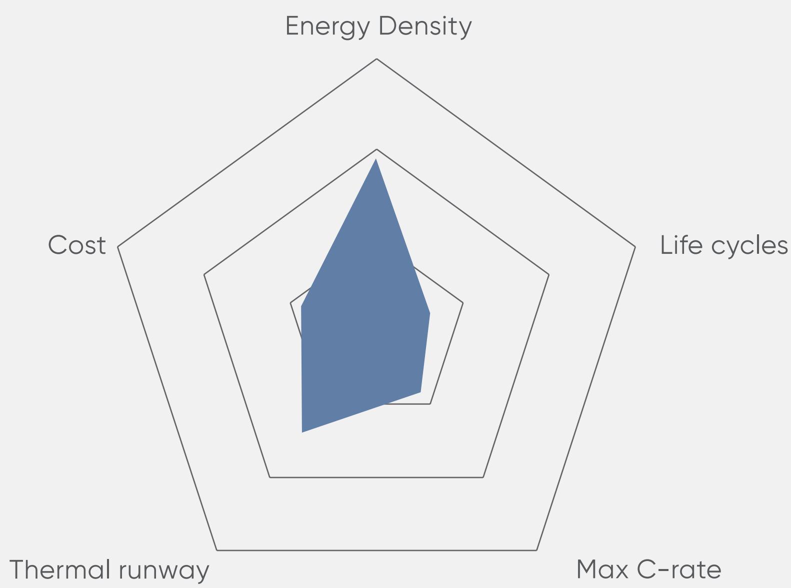
Source: BMO (2018), The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See

Lithium cobalt oxide

LCO, discovered in the 1980s, was the first LIB to be commercialised. Some of its specs, such as high volumetric energy density, great charge discharge cycles and reasonably high gravimetric energy density, made this the best choice for consumer electronics like smartphones, tablets and laptops.[18]

The high energy density of these batteries comes from the high concentration of cobalt (~60% of cell weight). The high cobalt concentration also makes LCO very unstable, with a low thermal runaway of just 150°C. **Cobalt oxides are also prone to releasing oxygen at high charging rates, generating heat and reacting violently with the electrolyte. This limits the charge and discharge rates of these batteries. This means LCO is not suitable for large-scale applications like EVs and stationary storage.**[19]

Figure 11: Characteristics of LCO batteries



Source: Authors' analysis, multiple sources

Also, as LCO contains cobalt in large quantities, the cost is comparatively high for EV application. Price volatility is also an issue for cobalt. Meanwhile, the mining of cobalt also involves environmental (e.g. deforestation) and social (e.g. child labour) concerns. Globally, most cobalt reserves (>50%) are in Democratic Republic of Congo (DRC). This poses a supply chain risk.[20]

[18] Battery University (2021), BU-205: Types of lithium-ion. https://batteryuniversity.com/article/bu-205-types-of-lithium-ion
[19] BMO (2018), The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See
[20] BMO (2018), The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See

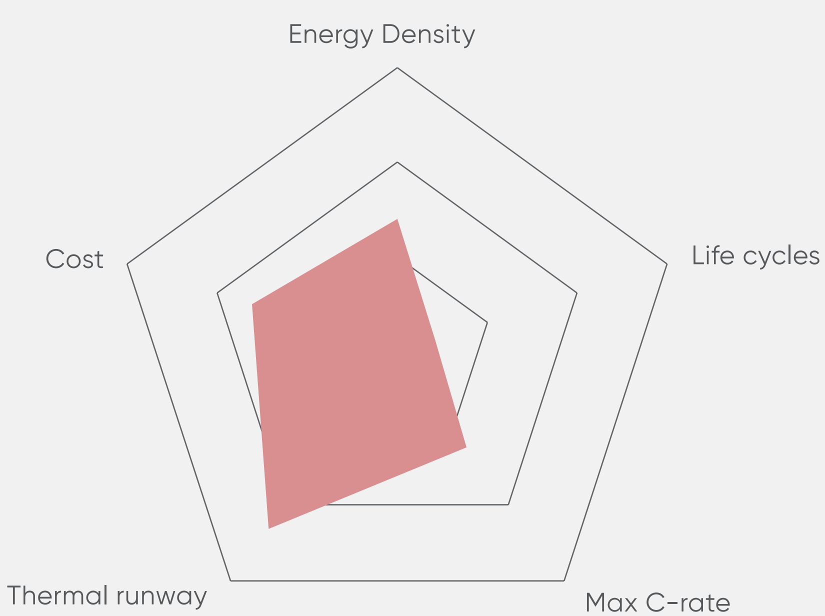
Lithium manganese oxide

LMO overcomes the major drawback of the high cost of cobalt and the instability in LCO by replacing the cobalt with manganese in the cathode chemistry. This allows LMO to be charged at a slightly higher rate. Manganese is also not as hazardous as cobalt to the environment. This makes LMO moderately safe. However, the safety of this chemistry comes at the price of reduced energy density.[21]

The key applications of LMO are medical devices and power tools. Because of the relatively lower cost, LMO has also been used in some early models of battery EVs, such as the Nissan Leaf.

Despite the advantages, LMO is being phased out or, in many cases, blended with other chemistries, because of its high self-discharge and the fact that it decays more rapidly beyond ambient conditions. The LMO cathode is susceptible to side reactions and tends to decompose at higher temperatures. This results in higher battery resistance and thus higher self-discharge. As such, LMO is not very suitable for EV applications, which involve a harsh environment with high temperatures.

Figure 12: Characteristics of LMO batteries



Source: Authors' analysis, multiple sources

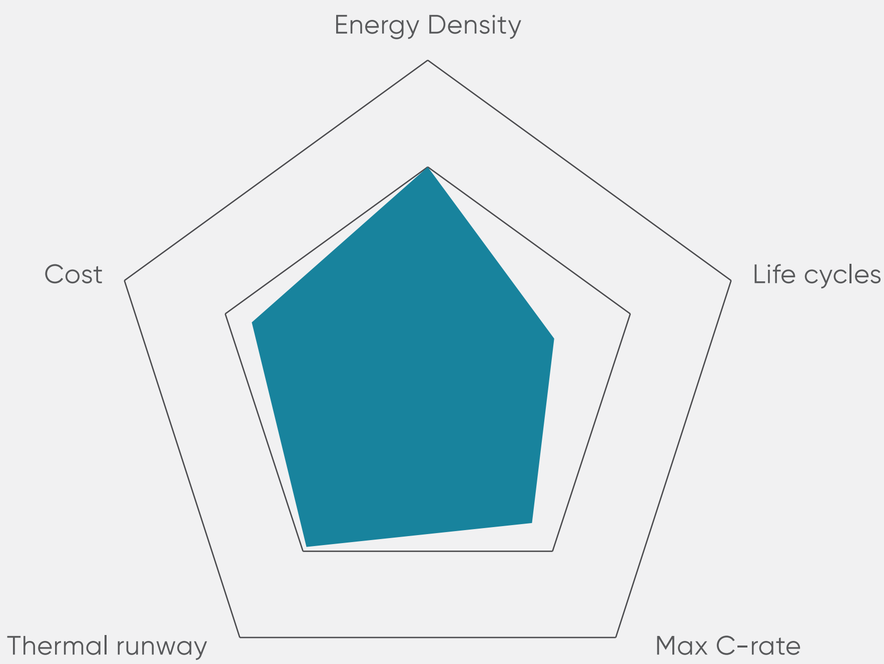
[21] Battery University (2021), BU-205: Types of lithium-ion. https://batteryuniversity.com/article/bu-205-types-of-lithium-ion

To overcome the challenges from using cobalt and manganese in the cathode, nickel was also used, which led to a new LIB chemistry, LNO. The LNO chemistry showed positive results by eliminating the overcharging issues of LCO and achieving higher energy density. But extensive research on LNO also showed that it was susceptible to destabilisation and in fact appeared to release oxygen at much lower temperatures compared with LCO. Though the use of LNO batteries was minimal, this led to the start of nickel-rich cathodes like NMC and NCA.[22]

Lithium nickel manganese cobalt oxide

The learnings on the LNO chemistry and the discovery of the potential of nickel as a stabilising agent in batteries led to research on nickel-rich chemistries using cobalt and manganese in the right proportions. The NMC chemistry represents a group of chemistries with nickel, manganese and cobalt in some proportions with a general formula of $LiNi_xMnyCo_{1-x-y}O_2$. For example, NMC111 is one such chemistry, with an equal share (33.3% each) of nickel, manganese and cobalt.[23]

Figure 13: Characteristics of NMC batteries



Source: Authors' analysis, multiple sources

[22] BMO (2018), The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See
[23] Battery University (2021), BU-205: Types of lithium-ion https://batteryuniversity.com/article/bu-205-types-of-lithium-ion

While nickel is known to increase energy density and to attain stability at higher charging rates, cobalt is known to increase energy density and manganese is known to reduce the oxygen released through the presence of both cobalt and nickel and to make the cathode safe. As such, mixing nickel (better rate capability), cobalt (higher capacity) and manganese (safety) makes NMC superior. Different NMC chemistries include NMC111, NMC433, NMC523, NMC622 and NMC811. Table 4 compares these different NMC chemistries.[24]

Table 4: Energy density and thermal runaway of different NMC chemistries

NMC chemistry	NMC111	NMC523	NMC622	NMC811
Energy density (Ah/kg)	199	205	225	270
Thermal runaway (°C)	305	295	265	240

From NMC111 to NMC 811, as the nickel proportion increases from 33% to 80%, the energy density increases while the thermal stability decreases. NMC currently is one of the preferred chemistries for EVs.

Lithium nickel cobalt aluminium oxide

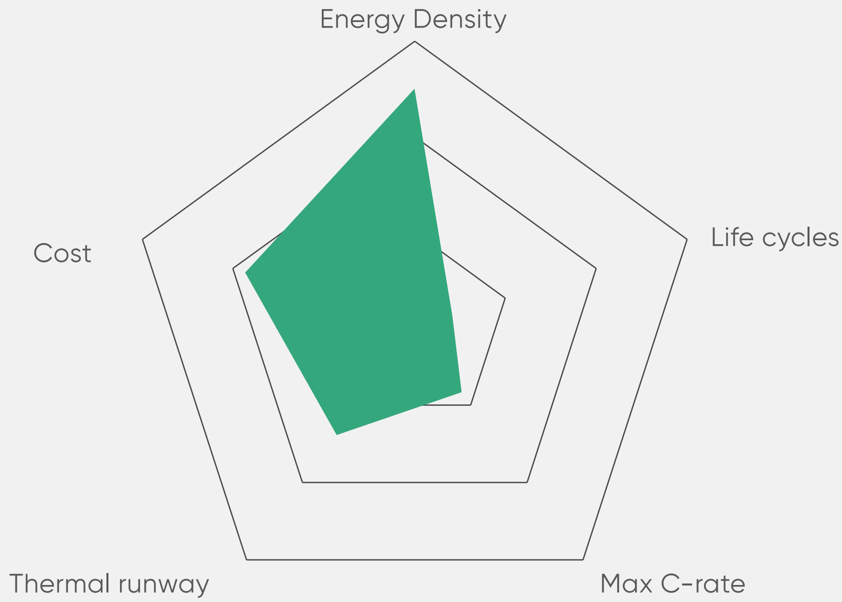
NCA is similar to NMC chemistry, with aluminium used to increase the safety of the battery chemistry instead of manganese. The general formula for these batteries is $LiNi_xCo_yAl_{1-x-y}O_2$. The typical values of x and y are 0.8 and 0.15, making these batteries nickel-rich close to NMC811[25].

As nickel content is increased and manganese is replaced with aluminium, the energy density and charging rate of these batteries increase significantly. But the risk of thermal breakdown and premature ageing of the battery also increases with the increase in the nickel concentration.

NCA batteries are particularly famous among battery original equipment manufacturers (OEMs) like Panasonic, Sony and Samsung. Because of the partnership of Panasonic with Tesla for cell production, NCA is also predominant in Tesla EVs. Apart from EVs, these batteries are also used in cordless vacuum cleaners[26].

[24] BMO (2018), The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See
[25] Battery University (2021), BU-205: Types of lithium-ion https://batteryuniversity.com/article/bu-205-types-of-lithium-ion
[26] BMO (2018), The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See

Figure 14: Characteristics of NCA batteries



Source: Authors' analysis, multiple sources

Lithium iron phosphate

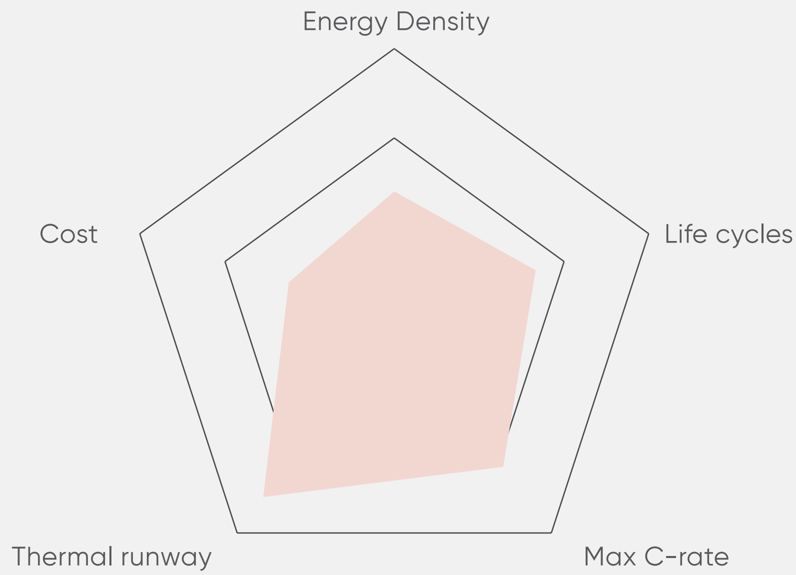
In 1990s, researchers discovered lithium phosphate as a cathode material for rechargeable lithium batteries. The li-phosphate offers good performance with low resistance.[27]

The beneficial performance traits include long cycle life, good thermal stability, high current rating, better safety and tolerance to harsh conditions. The absence of cobalt also makes LFP cheaper than other cobalt-based LIBs. As a trade-off, LFP in the absence of cobalt has a low nominal voltage and reduced energy density.

This makes these batteries a good choice for large-scale applications like stationary storage and EVs. LFP is currently used in different applications like electric cars, electric buses and electric trucks. Because of their low cost, LFP batteries are particularly suitable for SAs as well as mobility applications like electric buses and trucks where volume and weight are not a major concern.[28]

[27] Battery University (2021), BU-205: Types of lithium-ion https://batteryuniversity.com/article/bu-205-types-of-lithium-ion
[28] BMO (2018), The Lithium Ion Battery and the EV Market: The Science Behind What You Can't See

Figure 15: Characteristics of LFP batteries



Source: Authors' analysis, multiple sources

Lithium titanate

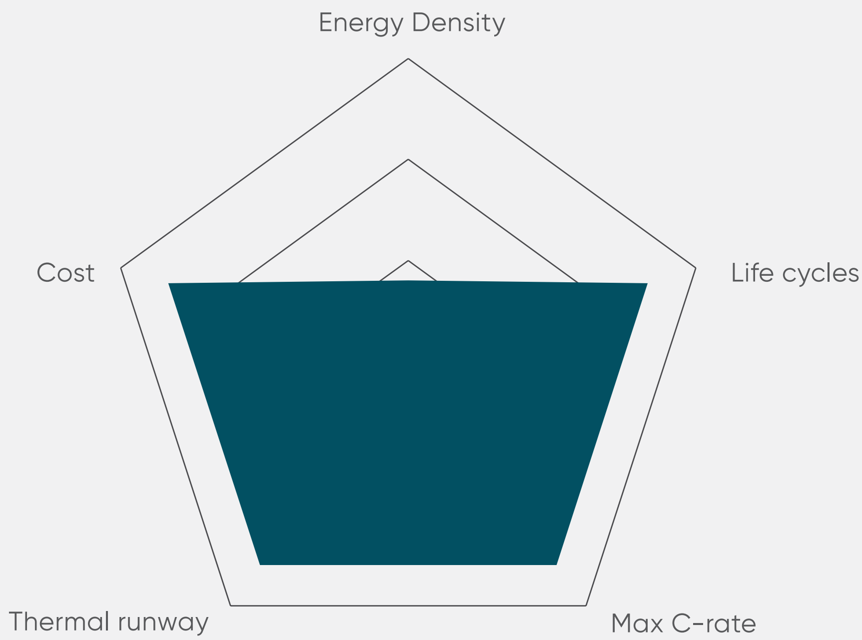
LTO is a fairly new LIB variant invented in 2008. Unlike the other LIBs mentioned, these batteries are differentiated based on the chemistry of the anode. In LTO, the graphite anode of LMO or NMC is replaced by lithium titanate (Li_2TiO_3). The cathode material is either LMO, NMC or LFP.

LTO offers advantages in terms of power and chemical stability but has lower voltage compared with LCO and LFP.

Nevertheless, the lower operating voltage brings significant advantages in terms of safety. Further, these batteries can be charged fast. Data shows that they can be safely charged at rates higher than 10C. The LTO-based batteries also have a wider operating temperature range and a recharge efficiency exceeding 98%. The energy density of LTO-based batteries is low compared with other LIBs.[29]

[29] Battery University (2021), BU-205: Types of lithium-ion https://batteryuniversity.com/article/bu-205-types-of-lithium-ion

Figure 16: Characteristics of LTO



Source: Authors' analysis, multiple sources

LTO is used in different applications, like UPS, electrical power trains, solar-powered streetlights and forklifts. Other applications include aerospace and military uses and, more importantly, wind and solar energy storage and smart grid creation.

The long cycle life and high-rate capability of LTO-based batteries brings unique advantages in applications where grid reliability is poor. For EVs, this fast recharge capability makes a huge difference in terms of recharge time compared with other LIB chemistries.[30]

2.1.5. Emerging battery technologies

Apart from the different LIB chemistries, other battery chemistries are emerging in the market. These chemistries are widely being discussed by experts and have the potential for mass deployment. They include all solid-state batteries (ASSBs), sodium ion (Na-ion), lithium sulphur (LiS), lithium air (Li-air) and redox flow batteries. These chemistries are described below.

All solid-state batteries

ASSBs are like LIBs but use solid electrolytes (SEs) instead of semisolid electrolytes. They also tend to have a lithium rather than a graphite metal anode. The SEs can be either inorganic or polymer-based. The SEs will help achieve higher energy densities compared with in liquid electrolyte LIBs. In conventional electrolytes, the ions are highly mobile and cause severe concentration gradients, limiting the cell current. Here, SEs will help achieve high energy densities and charge/discharge current limits. They

[30] NEI Corporation, Lithium Titanate Based Batteries for High Rate and High Cycle Life Applications

will also result in a higher life even in harsh conditions as the electrodes in these batteries are less prone to corrosion.[31]

Despite the advantages, there are certain challenges in both manufacturing and fundamental technology understanding. The Li-ion conductivity in polymers is too low at room temperature, limiting the overall charging speed. Hence, the search for stable polymer electrolytes for use with lithium-metal anodes and NMC or NCA cathodes at ambient temperature at a sufficient C-rate is one of the challenges scientists and engineers face in the forthcoming years.[32]

Lithium sulphur

LiS batteries have been popularised to avoid the use of precious scarce metals like cobalt in batteries. LiS batteries use abundantly available sulphur as the cathode in the form of S_8. The sulphur cathode can achieve an energy density of 250 Wh/kg. As such, high-capacity sulphur-containing cathodes and lithium anodes are considered among the most promising candidates to achieve a low-cost and high-energy-density system[33].

The key challenge with LiS batteries is the unwanted reaction of sulphur with the electrolyte, forming several intermediate products; this is called the polysulphide 'shuttle effect'. This results in continuous leakage of active material from the cathode, lithium corrosion and low battery life. As such, use of an electrolyte that reduces the shuttle effect is the main challenge for researchers and engineers.

Companies such as Sion Power have piloted LiS batteries, partnering with Airbus Defence and Space. They have been able to achieve an energy density of 350 Wh/kg used in a prototype aircraft powered by solar energy. British firm OXIS Energy has also developed a prototype LiS battery.[34]

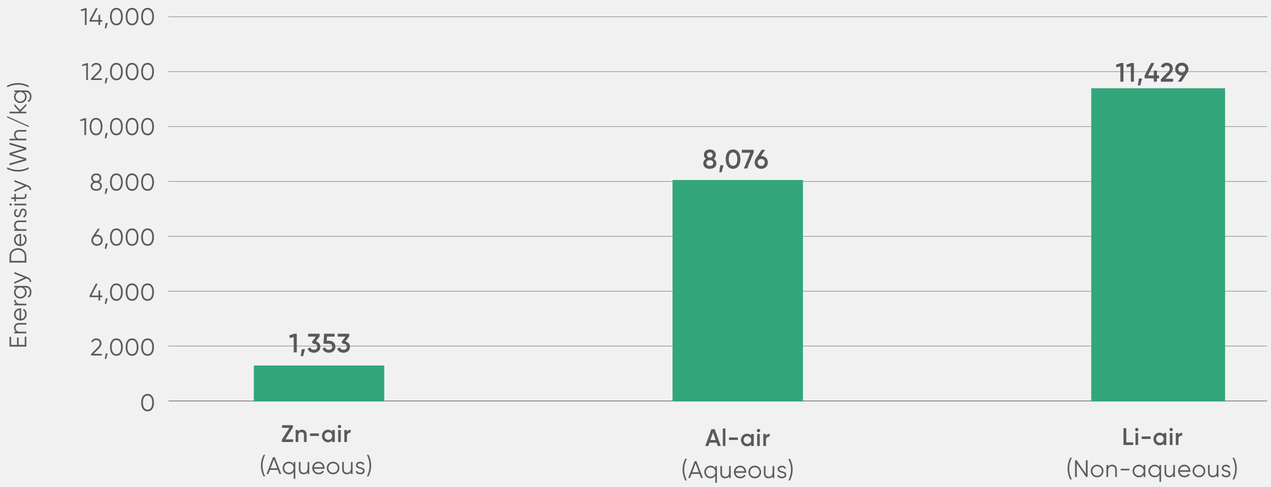
Metal air

Metal air batteries have a metal anode and a breathable cathode that is continuously supplied with oxygen from the surrounding air. These batteries have a higher theoretical energy density than LIBs, making them a potential candidate for energy storage solutions in EVs and SAs.

These batteries can be divided into subcategories based on the electrolytes used. The metal, such as lithium, is highly reactive in aqueous solutions, so a non-aqueous electrolyte like aprotic acid is generally preferred, making the Li-air battery a non-aqueous metal air battery. For zinc and aluminium (Zn-air and Al-air), as they are less reactive and relatively stable in aqueous solutions, aqueous electrolytes are preferred, making them aqueous metal air batteries.[35]

[31] Boon-Brett, L., Lebedeva, N. and Di Persio, F. (2018) Lithium Ion Battery Value Chain and Related Opportunities for Europe. European Commission.
[32] Boon-Brett, L., Lebedeva, N. and Di Persio, F. (2018) Lithium Ion Battery Value Chain and Related Opportunities for Europe. European Commission.
[33] CSTEP (2020). Existing and Emerging Lithium-ion Battery Technologies for India
[34] Kopera, J (2014) Sion Power's Lithium-Sulfur Batteries Power High Altitude Pseudo-Satellite Flight
[35] Li, Y. and Lu, J. (2017) Metal–Air Batteries: Will They Be the Future Electrochemical Energy Storage Device of Choice? ACS Energy Letters 2(6).

Figure 17: Theoretical energy density of metal air batteries (Wh/kg)



Source: Authors' analysis, multiple sources

These batteries are not electrically rechargeable; rather, part of the battery – either the electrolyte or the metal anode – need to be replenished. This characteristic separates them from LIBs and other chemistries, and makes them hard to compare with respect to battery life cycle.

Despite significant research over the past decade, there is a lack of a true understanding of the underpinning chemistry and electrochemical processes in metal air batteries. These batteries also have much lower charge/discharge rates compared with LIBs.

Li-air

Li-air batteries with a non-aqueous electrolyte have a highest theoretical specific energy density of more than 11,000 Wh/kg, which is comparable with the energy density of gasoline (13,000 Wh/kg). Estimates of practical energy storage are uncertain, as many factors are unknown, but values in the range of 500–1,000 Wh/kg – sufficient to deliver significantly more than a 500 km driving range if deployed in an EV battery – have been proposed.
Li-metal electrodes still do not deliver the necessary cycling efficiency and LiO2 faces several challenges, including stability of the electrolyte solution and the cathode towards reduced oxygen species.

Al-air

Al-air batteries with an aqueous electrolyte have a theoretical energy density of about 8,000 Wh/kg. Some studies suggest the practical energy density that can be achieved to be about 1,300 Wh/kg. Phinergy, a key player in Al-air battery research and manufacturing, has claimed that a car with an Al-air battery can achieve a 2000 km range before replacement of the aluminium anodes is required.[36]

In March 2021, Phinergy, and Israel based clean energy company, and Indian Oil

[36] Edelstein, S. (2014) Aluminium Air Battery Developer Phinergy Partners with Alcoa. https://www.greencarreports.com/news/1090218_aluminum-air-battery-developer-phinergy-partners-with-alcoa

formed a joint venture for collaboration in the sector of Al-Air battery system. This includes research and development (R&D), customisation, assembly, manufacturing and sale of Al-air batteries for the global market, specifically EVs.

Zn-air

Zn-air batteries with an aqueous electrolyte have a theoretical energy density of about 1,300 Wh/kg. According to studies, this is the most developed and closest to commercialisation among all the metal air battery chemistries for EVs and SAs. These batteries have achieved a practical energy density of about 400 Wh/kg.

These batteries have been under use as primary (non-rechargeable) batteries in applications like navigation equipment and oceanographic experiments.[37] A Zn-air grid-level energy storage system of 1 MWh has been implemented by Eos Energy Systems.[38]

Sodium ion batteries

Na-ion cells are a promising battery technology with no cobalt or nickel that looks to reach 160 Wh/kg, near-LFP-specific energy. Compared with widely used LIBs, Na-ion cells have lesser energy density and cycle life but they have a wider operational temperature range and are safer.[39]

Na-ion cells have a similar working principle to LIBs and are expected to be at least 20% cheaper than LFP as a result of their lithium-free nature. However, separator and electrolyte costs could be significant and result in Na-ion being more costly.

Na-ion cells are expected to be less sensitive to rising material costs compared to lithium, given sodium is abundantly available in many countries. If all material prices rise 10%, Na-ion material costs will increase by only 0.8%, while LFP and NMC 532 costs will increase by 3.2% and 4.6%, respectively.

Na-ion material costs are expected to remain stable over the next 10 years. As such, it is expected that the cost of Na-ion battery packs will fall and mitigate the supply chain pressure currently falling on LFP and NMC battery cells.[40]

Redox flow batteries

Flow batteries are a type of electrochemical cell where chemical energy is provided by two chemical components dissolved in liquids that are pumped through the system on separate sides of a membrane. Ion exchange (accompanied by a flow of electric current) occurs in the cell through the membrane while both liquids circulate in their own respective space; these liquids are stored in huge tanks. Examples of flow batteries are vanadium flow batteries and polysulphide bromide batteries. Vanadium electrolytes have been widely studied and are well known, having already been commercialised worldwide.[41]

These batteries have a low energy density because of their bulky nature but offer higher life cycles compared with LIBs. They are popular for grid-connected energy storage applications. In case of redox batteries, unlike other battery chemistries

[37] Linden, David., Reddy, Thomas B (2001) Handbook of Batteries.
[38] Cardwell, D. (2013) Battery Seen as Way to Cut Heat-Related Power Losses. New York Times, 16 July.
[39] Hwang, J.Y., Myung, S.T. and Sun, Y.K. (2021) Sodium-Ion Batteries: Present and Future. Chem. Soc. Rev. 46: 3529–3614.
[40] Hwang, J.Y., Myung, S.T. and Sun, Y.K. (2021) Sodium-Ion Batteries: Present and Future. Chem. Soc. Rev. 46: 3529–3614.
[41] Arenas, L.F., Ponce de León, C. and Walsh, F. (n.d.) Redox Flow Batteries for Energy Storage: Their Promise, Achievements and Challenges. Current Opinion in Electrochemistry.

discussed, the energy storage capacity depends on the electrolyte stored in the tanks and the power depends on the flow at which the electrolyte can be pumped. This feature of the batteries gives flexibility in design with separation of power and energy.[42]

There are very few case studies that demonstrates large size deployments. This may limit the wider rollout of these batteries.

All the emerging and existing batteries discussed above are mapped in Figure 18 to an ACC matrix as defined for the new Production-Linked Incentive (PLI) scheme (see Section 2.2). The figure shows the battery chemistries that are eligible for the production incentives under such a scheme.

The cells highlighted in red are eligible for the PLI scheme. As per the matrix, energy density and lifecycles are two parameters to gauge battery chemistry performance. The higher the energy density and life cycles, the higher the incentives.

As for the current commercially available LFP and LTO batteries, these may or may not be eligible for PLI incentives. The incentive scheme will encourage the battery manufacturer to produce LFP and LTO of higher energy density and life cycles. This is shown using different variants of these chemistries like LFP (1) and LFP(2) and LTO(1) and LTO(2). Similarly, based on their characteristics, NMC and other emerging chemistries (ASSB, LiS, etc.) would be eligible for the PLI scheme.

Figure 18: Mapping of LIBs and emerging battery chemistries on an ACC matrix

ACC matrix		Energy density (Wh/kg)				
		≥ 50	≥ 125	≥ 200	≥ 275	≥ 350
Life cycle	≥ 1,000	Lead acid	LCO, LMO	NCA		Li-air* Zn-air* Al-air* LiS Solid state(1)
	≥ 2,000	Advanced lead acid	LFP(1)	NMC111	NMC811	Solid state(2)
	≥ 4,000	LTO(1)	LFP(2) Na-ion LTO(2)			
	≥ 10,000	Redox flow				Solid state(3)

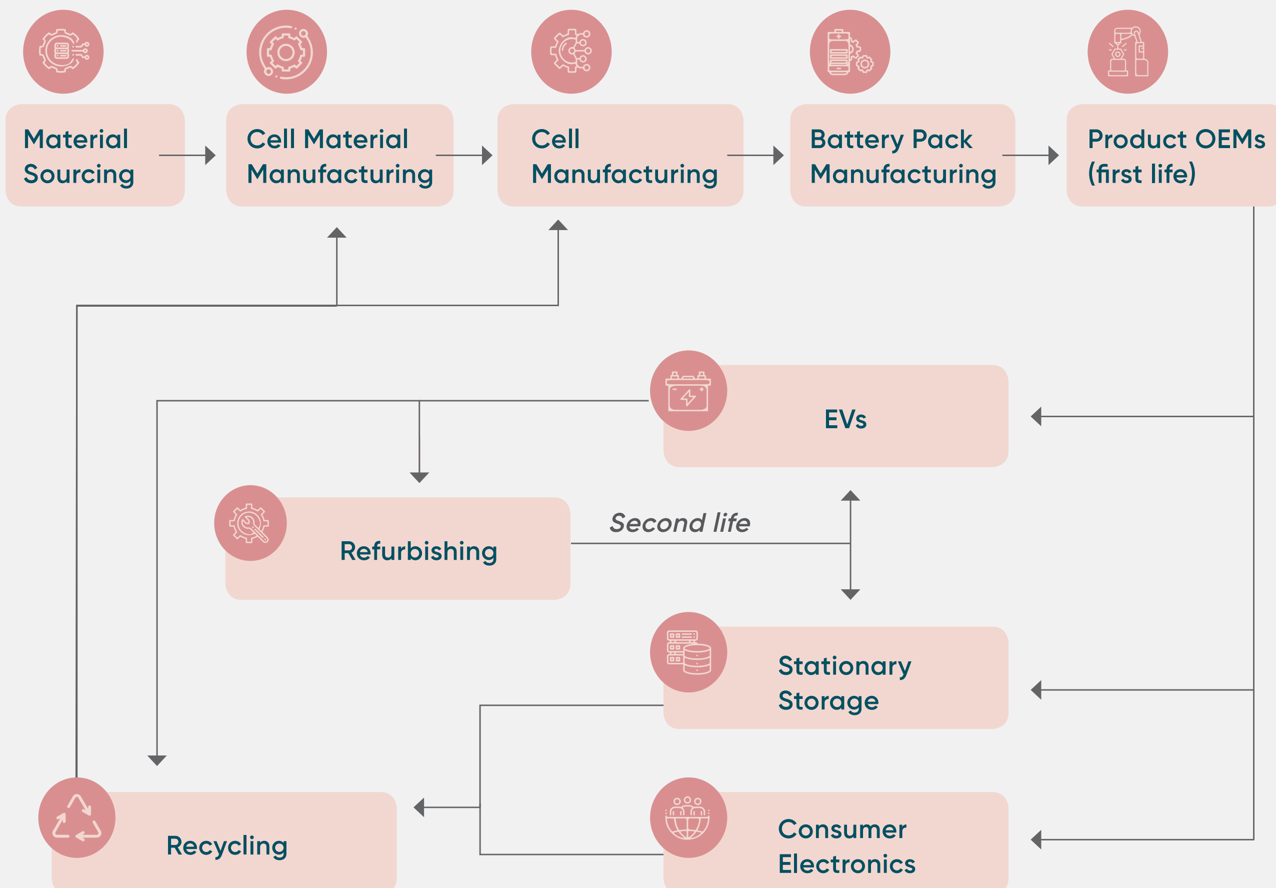
Note: *Since the life cycle of metal air batteries is not available, it is assumed to be more than 1,000 for all chemistries.

[42] Arenas, L.F., Ponce de León, C. and Walsh, F. (n.d.) Redox Flow Batteries for Energy Storage: Their Promise, Achievements and Challenges. Current Opinion in Electrochemistry.

2.2. Battery storage value chain

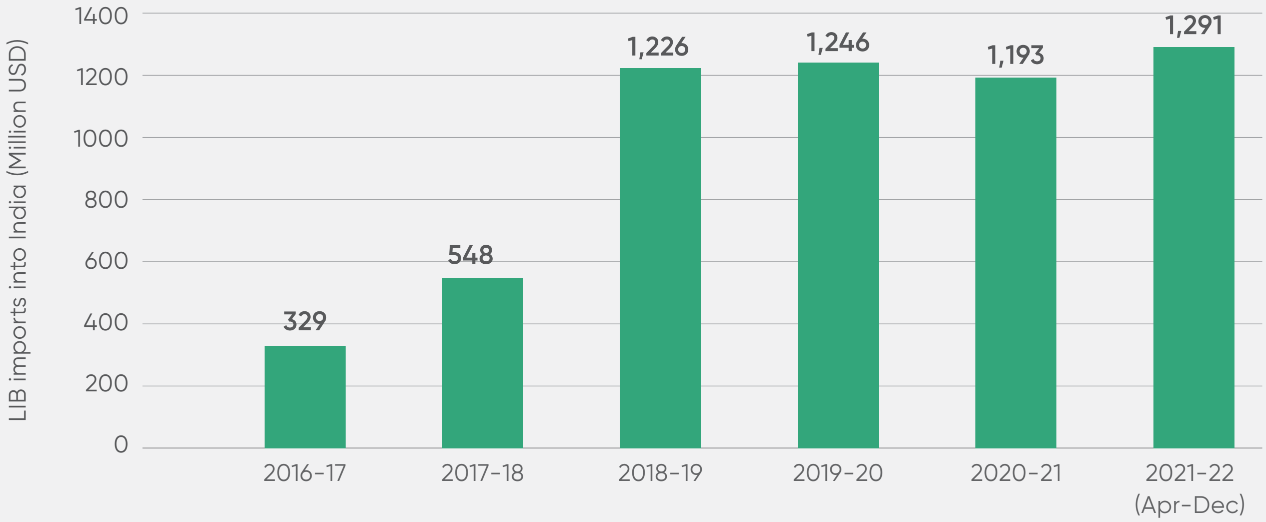
Figure 19 presents a typical value chain of battery energy storage. The key steps in this, include sourcing of material through mining/imports, cell component manufacturing, battery pack manufacturing, battery-driven product manufacturing, sales and usage of battery driven applications, reuse of batteries and recycling of batteries. This section focuses on LIBs as these batteries are expected to dominate the battery market in India.

Figure 19: Value chain of LIBs



Material sourcing, cell component manufacturing and cell manufacturing are yet to kick off for mass production in India. Presently in India, either the cells are imported and are assembled into battery packs or the entire battery packs are imported. In 2020-21, the India LIB import bill stands at about US$1,193 million, with China and Hong Kong combined accounting for 87%. In FY 2021-22, between April and December, the import bill stands at US$1,291 million; if this continues at same pace the bill is expected to reach US$1,720 million by the end of the financial year.

Figure 20: LIB imports into India (US$ millions)



Source: Authors' analysis, industry insights.

Recently, the Indian Ministry of Heavy Industries, has come up with a new Production-Linked Incentive (PLI) scheme to encourage domestic manufacturing of ACCs, which includes LIBs. Through this scheme, the Government of India (GoI) envisages reducing the dependency on imports for LIB cells. Ten companies have quoted for about 130 GWh against 50 GWh planned capacity. But raw material sourcing for the cell manufacturing is not well established, with limited resources in the country. As such, India is expected to continue depending on imports for the raw materials required for LIB cell manufacturing.

Against the backdrop of this scheme, GoI is also looking to improve the sourcing of raw material through mining in the country and bilateral understandings with resource-rich nations like Chile and Bolivia, etc.

Here, recycling of used batteries could close the gap and help make a circular economy for LIBs possible. The material recovered from used batteries could be used to offset the imports of raw material. Through large-scale expansion and aiding policies, the country could establish adequate recycling capacity not only to recycle the spent LIBs coming from the Indian market but also imported spent batteries from markets around the world. This would create a new source for the raw materials required for cell manufacturing.

2.2.1. Raw material sourcing

Lithium cells comprise different components: the cathode, the anode, the electrolyte and the separator, along with the casing of the cells.

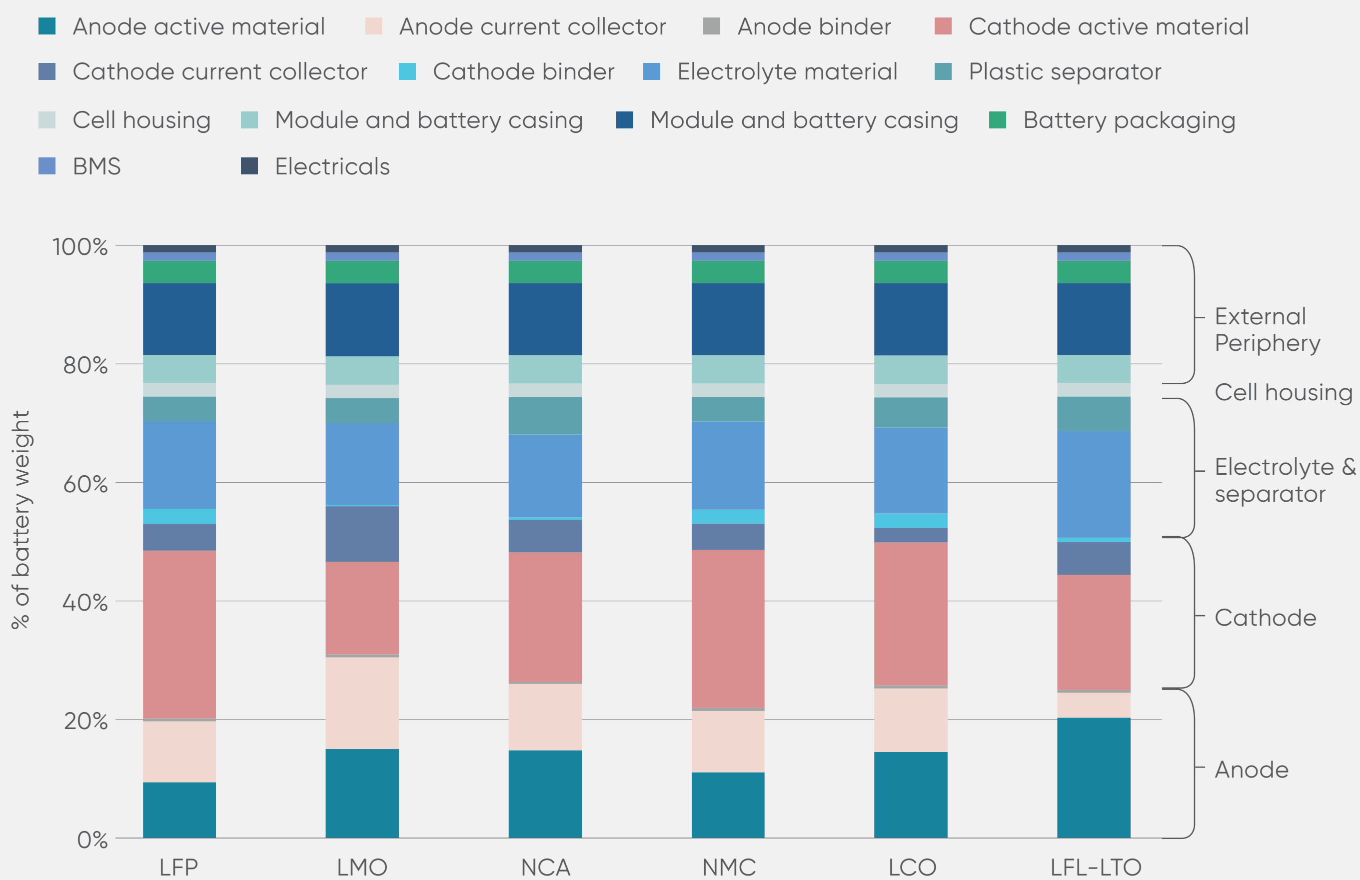
The anode materials in LIBs include an active material and a current collector. The widely accepted anode material in LIBs is graphite. The current collector is either Cu or Al.

The cathode also includes an active material and a current collector. Aluminium is the popular current collector for the cathode, while the cathode active material changes with the battery chemistry.

The electrolyte material used in LIBs is majorly lithium hexafluoro phosphate (LiPF[6]). The fluorene in this compound risks reacting to make hydrofluoric acid (HF). To reduce this risk, it is mixed with ethylene carbonate, and dimethyl carbonate (EC-DMC).

The separator in the cell is made up mainly of plastics like polypropylene, polyethylene or polyvinyl fluoride.

Figure 21: LIB components and share by weight of battery (%)

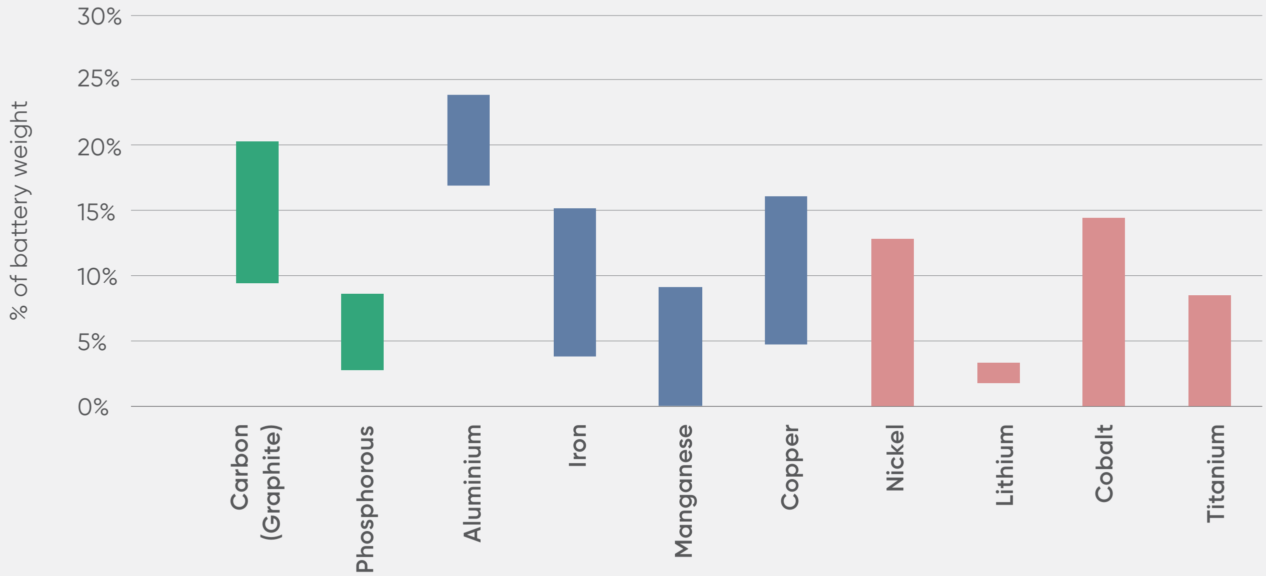


Source: Authors' analysis, industry insights.

Cells are the primary component of a battery and account for a sizeable share in the final battery value. **Cells account for 75–80% of total battery weight.** They are composed of several subcomponents, each of which requires exclusive technologies manufactured from different sets of raw materials like base metals, polymers, alloys and salts. These materials generally need to be sourced through mining within the country or from other countries endowed with the natural resource (e.g. DRC for cobalt), necessitating global supply chains.

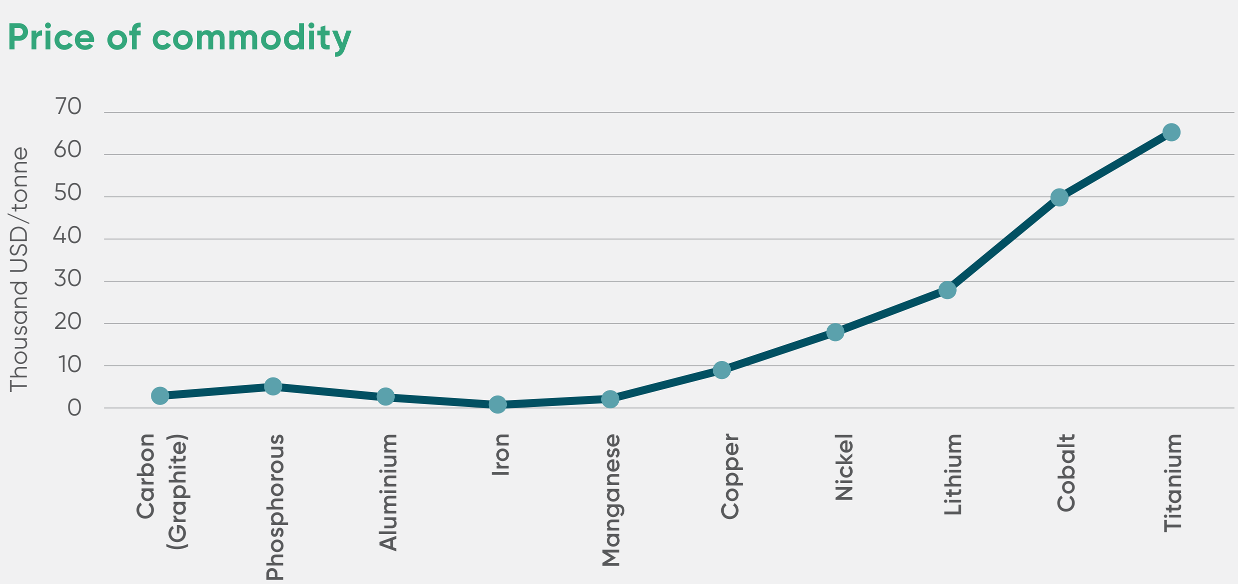
Figure 22 presents the range of different materials as a percentage of battery weight considering different LIB chemistries. On average, metals accounts for 35–50% of LIB weight. Metals such as aluminum, copper, lithium and iron are the most commonly used material across LIBs. These account for 20–30% of total battery weight. Precious metals like manganese, nickel, cobalt and titanium are other metals used in the manufacturing of LIB cathodes. The composition of these metals is dependent on the cathode chemistry; on average, they constitute ~15% of battery weight.

Figure 22: Share of different materials by weight of LIB (%)



Source: Authors' analysis, industry insights.

Figure 23: Price of the commodity, 2020



Source: LME; other sources

India has its own resources of precious battery materials like lithium, nickel and graphite.

Against the backdrop of the PLI scheme for ACCs, during the current Field Season Programme (FSP)[43] 2021–2022, Geological Survey of India (GSI) has taken up seven projects on lithium in various regions of the country. However, GSI has not yet augmented these lithium resources. Further, the Atomic Minerals Directorate for Exploration and Research (AMD), a constituent unit of the Department of Atomic Energy (DAE), is carrying out exploration for lithium in potential geological domains in parts of Karnataka and Rajasthan. AMD is also carrying out subsurface exploration in these states. These explorations have shown presence of lithium resources of 1,600 tonnes in the country. Exploratory work to extract lithium from the brine pools of Rajasthan and Gujarat, and the mica belts of Odisha and Chhattisgarh, is also being carried out.

Also, India and Bolivia have forged a partnership in which India is to invest in the development of mining of abundantly available lithium and cobalt resources in return for the supply of lithium, lithium carbonate and cobalt.[44]

India is also blessed with nickel resources. As per the National Mineral Inventory database, based on the United Nations Framework Classification for Resources (UNFC), resources of nickel are estimated at 189 million tonnes. The state of Odisha is endowed with the largest share of resources of nickel ore in the country, at 175 million tonnes (93%), followed by Jharkhand & Nagaland. Nicomet Industries Ltd is presently the only producer of nickel metal and its derivatives; its annual production capacity from its Goa plant is about 5,400 MTPA.[45] Currently serving the demand for stainless steel production, the company is preparing to foray into the battery market as the local manufacturing of cells starts. Nickel is also produced as a by-product of copper mining. Hindustan Copper Ltd with extended lease of its Surda mining site in Ghatsila region is expected to start production of London Metal Exchange (LME)-grade nickel in India.[46,47]

India is also the second-largest producer of graphite, which is the key material for the anode in LIBs. Currently, the graphite produced is used mainly in the steel industry, as a lubricant, and in making graphite crucibles and carbon brushes. Battery -grade graphite is currently being imported from China.[48]

In future, end of life (EOL) EV LIBs are likely to be the major source of metals for cobalt, lithium and nickel. Recovering these metals from used LIBs to channel back into precursor materials is likely to be the most economic route compared with returning them to pure metals from other sources.

[43] The FSP of the Geological Survey of India (GSI), an office attached to the Ministry of Mines, takes up different stages of mineral exploration every year – reconnaissance surveys (G4), preliminary exploration (G3) and general exploration (G2) – following the guidelines of the United Nations Framework Classification (UNFC) and the Mineral Evidence and Mineral Content Rules 2015.

[44] EVreporter (2019) Lithium Ion Battery Manufacturing in India – Current Scenario. 24 September.

[45] Indian Minerals Yearbook 2019, Nickel.

[46] Care Ratings (2019) Nickel Industry Research. https://www.careratings.com/uploads/newsfiles/Nickel%20Industry.pdf

[47] PSU News (2021) Cabinet Approved Extension of Surda Mining Lease of Hindustan Copper Limited. 11 December.

[48] CSTEP (2018) Indigenisation of Lithium-Ion Battery Manufacturing: A Techno-Economic Feasibility Assessment.

[49] Boon-Brett et al. (2018) Lithium Ion Battery Value Chain and Related Opportunities for Europe.

2.2.2. Cell component manufacturing

Globally, Asia dominates in cell component manufacturing. China is manufacturing 39% (by weight) of the total amount of cathode materials globally, while Japan and Korea account for 19% and 7%, respectively. In the case of anode material manufacturing, Hitachi Chemicals (Japan) has a share of 31%, Nippon Carbon (Japan) has 19% and BTR Energy (China) has 7%. For electrolytes, China produces close to 60% of the total market weight; Japan and Korea account for 18% and 14%, respectively.

Cell manufacturing

Lithium cell manufacturing involves the assembly of cell components. Currently, there is only one manufacturing unt for lithium cells in India, and demand for battery cells is met manly through imports. Asian companies, notably Samsung SDI (Korea), LG Chem (Korea), Sanyo-Panasonic (Japan), Sony (Japan) and BYD (China), among others, dominate LIB cell manufacturing.

To reduce import dependency for LIBs, GoI's new PLI scheme, the National Programme on ACC, aims to increase cell manufacturing in India. Through this scheme, GoI intends to optimally incentivise potential investors, both domestic and overseas, to set up giga-scale ACC manufacturing facilities with an emphasis on maximum value addition and quality output and achieving pre-committed capacity levels within a predefined time period.[50] The total outlay is INR18,100 crore for five years. The Request for Proposals was released in October 2021 for opening to technical and financial bids in January 2022.

Apart from the PLI scheme, GoI is pushing for local manufacturing of LIBs and advanced cells through increased import duty on lithium cells (from 5% to 10% from April 2021) and lithium battery packs (from 5% to 15% from April 2021).[51]

Several companies have started setting up manufacturing units in India under different joint ventures. These include Exide–Leclanche's Nexcharge, Toshiba–Denso–Maruti Suzuki's TDS LIB and a joint venture of Lucas TVS–24M Technology.

Battery pack manufacturing

Cells form the functional component of batteries; they are assembled into modules and then into battery packs. However, in order to ensure safe operation of the batteries, the modules need to be integrated properly with the battery management system and the thermal management system. To ensure mechanical stability, a metal or plastic jacket also needs to be added. Some sensors and controllers are also needed to track the state of health (SoH), state of charge (SoC) and temperature of the pack.

Battery pack manufacturing represents the integration of all these elements of the battery. On average, the battery module periphery accounts for 18–25% of the total battery weight and the remainder is made up of cells.

Some EV manufacturers in India have developed battery pack assembling facilities in-house and use cell units imported from China or elsewhere. This strategy helps them protect their intellectual property rights and strengthen their value proposition to their customers and investors.

[50] Ministry of Mines (2021) Production Linked incentive Scheme for Manufacturing of Advance Chemistry Cell to Reduce Import Dependence on ACC Battery. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1744879
[51] EVreporter (2019) Lithium Ion Battery Manufacturing in India – Current Scenario. 24 September.

Other Indian players in the market are entering the LIB manufacturing business (pack assembly) as a result of its high growth and untapped market potential. For example, many traditional LAB manufacturers have stepped into the LIB business catering to both business-to-business and business-to-consumer market segments.

2.2.3. Reuse of batteries

Second life is another key component of the battery value chain. EV batteries have greater scope for reuse. EV batteries are in general designed for high performance in terms of charge/discharge rates, lifecycles and thermal tolerance. They are generally retired at an 80% SoH. As such, these batteries at EOL may still have some healthy modules that can be reused directly for other EV applications; or, the entire pack itself can be used for other stationary storage applications. The used EV battery may be suitable for certain applications like invertor backup for homes or RE storage at grid level, which requires lower charge/discharge rates. This stationary usage presents great opportunities for the reuse of these batteries and recovery of some proportion of its overall cost.

The repurposing of the batteries includes testing, assessment, cell auditing and refabrication of used batteries. Several hundreds of cells that are present in an EV battery need to be tested to figure out the overall health of the battery in a non-invasive manner, ensuring no damage to the cells. The second life battery developers use methods like tracking charge/discharge rates, thermal imaging and parsing of data from the battery management system to evaluate the life of the battery.

Battery reuse can also involve creating price discovery for EOL batteries, which will be higher than the scrap value of the batteries. This will help in creating new business models, such as a buy-back model by OEMs, which can help reduce the battery replacement cost for old vehicles.

Key players who have started out in this sector include Nunam, Ziptrax Cleantech, etc.

2.2.4. Recycling of batteries

LIBs are composed of pure metals and metal alloys along with certain chemical and plastic parts. These cells are almost completely recyclable with the use of appropriate technologies. Recycling rates are expected to be around 95% for metal recovery from the cells.

The recycling of batteries can be conducted through different processes involving key technologies, such as mechanical recycling, pyrometallurgy and hydrometallurgy. The use of these technologies in addition to pre-treatment of batteries allows for a higher recovery rate of metals in the battery.

The key players in this sector include domestic players like Attero, Exigo, TATA Chemicals and Lohum, along with some global players like SungEel (Korea) and Recupyl (Canada), which are venturing into the Indian battery recycling space.

Chapter 3

Battery storage market and potential in India

GOI's goal to shift to a low-carbon economy through adopting clean energy presents a profitable set of opportunities for energy storage in India. Battery storage has become a reality because of the energy sector's growing technology landscape and efficient cost-cutting tactics across the supply chain. With the introduction of ACCs, developing application-specific tailored storage solutions, which was once difficult and time-consuming, has become possible. A future disruptive battery manufacturing ecosystem may be created via coordinated governmental and private sector activity.

Since 2016, the overall market for advanced cells, particularly LIBs, has expanded at an exponential rate, with most of the growth coming from the usage of LIBs in EVs. There has also been a rise in the demand for LIBs in consumer gadgets.

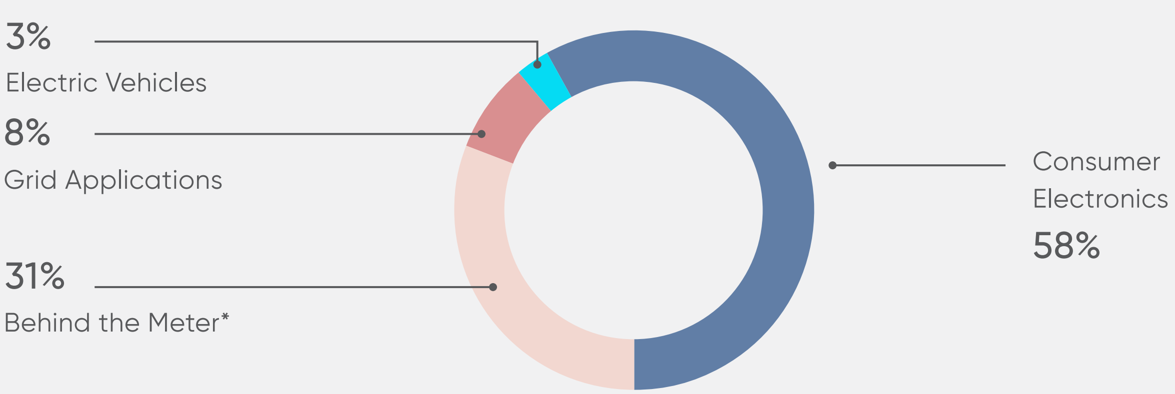
The trend is anticipated to continue, and India will remain primarily reliant on imports unless domestic cell production facilities are created. Such a heavy reliance on imports will result in a trade imbalance, which will have second- and third-order economic consequences such as currency devaluation and employment losses.

3.1. Overview of battery storage deployment in India

The current deployment of LIBs in India is dominated by consumer electronics, which comprises smartphones, laptops, notebooks, tablets, etc. and is further expected to grow with the digitalisation of platforms and the integration of technology in our daily lives.

In 2020, consumer electronics energy storage was the biggest market for LIBs, with a cumulative market of 4.5 GWh, though EV sales accounted for around 10% of the LIB market (0.92 GWh).

Figure 24: Market share of LIBs in India, 2020



Note: *Excluding consumer electronics.
Source: Authors' analysis.

The smartphone market in India has recorded a 10-fold expansion, from ~14.5 million shipments in 2011 to ~150 million in 2020, making it one of the most lucrative markets in the world.

The next big segment is the BTM applications, which includes inverter and UPS backup, telecoms and diesel gensets. It is estimated that around 1.4 GWh of LIBs were deployed in the telecom sector in 2020. The UPS and inverter backup market in India has also grown significantly, with total cumulative installation of around 0.98 GWh of lithium ion-based battery backup (2020); however, the overall battery energy storage capacity is more than 15 GWh, comprising the LAB segment. The IT sector, especially data centres, remain the biggest consumers of UPS. The deployment of the internet of things (IOT) in production is also booming, and that is contributing to the increase in the use of UPS.

3.2. Recent tender and battery energy storage projects

GoI has been promoting battery storage adoption through tenders for grid-connected battery storage. Some of the prominent storage tenders that are under various stages of development are listed in Table 5.

Table 5: Battery energy storage projects in India (commissioned and pipeline)

Battery storage project	Location	Capacity (MWh)
20 MW Solar with 20 MW/50MWh (SECI, Leh-Laddakh)	Jammu and Kashmir	50
3MW solar with 3.2 MWh Storage (SECI-Sunsource, Leh)	Jammu and Kashmir	3.2
14 MW solar with 42 MWh BESS (SECI, Leh Kargil)	Jammu and Kashmir	42
500 MW/1000MWh Standalone BESS (SECI)	Pan India	1000
150 MWh BESS Renew Power	Pan India	150
1600 MW Solar with 3900 MWh BESS (SECI)	Pan India	3900
200MW Solar with 50 MW/150MWh (SECI, Rajnandgaon)	Chhattisgarh	150
200kWh flow battery, 300 kWh Advanced LAB, 500kWh Li-Ion (Hyderabad- BHEL)	Telangana	1
160 MW Wind solar Hybrid with 30-40 MWh BESS (SECI)	Andhra Pradesh	40
100 MW Solar with 40 MW/120MWh (SECI- Dollygunj & Attampahad)	Andaman & Nicobar Islands	120
4 MW Solar with 2 MW/1MWh (Sunsource- Diglipur)	Andaman & Nicobar Islands	1
500KW/250KWh (Li-ion Battery), 50KW/250KWh (Advanced Lead Acid Battery) & 250KW/1MWh (Flow Battery)	Puducherry	1.5
1 MW solar with 1MW/3MWh BESS	Tamil Nadu	3

1.95 MW + 2.15MWh (4 islands- Sunsource Energy)	Lakshadweep	2.15
20 MW Floating solar with 60 MWh BESS	Lakshadweep	60
15 MWh + 150 kWh (Sun Temple, Mehsana- Susten)	Gujarat	15.15
0.52 MWh (Nexcharge)	Delhi-NCR	0.52
160 kWh advanced lead acid, & 350 kWh Li-ion (CEL Sahibabad)	Delhi-NCR	0.51
900 kWh (Raychem-RPG)	Delhi-NCR	0.9
410 kWh (BHEL-Okaya)	Delhi-NCR	0.41
674 kWh (6 locations)	Delhi-NCR	0.647
10MW/10MWh TPDDL (AES Mitsubishi)	Delhi-NCR	10
2MW Solar with 1MWh BESS (Sun Temple, Mehsana- Susten)	Himachal Pradesh	1
Greenko – BYD 1 MW BESS	Andhra Pradesh	1
Neyveli Lignite Corporation Limited8 MWh/16 MW BESS, 2 *10 MW Solar PV	Andaman & Nicobar Islands	8
Andhra Pradesh Eastern Power Distribution Company Limited (APEPDCL) 4 MWh BESS, 5 MW Solar PV	Andhra Pradesh	4
Transmission Corporation of Andhra Pradesh (APTRANSCO), 400 MW with 8 hours discharge- 3200 MWh	Andhra Pradesh	3200
TNEB 1 MW solar with 1MW/3 MWh BESS	Tamil Nadu	3
SECI 1000 MWh BESS in Rajasthan	Rajasthan	1000
Total		**9879.987**

3.3. Policies and regulations supporting battery storage deployment

Policy and regulatory frameworks are the biggest drivers in terms of mobilising market penetration for the adoption of battery manufacturing technologies. It is important, at the central level, to have a stable policy framework with minimal amendments that provides adequate support mechanisms to investors as they plan and develop their entry strategy for Indian markets. Additionally, assessments at the state level are of equal importance, considering the plethora of enabling policies provided by state governments in the form of EV, industrial and battery storage policies, and deciding on the best location for setting up battery manufacturing plants. These two assessments, critical at central and state levels, are presented below.

3.3.1. Key policies and interventions at central level

At the central level, GoI has launched programmes like Make In India, the National Smart Grid Mission and the National Programme on ACC Battery Storage to push the agenda of domestic manufacturing in India. The aim is to help build an ecosystem of domestic battery manufacturing and R&D,

with a strict focus on 100% value captured being realised in India. The National Policy on Electronics, released in February 2019, stressed promoting domestic manufacturing and exporting in the entire value chain of electronics system design and manufacturing for economic development, with a target to achieve turnover of US$400 billion by FY 2025. The National Energy Storage Mission has also agreed on the need to create policy and regulatory frameworks for battery manufacturing growth, scaling supply chain strategies and scaling of battery cell manufacturing.[25]

Figure 25: A glimpse of national-level policies over the years in India

National Smart Grid Mission (Draft) Launch by Ministry of Power

- Development of smart gird and mini grid projects with a total outlay of ~INR1,830 crore
- Enable access to and availability of quality power to all through RE power and energy efficiency, and energy storage

National Mission on Transformative Mobility and Battery Storage

- Phased Manufacturing Programme (PMP) valid five years till 2024 to support domestic cell manufacturing
- Creation of a PMP valid five years till 2024 to localise entire value chain of EV production energy storage

National Programme on ACC Battery Storage

- Achieving manufacturing capacity of 50 GWh of ACC and 5 GWh of 'niche' ACC
- The PLI scheme will be implemented by Department of Heavy Industry with an outlay of ~INR18,100 crore

GoI's policy framework in the recent past aims to upgrade the manufacturing sector for it to work towards practical solutions to add value and create new products, thereby developing a niche market. The intention is to create forward and backward linkages in manufacturing to create a strong multiplier effect in the economy, in addition to driving export competitiveness, thereby supporting battery storage deployment in the country.

3.3.1.1. National Mission on Transformative Mobility and Battery Storage

The National Mission on Transformative Mobility and Battery Storage is a central government programme aiming to boost mobility solutions and encourage development of a competitive domestic manufacturing ecosystem, focusing on maximum value capture within India. Cabinet approval for the mission was given on 7th March 2019, with the programme chaired by NITI Aayog. The mission will serve as a cross-cutting/multi-disciplinary platform and take feedback from concerned ministries. Its vision includes developing a Phased Manufacturing Plan (PMP) for implementation of giga-scale integrated cell and battery manufacturing plants, focusing on global benchmarking to ensure export competitiveness, transparent procurement and domestic demand creation for five years. The broader goal is to establish a PMP for localising production for the EV supply chain till FY 2024.

[52] MNRE(2018) National Energy Storage Mission. https://pib.gov.in/newsite/PrintRelease.aspx?relid=181698

Figure 26: Key roles, roadmap and anticipated impact envisaged under the National Mission on Transformative Mobility and Battery Storage

Role

- Localising EV production across the entire value chain through a PMP
- Integrating various initiatives to transform mobility and storage in India through coordinating with officials in ministries/ departments/states

Roadmap

- Building giga-scale integrated cell factories by 2021-22, followed by large-scale module and pack assembly plants by 2019-20
- Achieving holistic growth and expansion of the Indian battery manufacturing industry through the PMP

Impact

- Improving air quality in cities, cutting oil import dependence and increasing the use of renewable energy and storage
- Enabling India to leverage its size and scale to develop an effective domestic manufacturing ecosystem

3.3.1.2. National Programme on ACC Battery Storage

In May 2021, GoI approved implementation of its PLI scheme, providing an outlay of INR 18,100 crore (about US$2.4 billion) to achieve manufacturing capacity of 50 GWh of ACC and 5 GWh of niche ACC through the National Programme on ACC Battery Storage to reduce dependence on imports and support the Atmanirbhar Bharat initiative.

Figure 27: Key features of the ACC PLI scheme

Transparent competitive bidding under the **quality- and cost-based selection** mechanism of ACC manufacturing and commissioning within **two years**

Manufacturer must commit to set up an ACC manufacturing facility of minimum **5 GWh** capacity with a maximum capacity of **20 GWh**

Ensure a minimum of **25%** domestic value addition at project level within **two years** and **60%** domestic value addition within **five years** from the appointed date

Incentive will be disbursed thereafter over a period of five years with a provision of increasing the amount with increased specific energy density and cycles and increased local value addition

This scheme provides incentives in the form of a subsidy to manufacturers, linked with output, to help lower the selling price of cells and enable them to become globally competitive. Moreover, according to a notification issued by the Department of Heavy Industry, incentives will be offered only for cell manufacturing and not for conventional battery pack assembly, as such activities already occur in the country. Table 6 presents the year-wise breakdown of the total subsidy.

Table 6: Financial year-wise budgetary provisions (subsidy) (INR crore)

2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	Total
Set-up of manufacturing facilities	2,700	3,800	4,500	4,300	2,800	1,8100

The proposed programme provides two levels of support: pan-support for all cell manufacturers and additional support to selected manufacturers based on a competitive ranking after the tendering process. Figure 28 presents the bid parameters.

Figure 28: Bid parameters for the National Programme on ACC Battery Storage

Bid parameters

The bid shall comprise a 'two-envelop' system: a qualification bid, which shall take up 80% and a commercial Bid of 20% of weightage

Net-worth criteria

The bidder must have a net worth of INR225 crore per GWh with a maximum cap of INR1,500 crore

Bid security

A bidder is required to deposit a bid security calculated at the rate of 1% of INR225 crore per GWh

The scheme received an encouraging response from local as well as global investors with bids of 2.6 times (~130 GWh) the manufacturing capacity offered were received. After both the technical and financial evaluation of the 10 bids, 9 companies were found to be responsive while meeting the eligibility requirements as specified in the RFP. In the final evaluations of the selected bidders, Quality & Cost Based Selection (QCBS) mechanism was utilized, and the bidders were ranked according to their combined technical and financial scores. The ACC capacities have been allocated in order of their rank, till a cumulative capacity of 50 GWh per year. The following list of companies were selected and waitlisted under the program:

Table 7: List of ACC PLI Selected Bidders

<table>
<tr><th>Applicant</th><th>Capacity quoted (GWh)</th><th>Status</th><th>Capacity awarded (GWh)</th></tr>
<tr><td>Rajesh Exports Limited</td><td>5 GWh</td><td>Awarded</td><td>5 GWh</td></tr>
<tr><td>Hyundai Global Motors Company Limited</td><td>20 GWh</td><td>Awarded</td><td>20 GWh</td></tr>
<tr><td>Ola Electric Mobility Private Limited</td><td>20 GWh</td><td>Awarded</td><td>20 GWh</td></tr>
<tr><td rowspan="2">Reliance New Energy Solar Limited</td><td rowspan="2">20 GWh</td><td>Awarded</td><td>5 GWh</td></tr>
<tr><td>Waitlisted</td><td>15 GWh</td></tr>
<tr><td>Mahindra & Mahindra Limited</td><td>15 GWh</td><td>Waitlisted</td><td>-</td></tr>
<tr><td>Exide Industries Limited</td><td>6 GWh</td><td>Waitlisted</td><td>-</td></tr>
<tr><td>Larsen & Toubro Limited</td><td>5 GWh</td><td>Waitlisted</td><td>-</td></tr>
<tr><td>Amara Raja Batteries Limited</td><td>12 GWh</td><td>Waitlisted</td><td>-</td></tr>
<tr><td>India Power Corporation Limited</td><td>5 GWh</td><td>Waitlisted</td><td>-</td></tr>
</table>

State governments will also be major contributors to the success of the programme, as they are encouraged to provide additional incentives to shortlisted investors (through a tendering process) for setting up manufacturing facilities. In turn, this will contribute to state economies and job growth. The scheme is therefore instrumental in putting India on the world map in terms of advanced chemistry storage manufacturing. Establishing battery storage facilities is anticipated to bring in a number of socioeconomic benefits, as well as environmental advantages in terms of reducing GHG emissions, reliance on conventional fuel sources and oil imports.

Table 8: Key benefits of the National Programme on ACC Battery Storage

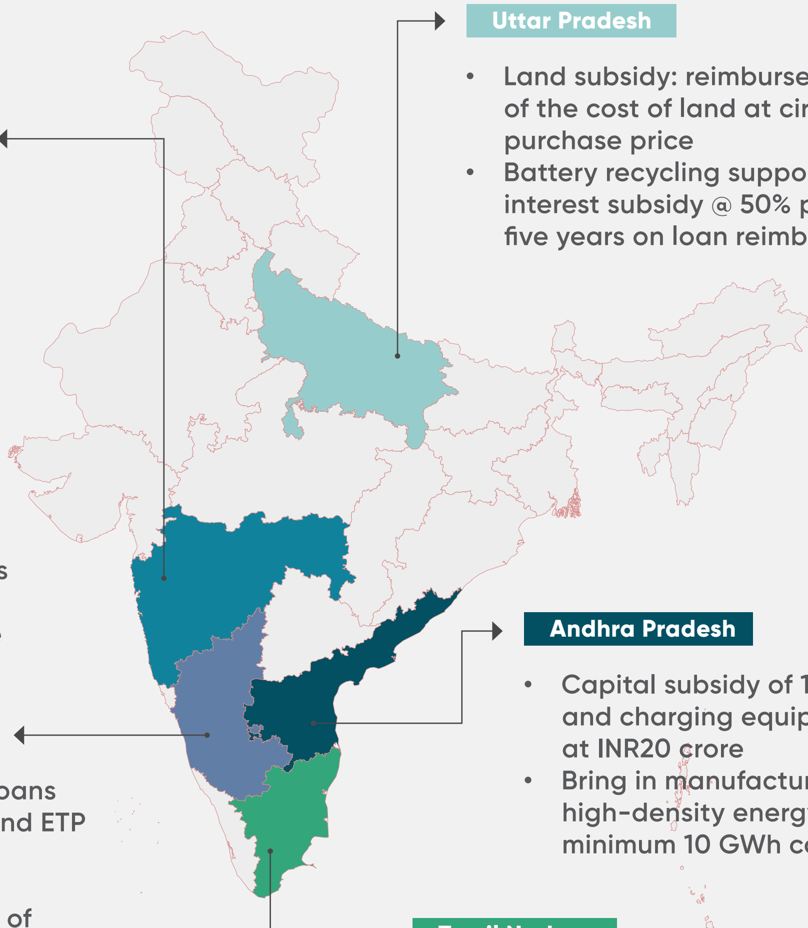
Benefit category	Key benefits
Environmental	• Reduction of GHG and CO2 emissions that would have resulted from the deployment of conventional fuel options • Assistance in meeting environmental/sustainability targets of GoI • Advanced cell storage adoption at grids will enable RE integration
Social	• Increasing number of employment opportunities • Increasing opportunity for skills development, incubation centres and entrepreneurship programmes • More effective learning opportunities with foreign technical entities, leading to more R&D opportunities
Economic	• Improved state GDP and export competitiveness • Increase in foreign direct investment, with an investment opportunity of INR8,000 crore • Increase in tax revenue collection

3.3.2. Key policies and interventions at state level

State governments are also promoting battery manufacturing, with various incentives to build a complete ecosystem to drive this segment. When designing their EV policies, some states have announced incentives specifically for EV battery manufacturing/assembly. Many of these policies have come up with firm incentives in the form of stamp duty exemptions, State Goods and Services Tax (SGST) reimbursements, capital subsidies, land conversion fee reimbursements, research subsidies and interest subsidies. Figure 29 presents an overview of incentives and announcements offered by states.

Figure 29: State-level incentives and announcements for battery manufacturing

Incentive Framework



Uttar Pradesh

- Land subsidy: reimbursement of 25% of the cost of land at circle rate or purchase price
- Battery recycling support: capital interest subsidy @ 50% per annum for five years on loan reimbursement

Maharashtra

- Benefits to battery manufacturing for EVs will be as per a fixed 'template' (approved by cabinet sub-committee)
- MSEDCL is exploring to procure power from RE sources along with energy storage

Andhra Pradesh

- Capital subsidy of 10% on battery and charging equipment, capped at INR20 crore
- Bring in manufacturing units of high-density energy storage of minimum 10 GWh capacity by 2023

Karnataka

- Interest-free loans on net SGST and ETP subsidy
- Production-linked subsidy of 1% on turnover to enterprises involved in manufacturing EV cells, battery pack and modules and battery swapping equipment

Tamil Nadu

- Target of 1.9–3.6 GWh of BESS by 2025
- Capital subsidy of 20% on investments made till FY 2025
- 100% electricity tax and stamp duty exemption till FY 2025
- Production-linked subsidy of 1% on turnover to enterprises involved in manufacturing EV cells, battery pack and modules and battery swapping equipment

3.4. Demand for batteries of current and upcoming chemistries/technologies

Government of India's goal to shift to a low-carbon economy through adopting clean energy presents a profitable set of opportunities for energy storage in India. Battery storage has become a reality because of the energy sector's growing technology landscape and efficient cost-cutting tactics across the supply chain creating unique storage solutions for certain applications. With the introduction of Advanced Cell Chemistries (ACCs), developing application-specific tailored storage solutions, which was once difficult and time-consuming, has become possible.

A future disruptive battery manufacturing ecosystem may be created via coordinated governmental and private sector activity.

3.4.1. Methodology for demand projections

For projecting the demand of battery energy storage in India by 2030, the authors used a bottom-up approach in the stationary storage, and electric mobility segment. The methodology adopted for demand projection of stationary storage applications is illustrated below

Figure 30: Stationary storage application demand methodology

Sector-based research: Data is based on extensive desk research to identify most relevant secondary information.

Data validation includes a review of existing reports and penetration levels and correlation of our projections

Analysis and **forecast model generation:** Based on data collected, our in-house subject matter experts convert this into critical insights. A bottom-up approach is considered for estimating the market size.

For each of the segments in the study, individual market forecast models are developed considering various assumptions, trends and data, to project the market forecast till 2030.

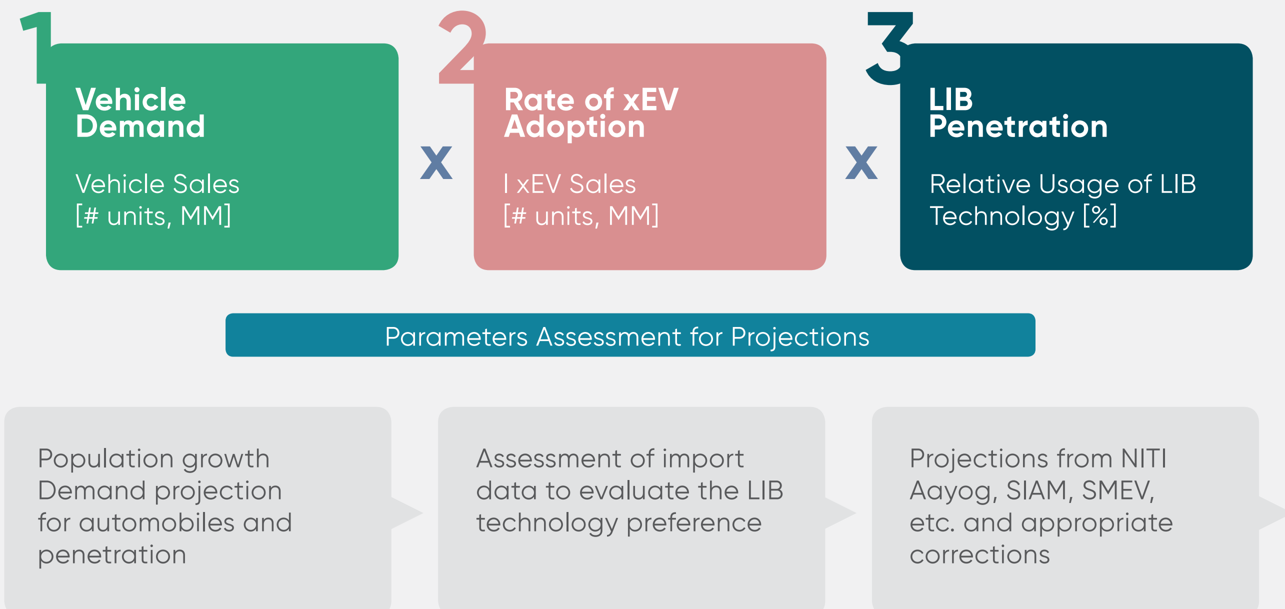
Three cases have been considered to estimate market growth – namely, **the base case (business-as-usual, BAU), conservative and optimistic cases.**

Annual demand for batteries for stationary storage applications is determined based on the projections from the above segments.

Grid-scale applications: A quantitative analysis of the tenders floated for RE integration (RE + storage) is conducted in view of the target of 450 GW of RE by 2030 to estimate the battery demand potential for grid-scale applications. On the basis of the present market scenario for solar, wind, rural electrification, distribution and transmission level, we estimate the annual demand for grid applications in GWh.

BTM applications: Based on an assumption that batteries will be used more frequently in telecoms, the number of mobile towers is projected at a CAGR of 7% till 2030. Using this projection and assuming that the average battery demand will be 5 KWh, the potential market demand for batteries in telecoms is estimated. Similarly, the battery demand for appliances like UPS and invertors is estimated. For consumer electronics, projections are taken from the Indian Cellular and Electronics Association and average battery requirements for mobile phones, laptops, etc. are used to forecast the annual battery usage till 2030.

Figure 31: E-mobility storage applications



3.4.2. Demand projections from 2021 to 2030

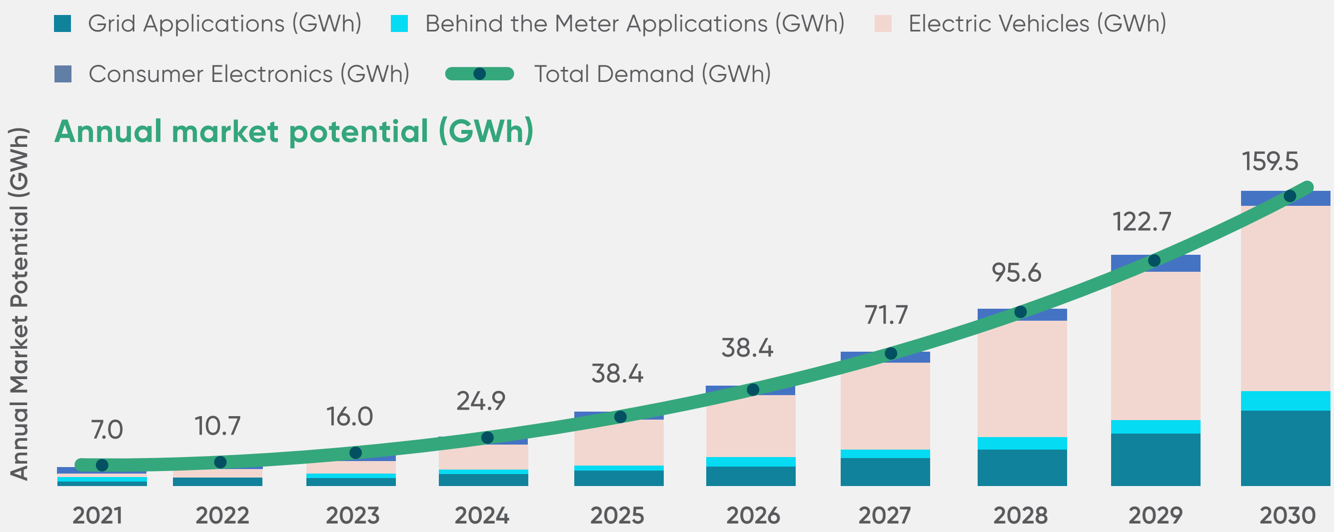
The demand projections were calculated under three cases – BAU, conservative and optimistic. Segments like EVs are projected to be major demand drivers for the adoption of battery storage in India.

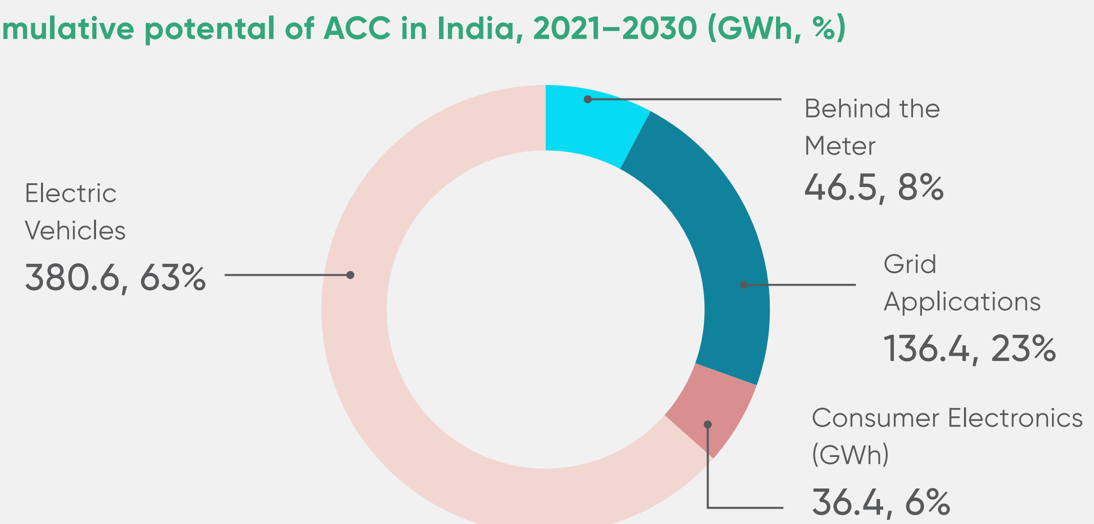
Based on the authors' analysis, the total cumulative potential for battery storage in India will be 600 GWh by 2030 – considering a base case scenario, with EVs making up a large chunk of this (63%), followed by grid applications (23%), BTM applications (8%) and consumer electronics (6%).

Table 9: Annual demand projections for battery energy storage in India, 2021–2030

Annual deployment (GWh)→	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Cumulative deployment (2021–2030)
Conservative	5.0	7.8	12.3	19.6	29.7	39.5	51.1	62.7	83.1	106.1	419 GWh
BAU	7.0	10.7	16.0	24.9	38.4	53.3	71.7	95.6	122.7	159.5	600 GWh
Optimistic	9.2	14.6	23.0	35.2	54.3	73.9	94.9	121.0	153.8	208.7	788 GWh

Figure 32: Cumulative potential of battery energy storage, 2021–2030 (BAU) (GWh)





Source: Authors' analysis.

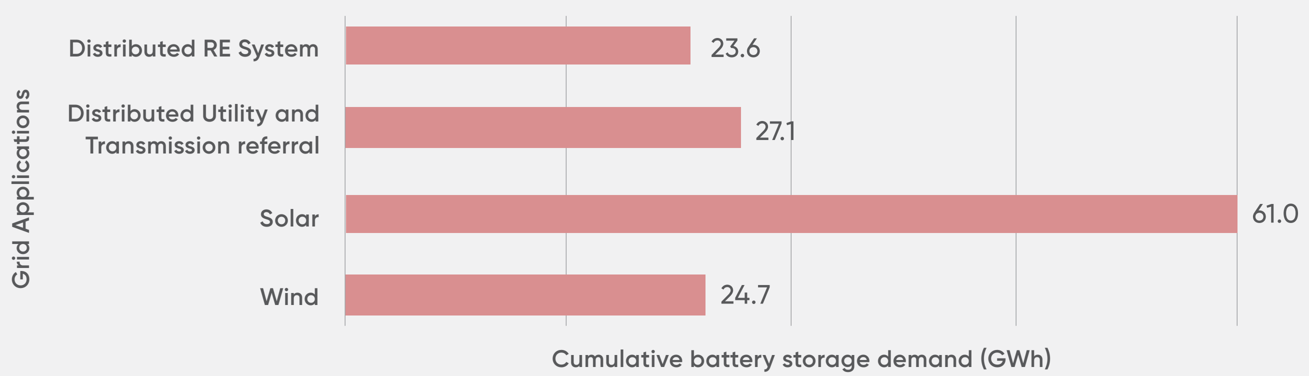
Stationary storage

Grid applications

India is on the cusp of energy transformation and moving rapidly towards cleaner and more reliable and sustainable forms of RE. GoI has established a very ambitious installed capacity target of 500 GW RE by 2030 that includes 170 GW of wind and 280 GW of solar, up from current capacities of around 42 GW and 48 GW.

RE sources are intermittent in nature, and the value and timing of their output cannot be controlled. As a result, the integration of RE into the grid at such a scale will be accompanied by various challenges. These include sharp changes in plant outputs, variability in generation and non-concurrence of generation and demand peaks. These challenges put a great deal of stress on the grid and call for flexibilisation of generation sources and enhancing the flexibility of the overall system. However, the amount of flexibility achieved through the current infrastructure may not be sufficient to integrate the targeted amount of RE. Hence, battery energy storage plays a vital role in providing round-the-clock power and balancing the transmission and distribution load. Figure 33 illustrates the cumulative battery storage potential from 2021 to 2030 in India.

Figure 33: Battery energy storage potential in grid applications, 2021–2030 (BAU) (GWh)



Source: Authors' analysis.

Another, pivotal segment in grid applications would be distributed RE systems such as microgrids, street lighting, lanterns, etc. Distributed renewables play a critical role in achieving true universal access to electricity in India. People have been utilising solar energy to operate their companies because electricity supplies in many areas remain unstable. Solar energy has reached some of these villages before government power lines have, so people have been using it to run their enterprises. In India, a sizable on-grid population is also reliant on off-grid alternatives. The deployment of stand-alone off-grid systems has increased significantly, owing mostly to lower technological prices, implementation innovation and the availability of low-cost concessional financing.[53]

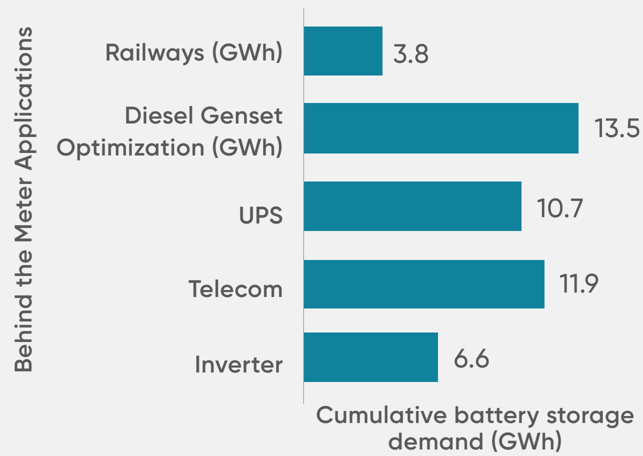
[53] CIF (2019) Dedicated Private Sector Program-Battery Storage. https://www.climateinvestmentfunds.org/sites/cif_enc/files/meeting-documents/ctf_22_7_dedicated_private_sector_program_battery_storage_0.pdf

On the distribution side, higher penetration of rooftop solar photovoltaic (PV), integration of EV chargers and rising commercial loads can create many difficulties for distribution grid operators in maintaining the stability and reliability of the network. Battery energy storage can provide flexibility to help address this. Several distribution companies in India, such as BSES Rajadhani, BSES Yamuna and TPDDL are in the various stages of battery energy storage system installation in their distribution grids. This market is expected to see moderate growth in the short term but, in the long term, when the impact of the factors listed above becomes stronger, dependence on storage will become inevitable, and this will be a major market driver.

Behind-the-meter

India is the second-largest telecommunications market in the world. The total subscriber base stands at 1,209.58 million,[54] comprising 55.4% of rural subscribers in September 2021 as compared with a 42.9% share of rural consumers in September 2019. This indicates potential demand growth from the rural sector and integration of battery energy storage as most telecom towers are located in remote areas. The total telecom tower count in India reached over 606,300 in 2020, marking annual growth of 7.1% from approximately 250,000 telecom towers in 2007. Over the past 13 years, an average of 29,000 new towers have been built per year.[55] It is expected that tower additions will increase twofold with expanding network coverage to rural areas and rollout of 5G during 2022–2024.

Figure 34: Battery energy storage potential in BTM applications, 2021–2030 (BAU) (GWh)



Source: Authors' analysis.

The UPS backup market is driven by demand from end-use groups such as IT/IT-enabled services, data centres, healthcare and manufacturing. With the adoption of energy efficiency practices and with the strengthening of grid reliability, market growth is expected to be slower in the long term. The major projected growth will be governed by data centres;it is expected that the load growth will be from 0.5 GW to 3.1 GW by 2030.[56] Sharp LIB penetration can be expected in data centres, health care and IT-enabled services during the forecast period.

Diesel gensets are being used widely by commercial and industrial users to supplement the unreliable grid, and it is estimated that currently there are over 80 GW of cumulative diesel gensets installed in the country, which is expected to increase to 128 GW by 2030 (at 5% CAGR). The model used for calculating battery energy storage accounts for those gensets operating 1,000 hours annually.

[54] TRAI Telecom Subscription Data, 22 November 2021, www.trai.gov.in/sites/default/files/PR_No.50of2021_0.pdf
[55] Tower and Infrastructure Providers Association (TAIPA) of India
[56] Business Standard (2021) India's Data Centre Industry Capacity to Double by 2023 to 1,008 MW: Report. 24 August.

The current inverter battery market in India is estimated to be around 13 GWh, with the majority covered by LABs (~97%). The overall market is shrinking as a result of a drop in sales from urban customers; however, demand is picking up in rural areas and this is expected to continue till 2030.

Consumer electronics

Consumer electronics is a dominant segment, covering around 60% of the overall LIB market in India (2021). The major appliances are laptops, mobile phones, power banks, notebooks and tablets, etc. With 1.2 billion telecom users and over 0.7 billion smartphones, India is one the leading markets for mobile phones, and this market is expected to grow at 14% annually. The average battery capacity considered for computation of battery demand is 3000 mAh till 2024 and 4000 mAh thereafter. Similarly, for laptop and notebook the annual market is around 13.5 million, with expected cumulative sales of around 150 million by 2030. The average battery capacity considered for computation of battery demand is 4400 mAh till 2024 and 4500 mAh thereafter.

The current consumer electronics battery market in India is estimated to be around 9.4 GWh, with the majority covered by LIBs. The overall market is expanding as a result of a increase in sales from customers as demand is picking up in urban as well as rural areas and this is expected to continue till 2030.

Electric vehicles

With the launch of the National Mission for Transformative Mobility, India is expected to witness a giant boom in EV penetration in the next decade. Out of 600 GWh of cumulative projected demand for battery energy storage in India from 2021 to 2030, 381 GWh will be catered to by EVs. This is quite significant considering that tier 2 and tier 3 cities are already swiftly adopting electric three-wheelers.

Table 10: EV penetration level assumption by 2030 considered for this study

Segment	Base case	Conservative case	Optimistic case
E3W	75%	55%	100%
E2W	70%	50%	80%
E4W (passenger)	20%	10%	30%
E4W (commercial)	40%	25%	50%
E-buses	30%	20%	40%

In FY21, E3W sales accounted for 40% of the overall three-wheelers – EV + internal combustion engine (ICE) – sold in India. The E3W segment is driven by e-rickshaws and will lead the demand for batteries for EVs in India. Another segment that is following a similar trend is E2W, which is providing better offerings in terms of operational and acquiring costs in metro cities.

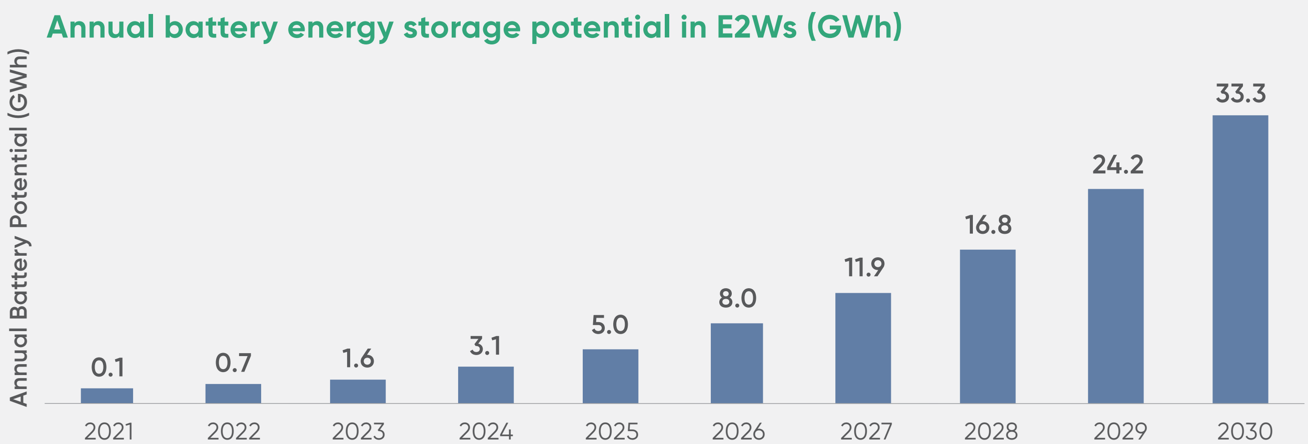
In order to project demand for battery energy storage in the e-mobility segment, annual sales penetration of EVs was calculated. As far as the 2021 - 22 sales are concerned, similar to the overall Indian automotive industry, the EV sector witnessed a slump in sales because of the economic inactivity resulting from the COVID-19 pandemic.

In this context, a total of 1,21,915 EVs were sold in 2021-22. E2Ws and E3Ws constituted the highest fraction of the sales. E4Ws and goods vehicles continued to occupy a meagre share of the total EV sales.

Table 11: Battery size assumption by EV category

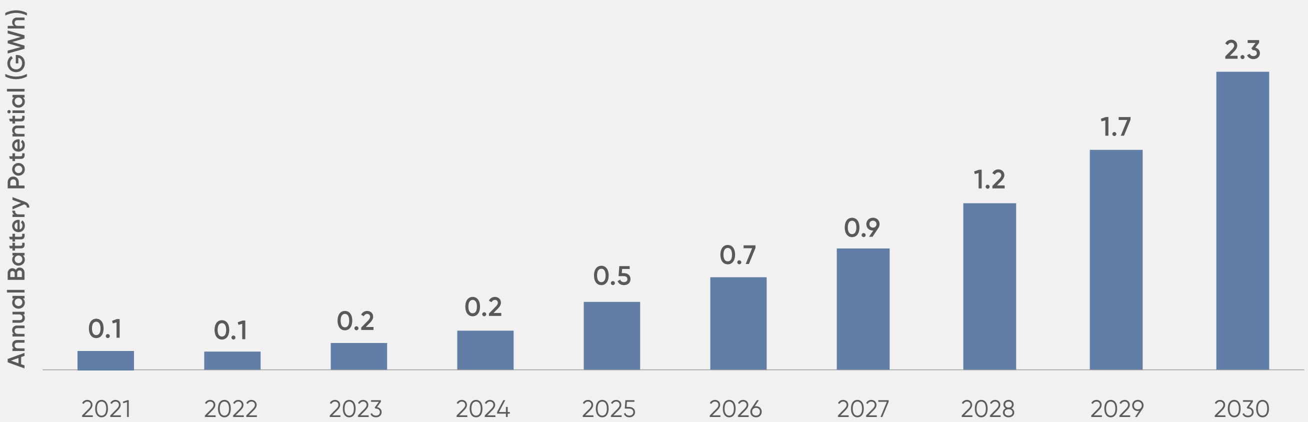
Category	Battery size (kWh) 2020–2024	Battery size (kWh) after 2024
E4W (passenger)	31	40
E4W (commercial)	31	40
E3W	5	7
E2W	2	2
Buses (public)	250	250

Figure 35: Annual battery energy storage potential in EVs, 2021-2030 (BAU) (GWh)

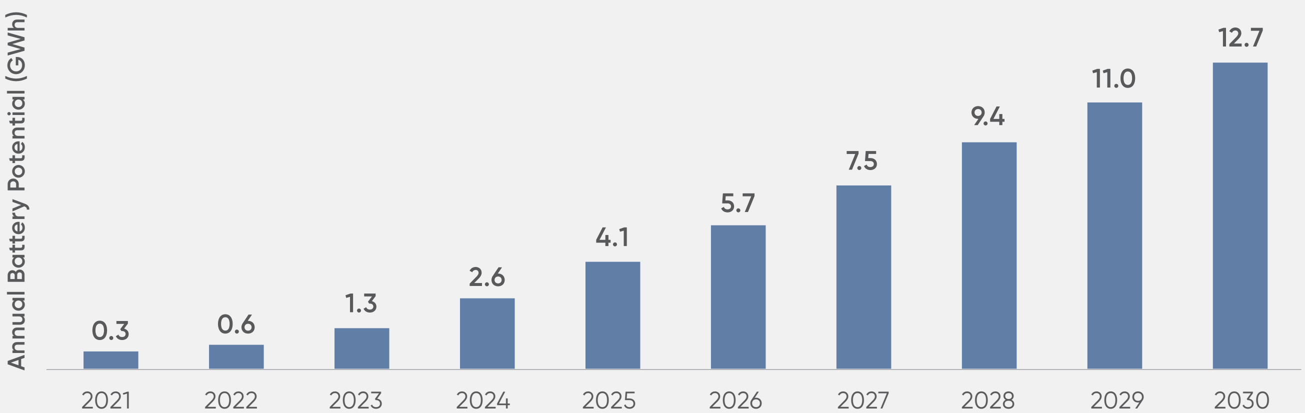


Source: Authors' analysis.

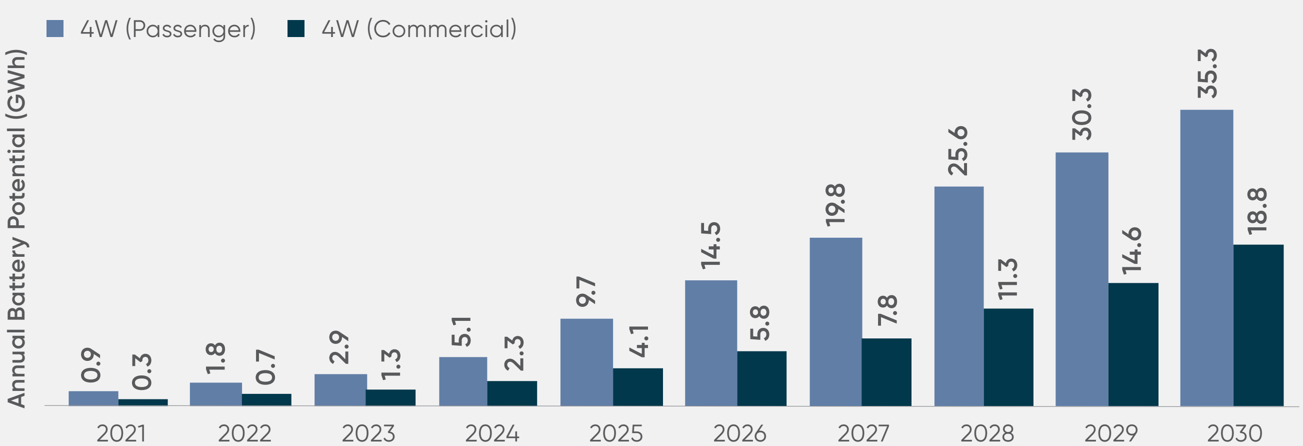
Annual battery energy storage potential in E3Ws (GWh)



Annual battery energy storage potential in electric buses (GWh)



Annual battery energy storage potential in E4Ws (GWh)



Source: Authors' analysis.

Electric two-wheelers

The demand for E2Ws has witnessed slow but steady growth in the recent years. The major factor behind this has been GoI pushing through various fiscal and non-fiscal incentives, including schemes, policies and subsidies. However, the stringent eligibility criteria for claiming the subsidies (i.e. a minimum localisation requirement and exclusion of lead-acid based E2Ws for a subsidy under FAME II) has been a major hurdle, decelerating the potential growth of the segment.

As per the VAHAN portal, E2W sales accounted close to 40,837 in FY2021, witnessing almost twofold 1.6 times growth on previous year's sales. The share of LIBs in overall E2W sales is around 39%, but it is expected to reach 80% by 2030.

Figure 36: LIB penetration as part of overall battery demand in E2Ws – ~80% by 2030

E2Ws

	2020(A)	2025(E)	2030(E)
Total Sales in Nos. (CAGR-7%)	151 L	212 L	297 L
EV Share (%)	0.3%	19%	50%
EV Sales	0.41 L	40.29 L	148 L

Annual ACC market potential (GWh)		
2025	2030	2021-2030 (Cumulative)
4.99	33.31	104.75

Electric three-wheelers

Sales of E3Ws were more severely impacted by the COVID-19 pandemic than those of E2Ws and E4Ws. This was visible in terms of negative growth rates during FY21 and FY22. Apart from the COVID-induced economic slowdown, the major bottleneck to the growth of this segment has been the lack of sufficient financing options owing to low awareness, absence of a standardised second-hand market and perceived uncertainties around vehicle components such as batteries. The driving factors for future adoption include surging demand for E3Ws for last-mile connectivity, such as in delivery of goods.

Figure 37: LIB penetration as part of overall battery demand in E3Ws – ~40% by 2030

E3Ws

	2020(A)	2025(E)	2030(E)
Total Sales in Nos. (CAGR-2%)	2.16 L	3.81 L	6.71 L
EV Share (%)	25%	44%	65%
EV Sales	0.54 L	1.67 L	4.36 L

Annual ACC market potential (GWh)		
2025	2030	2021-2030 (Cumulative)
0.48	2.29	7.79

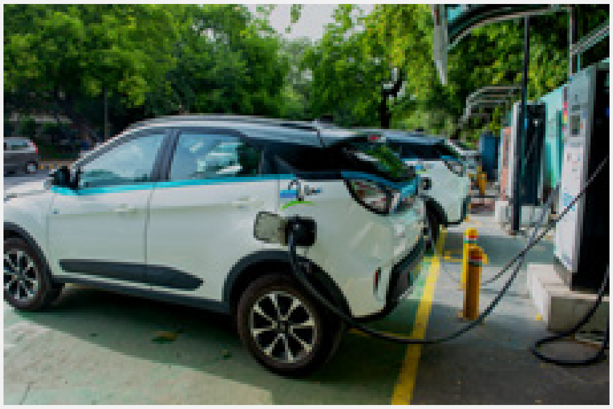
Electric four-wheelers

E4Ws make the least contribution to the country's overall EV sales vis-à-vis E2Ws and E3Ws. The major reason for these relatively lower sales is high cost of acquisition as well as limited availability of EV models in the E4W segment in India. As far as goods vehicles (4W commercial) are concerned, sales have started gaining traction again after plummeting heavily during the COVID-19 pandemic.

On the positive side, multiple OEMs in each segment have planned to introduce a wider range of EV models in an effort to accelerate EV adoption in India. Furthermore, both central and state governments are showing dedicated support in the development of local manufacturing hubs for EV components along the value chain.

Figure 38: LIB penetration as part of overall battery demand in E4Ws (commercial) – ~100% by 2030

E4Ws (commercial)



	2020(A)	2025(E)	2030(E)
Total Sales in Nos. (CAGR-2%)	4.53 L	7.31 L	11.7 L
EV Share (%)	0.2%	14%	40%
EV Sales	769	1.02 L	4.71 L

Annual ACC market potential (GWh)		
2025	2030	2021-2030 (Cumulative)
4.09	18.84	66.88

Figure 39: LIB penetration as part of overall battery demand in E4Ws (passenger) – ~100% by 2030

E4Ws (passenger)

	2020(A)	2025(E)	2030(E)
Total Sales in Nos. (CAGR-7%)	27.1 L	34.6 L	44.1 L
EV Share (%)	0.2%	7%	20%
EV Sales	4.6 k	2.42 L	8.83 L

Annual ACC market potential (GWh)		
2025	2030	2021-2030 (Cumulative)
9.69	35.33	146.01

3.5. Projections of volumes of EOL batteries expected over the next decade

A three-step approach was undertaken to project the volumes of EOL batteries expected over the next decade – that is, by the year 2030.

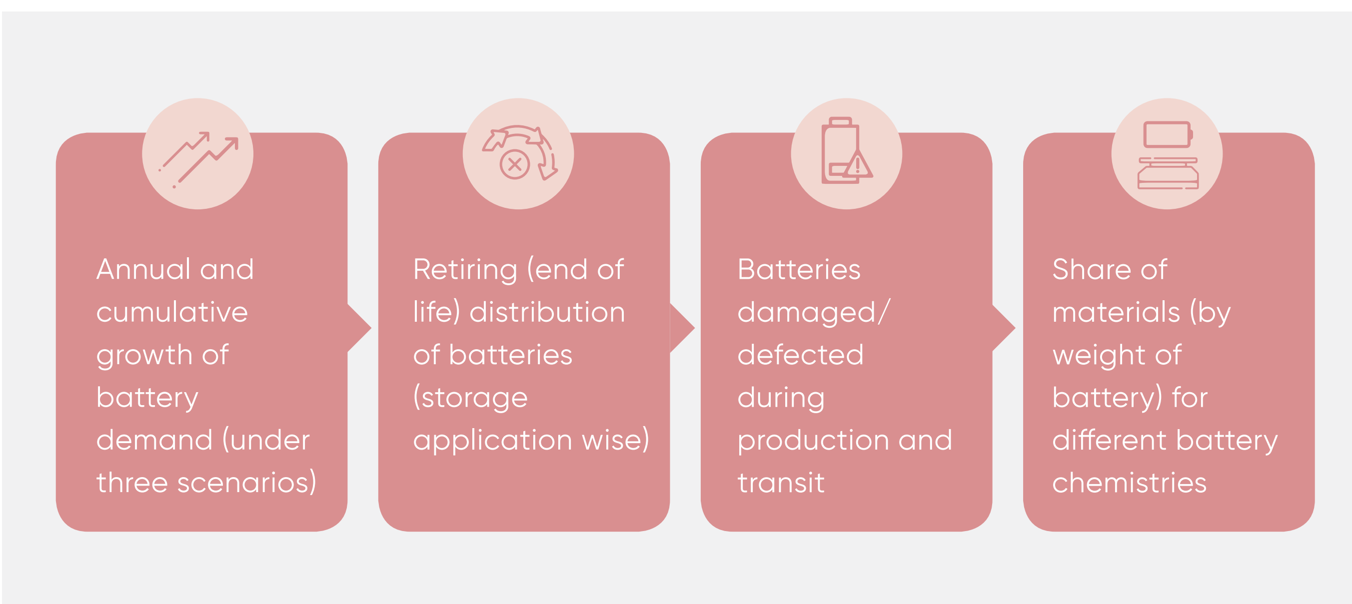
First, the annual and cumulative growth of the battery storage market in India is estimated under three scenarios (conservative, base and optimistic). In addition, a number of assumptions are made with regard to battery module weight, application-wise battery replacement rates and batteries damaged during transportation and construction. Based on these scenarios, the battery recycling quantum is calculated in GWh terms both annually and cumulatively till the year 2030.

Second, the volume of different battery chemistries coming from projected recycling market is calculated using a similar pattern of technology forecast for each segment with a forecast period of 2021–2030. Following this, the volume is converted into tonnes by using the average energy density (Wh/kg) of respective battery chemistries.

Finally, the cumulative mineral share (amount of copper, graphite, etc.) that can be recovered through battery recycling is calculated.

3.5.1 End of life volume potential

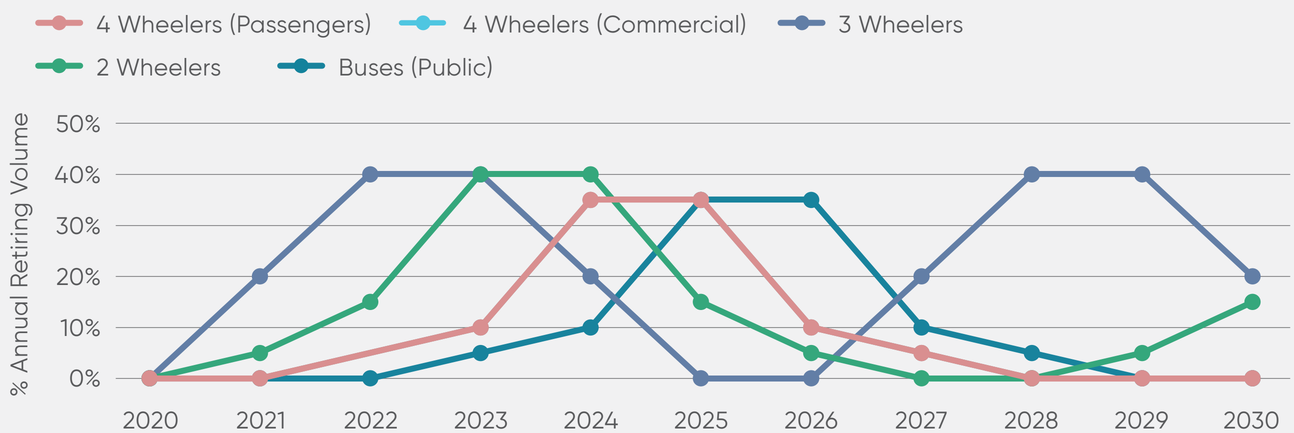
To calculate the battery recycling market and the recoverable cumulative mineral share over the next decade, we have made a few consequential assumptions regarding:



Based on the total battery demand in each of the segments, we estimate the EOL of batteries, using scrappage and defect percentages. A distribution pattern of EOL for each segment is considered to calculate batteries coming in for recycling.

Figure 40 presents the EOL distribution of EV batteries coming in for recycling. For example, batteries with a life cycle of seven years are distributed across years, with 35% coming in the sixth and seventh years, 15% in the fifth and eighth years and 5% in the fourth and ninth years. A similar distribution of battery EOL is taken for stationary and consumer electronics, with seven years. Additionally, a defect percentage of 7% is considered for calculating recycling volumes in each segment.

Figure 40: End of life distribution pattern of EV batteries

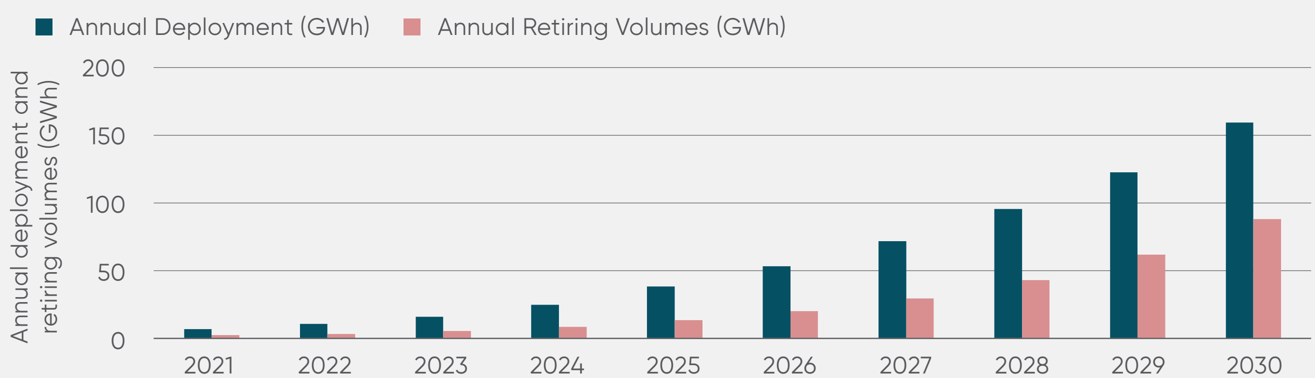


Source: Authors' analysis.

Note: The retiring or end of life distribution pattern for 4 Wheelers (Commercial) and Buses (Public) batteries are assumed to be the same and as such their lines overlap each other in the graph

Based on the above EOL distribution pattern, the retiring quantum for each category is calculated in GWh.

Figure 41: Annual demand projection and retiring volumes (GWh)

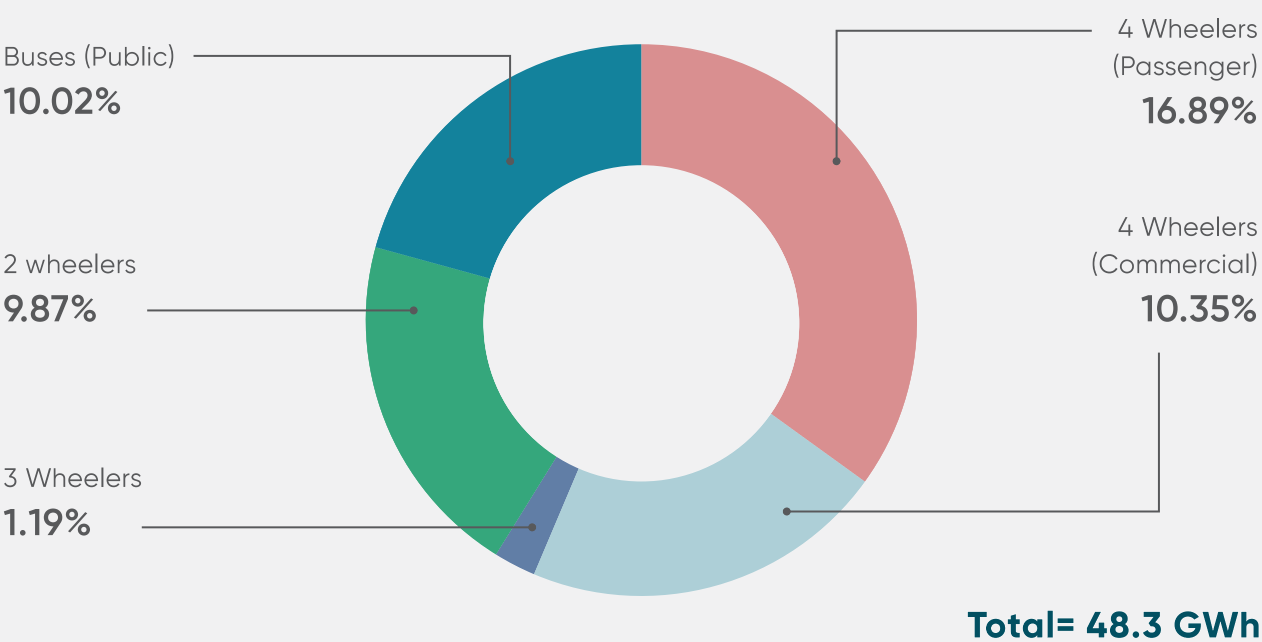


Source: Authors' analysis.

3.5.2. Reuse volume potential

Determined by the rapid uptake of batteries in the EV segment and their cost of production, LIBs are increasingly being reused, and eventually recycled to recover all the valued components. Usually, battery replacement occurs when their performance falls below 70–80% of the initial nameplate capacity and these batteries can further support operations in different applications. EV batteries completing their full life cycle usually retain 70–80% valid energy and can be reused in grid-connected and BTM applications. However, this also depends on the type of cell packaging, the ease of disintegration, efficient removal of battery management system, etc.

Figure 42: Cumulative reuse volume potential, 2021–2030 (GWh)



Batteries from E2Ws and E3Ws have a lower second life because they have seen more charging and discharging cycles and because of their size and their further reuse in other segments. To calculate reuse volume projections, it is assumed that only 25% of retiring batteries of E2Ws and E3Ws will go for reuse for an extended life of two to three years in segments like inverters, UPS, telecoms, etc. Similarly, 60% of retiring batteries of E4Ws and e-buses will be reused for an extended life of four to five years in grid applications. After their expected life, the reuse volumes are added to the recycling volume of that year.

The reuse percentage for the E2W and E3W segments is kept at a lower rate since most batteries cannot be reused when their performance falls below 70–80% of the initial nameplate storage capacity, as their charge holding capacity also decreases and they cannot be reused in the market. Also, for the same reason, the expected secondary life of such batteries is less.

Moreover, we consider that battery packs may get damaged over the course of their usage and, also, they may not be suitable for reuse, owing to their size, packing or any other defects. The reuse volumes coming from E4Ws and buses is larger and hence we have assumed that they are reused in small and large grid-scale storage.

Figure 43: Annual reuse and recycling volumes coming from EVs (GWh)

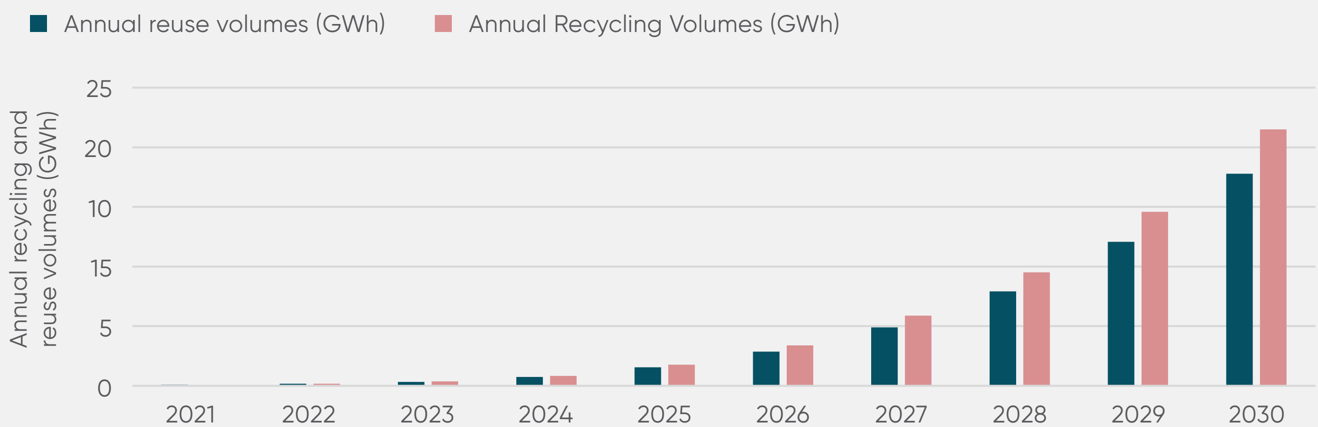


Figure 43 illustrates the annual reuse and recycling volume coming from the EV segment. It is to be noted that the reuse volumes do not come back for recycling after their extended life in the EV segment, as this is used predominantly in SAs. Therefore, all the reuse batteries coming from the EV segment end up recycled in SAs once they are utilised for their second life.

3.5.3. Recycling volume potential

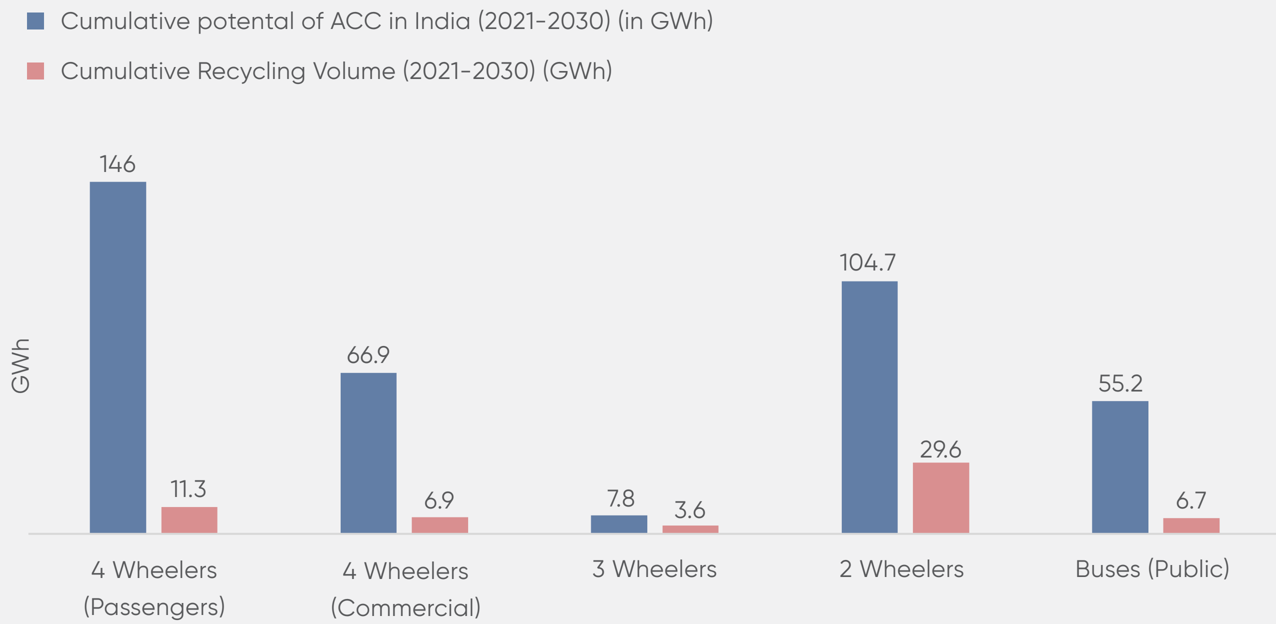
Since only batteries from EVs are reused, given their 70–80% charge availability, other batteries utilised in SAs and CEAs are considered for recycling once they complete the EOL distribution. It is assumed that 25% of batteries of E2Ws and E3Ws and 60% of batteries of E4Ws and e-buses will go for reuse in stationary storage applications. Once the batteries have been utilised in their extended life, they will be recycled in the same segment.

Figure 44 illustrates the cumulative demand projections from 2021-30 of lithium-ion batteries in India and the corresponding recycling volumes.

It is estimated that the cumulative potential of lithium-ion batteries in India from 2021-30 across all segments will be around 600 GWh (base case) and the recycling volume coming from the deployment of these batteries will be 125 GWh by 2030. Out of which almost 58 GWh will be from electric vehicles segment alone.

Figure 44: Demand projection for LIBs and recycling volume projection, 2021–2030

Demand projections v/s recycling volumes in e-mobility segment



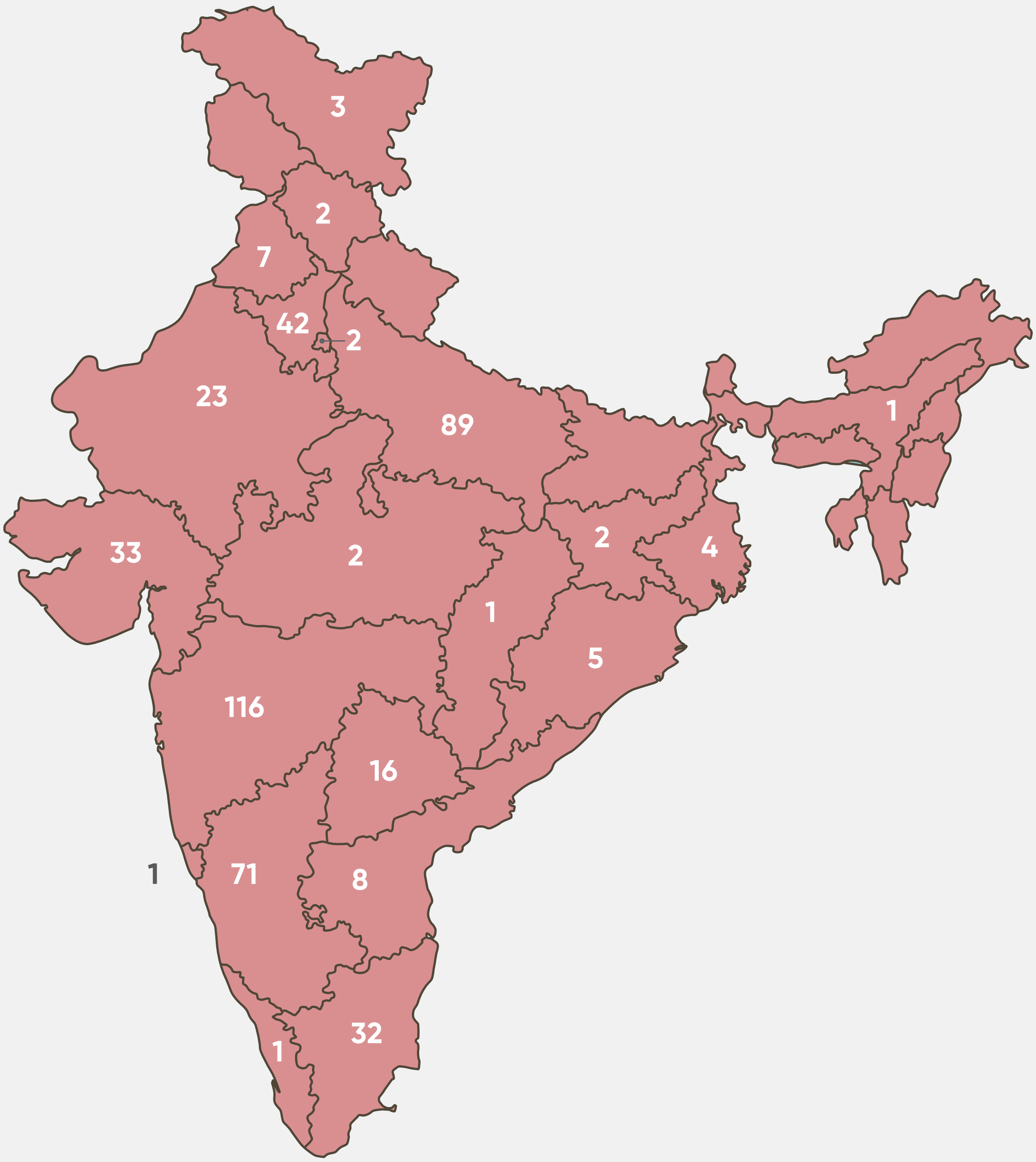
Demand projections v/s recycling volumes in stationary and consumer electronics segments

Source: Authors' analysis.

The recycling volumes in SAs not only account for the older batteries coming after their EOL but also for EV batteries that are reused and further end up in recycling.

As of December 2021, there are around 468 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 13,85,932 MT per annum. A complete list of authorised recyclers is enclosed in Annexure A4.

Figure 45: State-wise number of authorised dismantlers/recyclers of e-waste in India



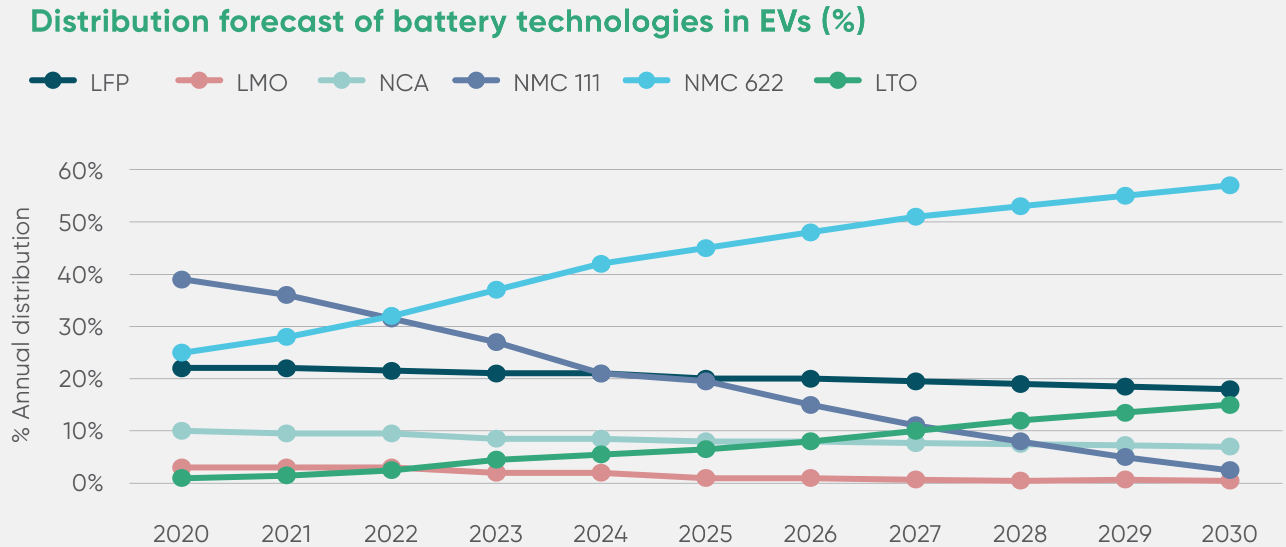
Source: CPCB.

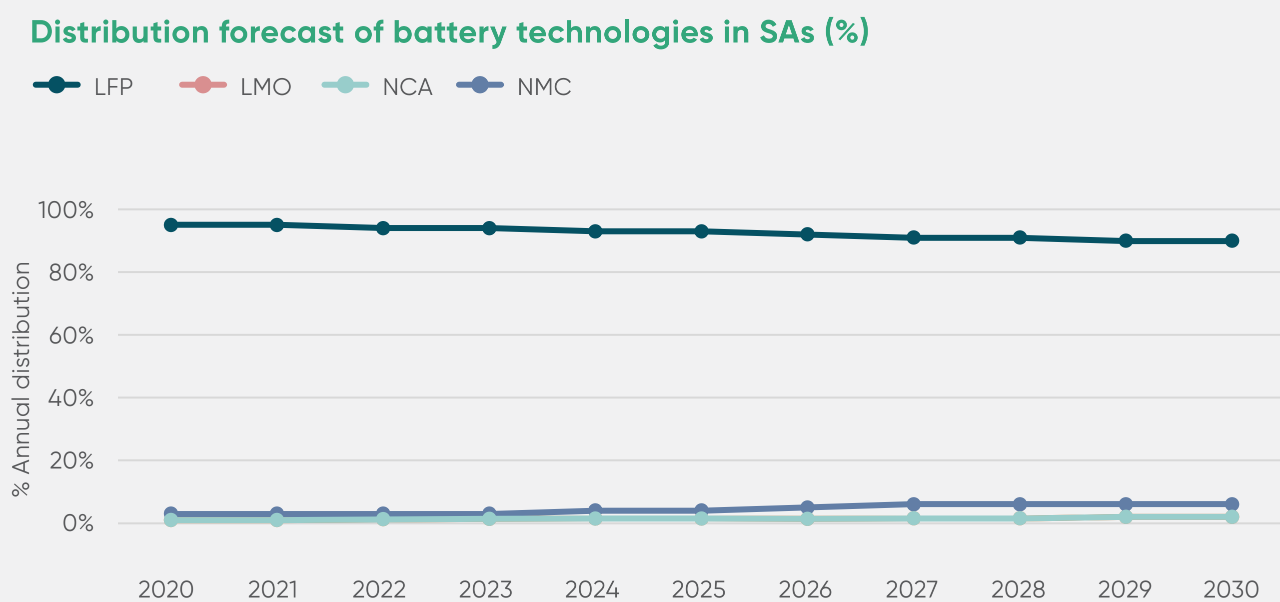
3.5.3.1. Distribution forecast of different chemistries

LIBs are one of the fastest-emerging technologies because of their light weight, portability and efficiency. They offer higher energy density compared with LABs, which makes them a first choice for EVs and electronic devices.

Advances in R&D on the internal chemistry of LIBs mean there are many variations available on the market, including LCO, LTO, LMO, LFP, NMC and NCA.

Figure 46: Distribution forecast of battery technologies in EVs and SAs, 2021–2030





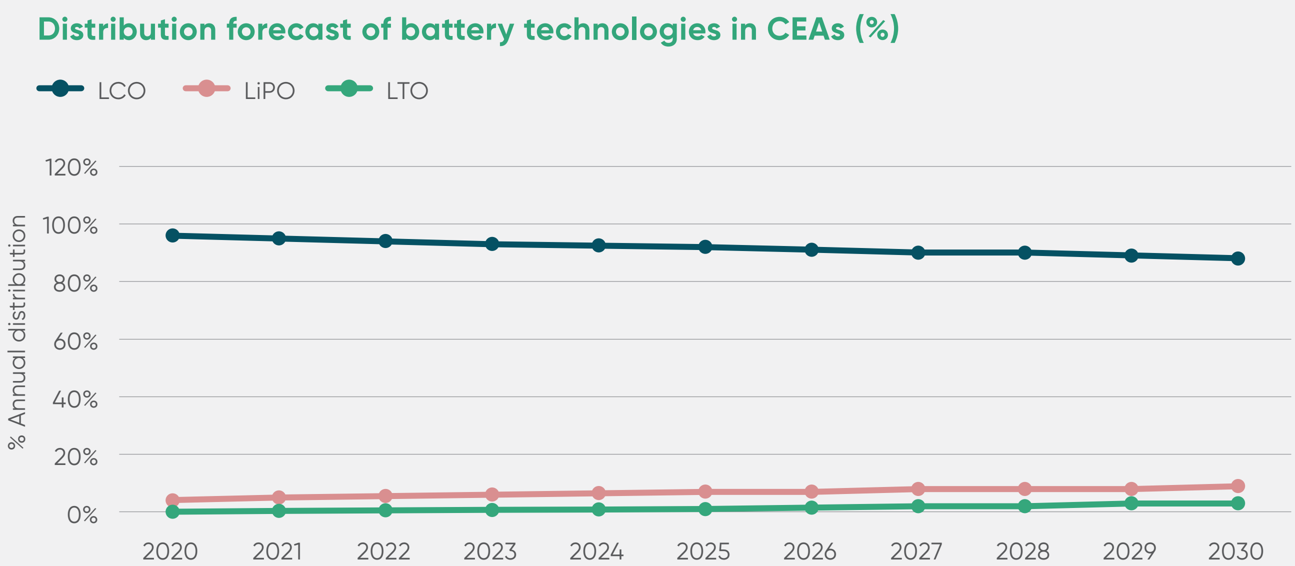
Source: Authors' analysis.

Currently, the EVs available in India predominantly use NMC batteries (NMC 111 and NMC 622), which take up an over 65% share, followed by LFP, NCA and LMO. However, Suzuki India mainly uses LTO batteries and, considering the overall share in the automobile market, the penetration of these batteries is expected to increase in future.

SAs predominantly use LFP chemistry batteries as they are known to be long-lasting, safe and the cheapest of all LIB technologies. LFP chemistry also guarantees a higher cycle life, with some Tier 1 manufacturers offering more than 4,000 cycles. With the advancement of technologies and improving energy densities, it is expected that penetration of NMC, LMO and NCA will also increase gradually by 2030.

The consumer electronics segment uses mainly LCO batteries; however, Lithium Polymer (LiPo) and LTO penetration is expected to increase in coming years.

Figure 47: Distribution forecast of battery technologies in CEAs, 2021–2030



Source: Authors' analysis.

3.5.3.2. Material share in different chemistries

The battery manufacturing space is evolving at a very fast pace, with demand for longer-run, fast-charging and safer operations; there has been a significant change in different chemistries. Modern batteries have been using three types of cathodes: LFP, NMC and NCA. For smaller and less frequent discharging operations, LFPs are widely used, and they are usually cheaper than NMCs and NCAs because of the absence of highly expensive materials such as cobalt.

Figure 48: Share of materials by weight of batteries in different chemistries

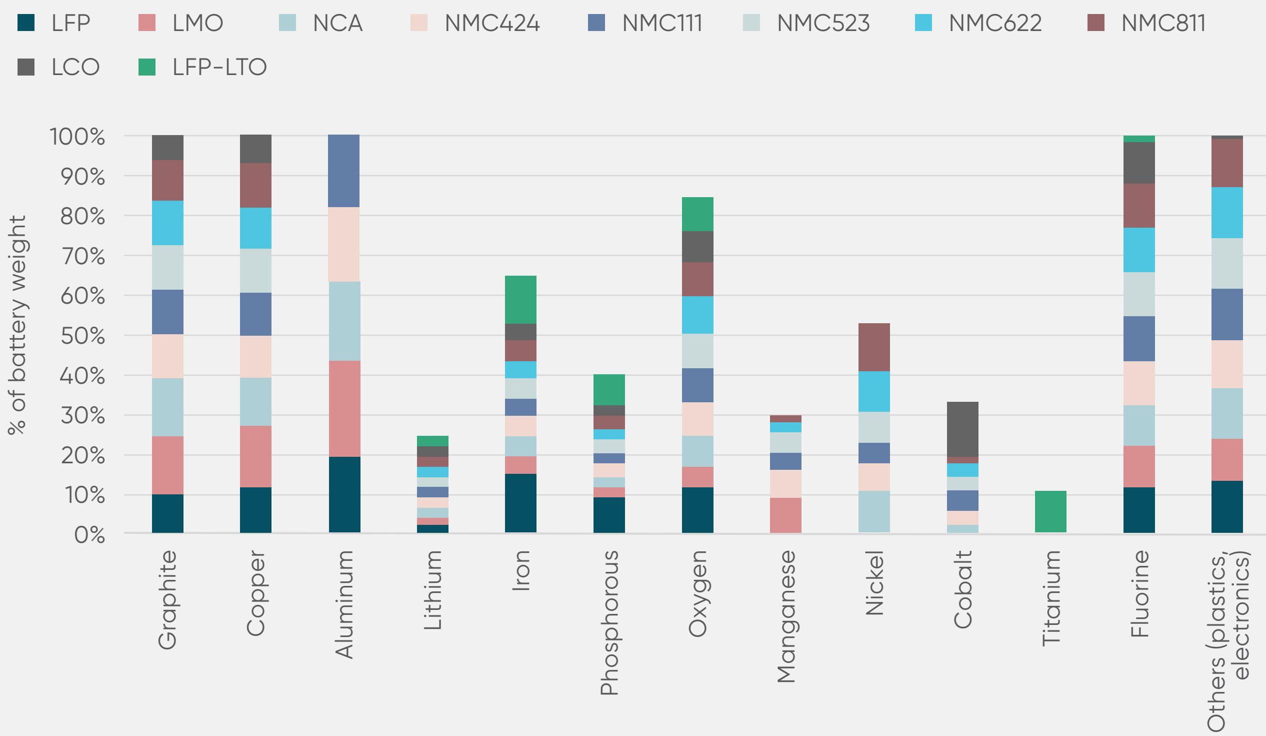
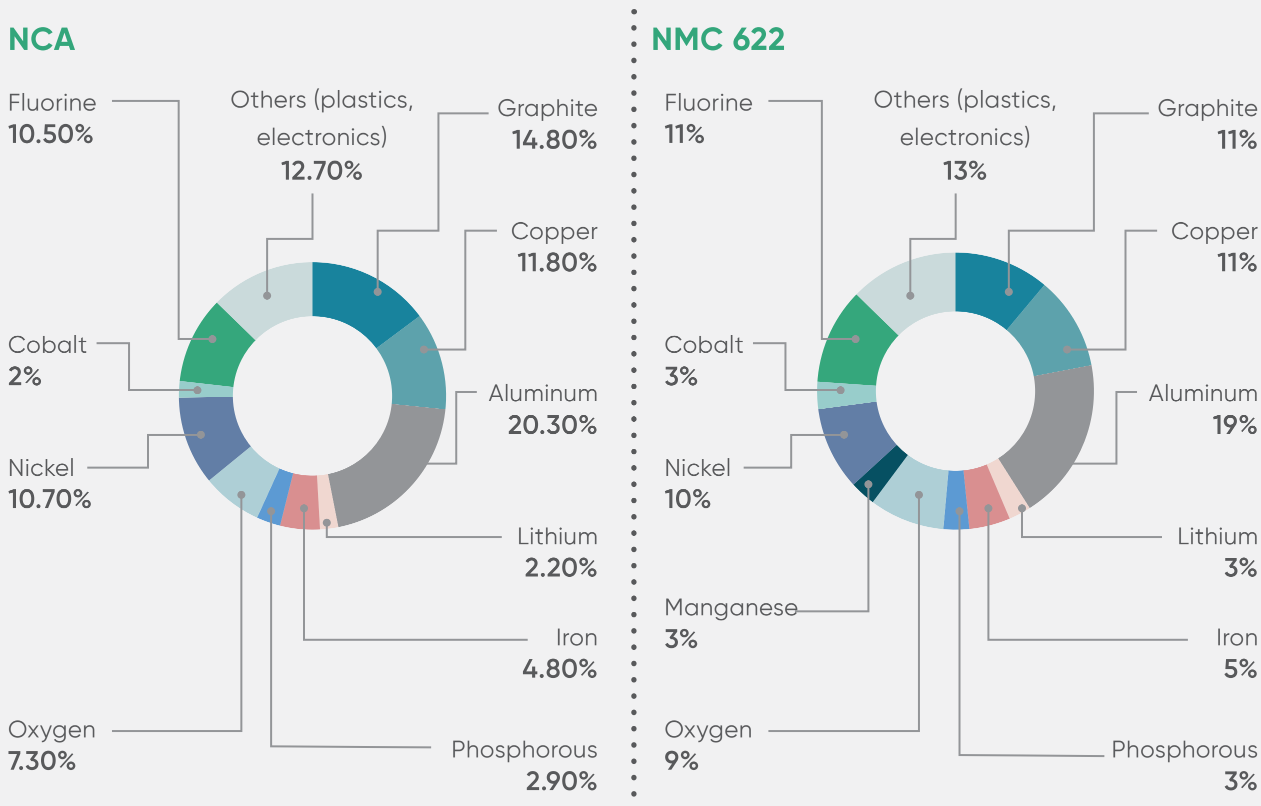
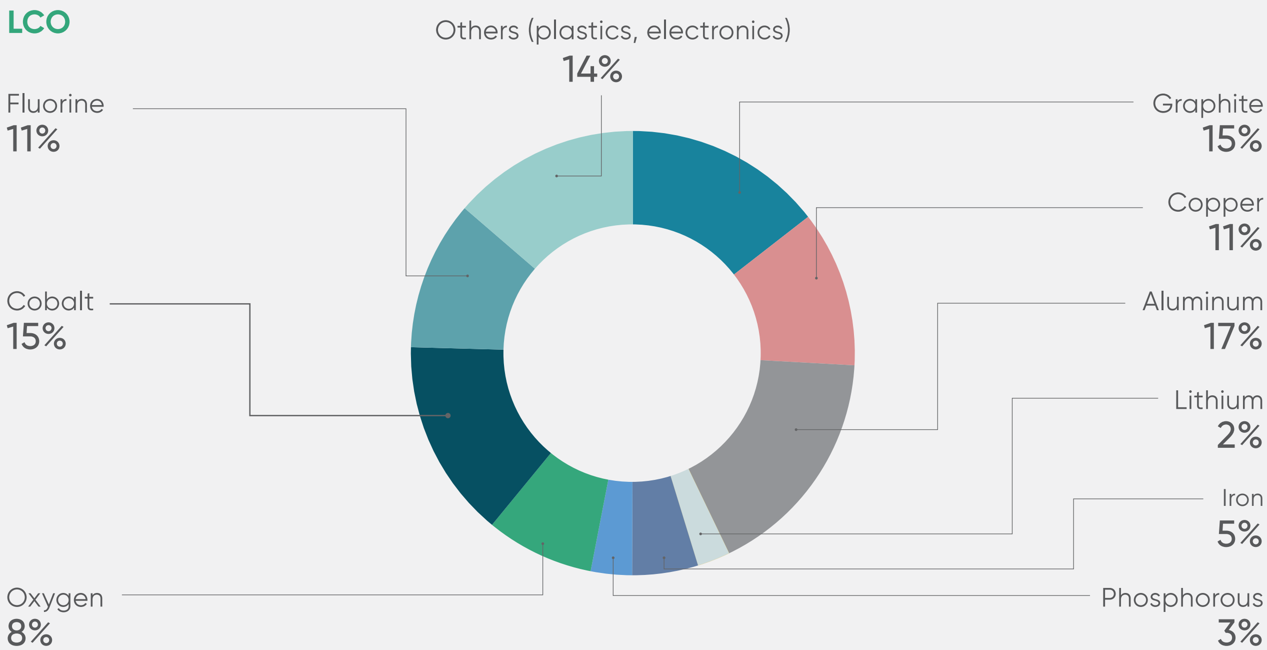


Figure 49: Share of materials by weight in NCA and NMC 622 batteries



However, when applications require higher energy densities and more frequent discharging, NMC is more commonly used (e.g. for EVs); the percentage of nickel, manganese and cobalt is changed to get different specifications within NMC. NCA, on the other hand, has a higher concentration of nickel, thereby providing higher energy density. Figure 49 shows key materials by weight in NCA and NMC 622 battery chemistry. The presence of aluminium is to stabilise the cathode.

Figure 50: Share of materials by weight in LCO and LFP battery chemistries



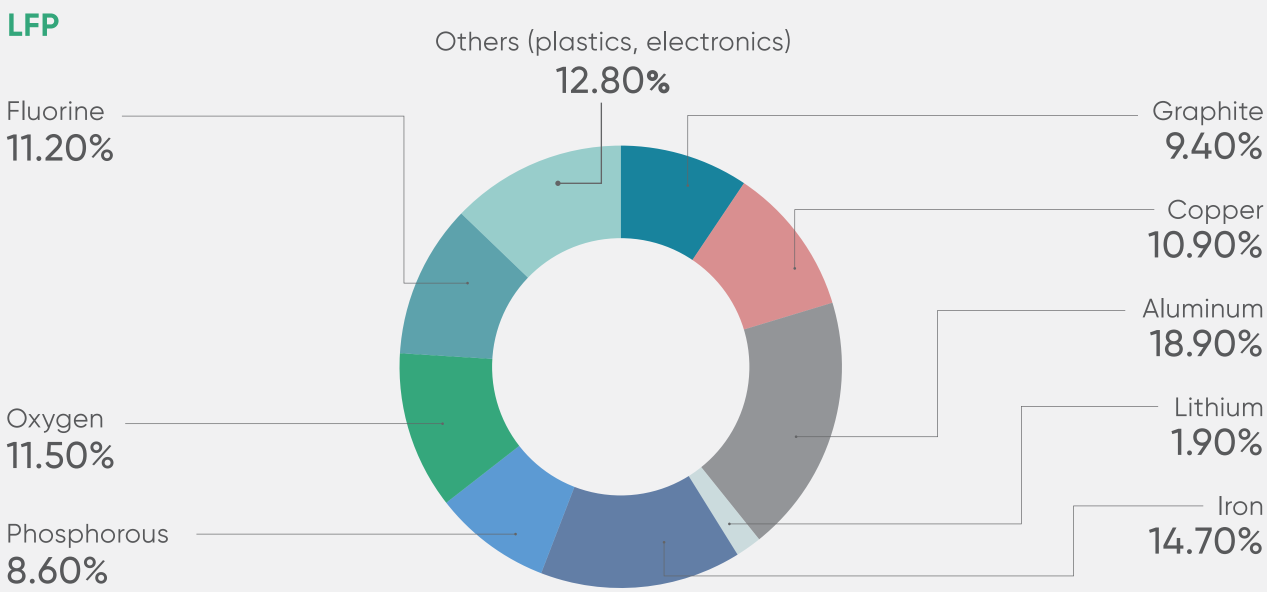


Table 12 illustrates the share of materials by weight of batteries in different chemistries. This pattern is used for determining the ton equivalent of materials that would be available in different chemistries after recycling.

Table 12: Share of materials by weight for different battery chemistries

Chemistry	LCO	LMO	LTO	LFP	NMC	NCA	LiPo
Energy density (Wh/kg)	150–190	100–140	50–80	90–140	140–200	200–250	100–158
Average (Wh/kg)	170	120	65	115	170	225	129

Based on the distribution of different chemistries in SAs and the average energy density (Wh/Kg), the cumulative recycling volume in thousand tons is calculated. We assume that 20% of the weight is from the battery casing.

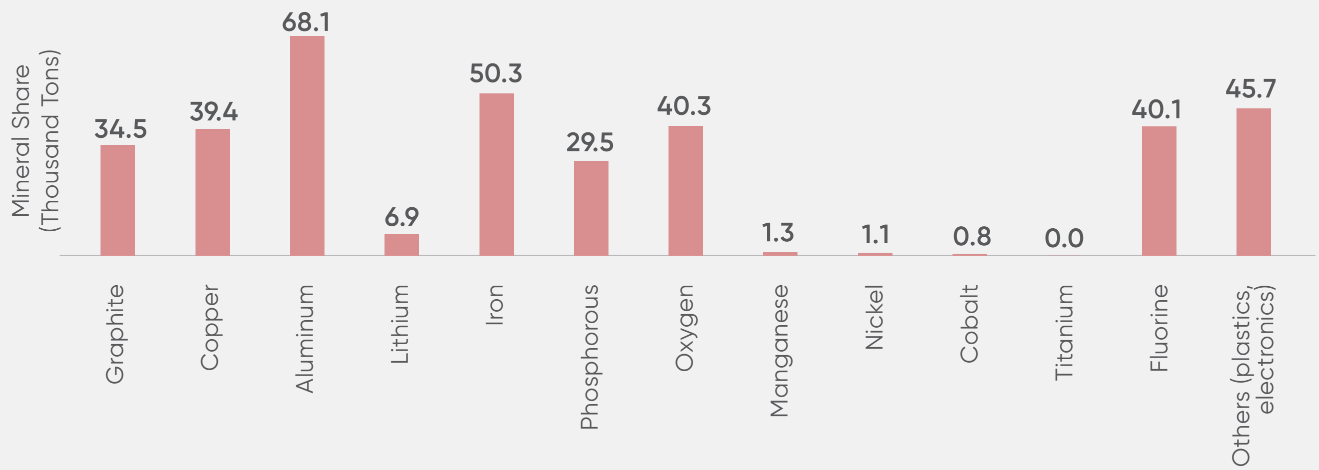
Stationary applications

The recycling volume potential from grid and BTM applications will be 33.7 GWh and 19.3 GWh, respectively, for 2021–2030, accounting 358,000 tons of batteries comprising LFP, LMO, NMC and NCA chemistries.

Assuming 100% metal recovery from these recycling volumes, several key minerals can be extracted. Figure 51 and Figure 52 illustrates the tentative share of minerals that can be recovered during the recycling process.

Stationary storage (BTM + grid)	LFP	LMO	NMC	NCA
Cumulative recycling volume 2021–2030 (GWh)	48.1	0.9	3.0	0.9
Cumulative recycling volume 2021–2030 (thousand tons)	334.7	6.2	14.3	3.3

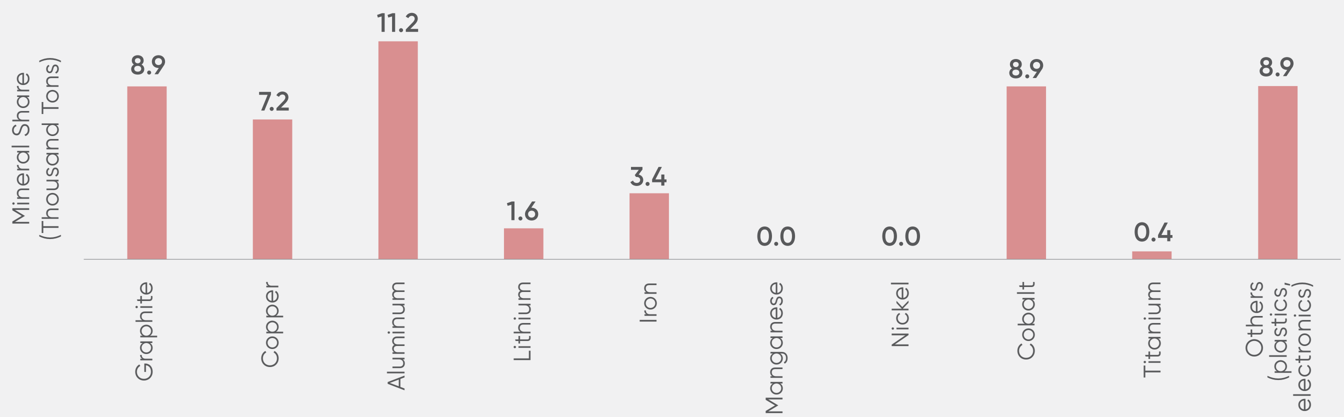
Figure 51: Cumulative mineral share in recycling SA batteries, 2021–2030 (thousand tons)



Consumer electronics

The recycling volume potential from consumer electronics will be 14.5 GWh for 2021–2030, accounting for 72,200 tons of batteries comprising LCO, LiPO and LTO chemistries. Out of 72,800 tons, the majority will come from the LCO chemistry (61,000 tons), given its extensive use in consumer electronic appliances.

Figure 52: Cumulative mineral share in recycling CEA batteries, 2021–2030 (thousand tons)

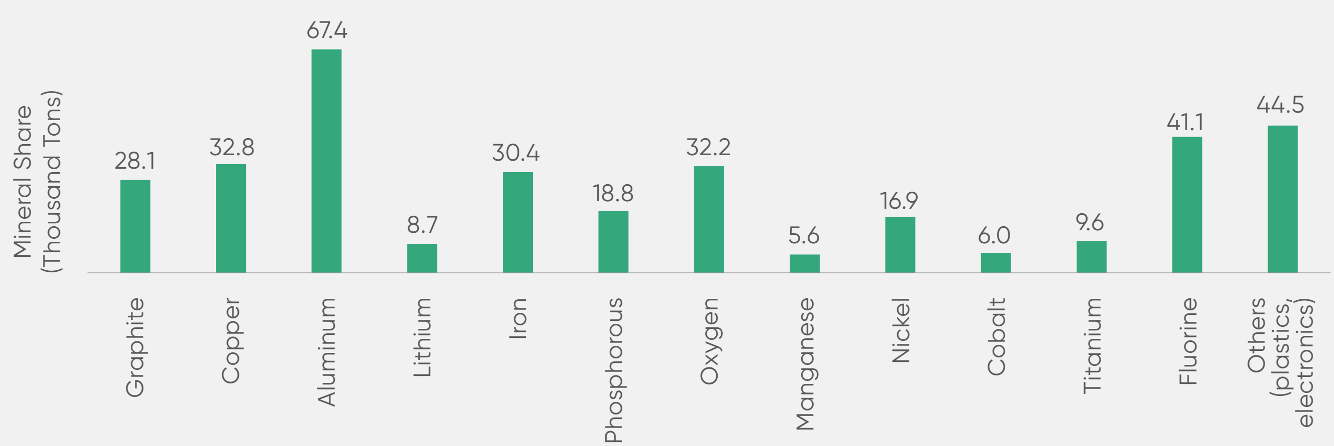


Electric vehicles

The EV category will account for close to 58 GWh of the recycling volume of batteries for 2021–2030, with a total volume of 349,000 tons from chemistries like LFP, LMO, NCA, NMC and LTO. Figure 53 illustrates the tentative mineral share assuming 100% recycling can be achieved.

Electric vehicles	LFP	LMO	NCA	NMC111	NMC662	LTO
Cumulative recycling volume 2021–2030 (GWh)	10.8	0.4	4.3	3.9	31.3	7.4
Cumulative recycling volume 2021–2030 (thousand tons)	75.4	2.5	15.2	18.2	147.2	90.8

Figure 53: Cumulative mineral share in recycling E V batteries, 2021–2030 (thousand tons)



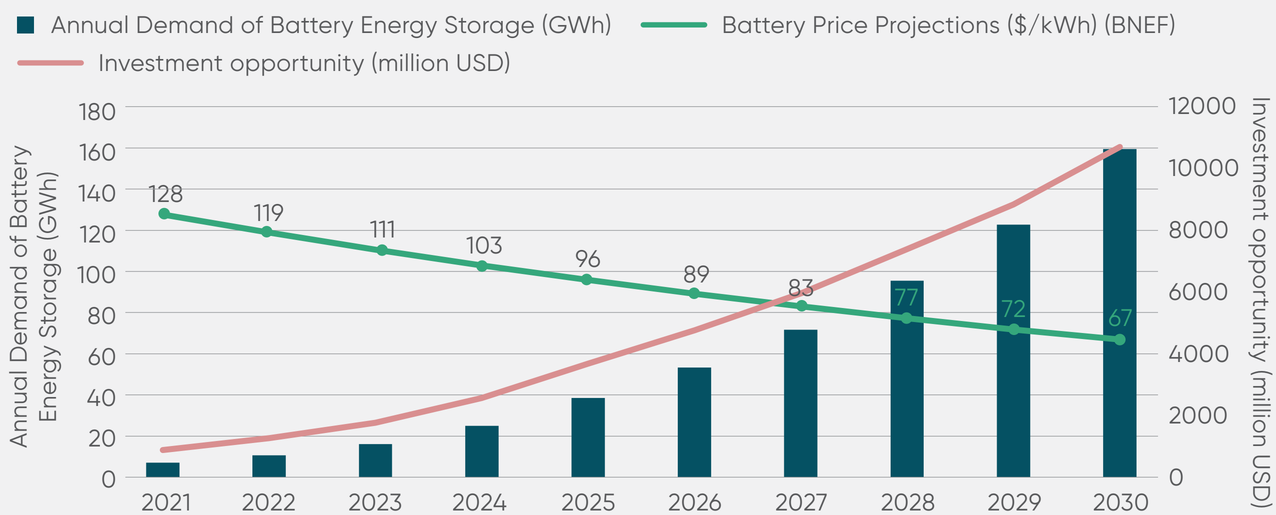
3.6. Investment opportunity

Based on authors' estimates, it is expected that the overall battery requirement will be around 600 GWh by the year 2030. Table 13 presents the annual requirement to arrive at the overall investment on a yearly basis.

Table 13: Investment opportunities in battery energy storage in India, 2021–2030

Total investment opportunity	Annual market	2021	2025	2030	Cumulative (2021–2030)
Grid applications	GWh	2.08	7.9	40.0	136.4
	US$ million	265	761	2,679	10,856
Consumer electronics	GWh	1.91	3.4	6.0	36.4
	US$ million	243	330	403	3,182
Behind-the-meter	GWh	1.36	3.7	11.0	46.5
	US$ million	173	351	737	3,886
Electric vehicles	GWh	1.64	23.4	102.5	380.6
	US$ million	209	2,239	6,868	29,876
India's total market potential	**GWh**	**6.99**	**38.4**	**159.5**	**599.9**
	US$ million	**891**	**3,681**	**10,686**	**47,801**

Figure 54: Investment opportunity in battery energy storage in India



It is estimated that India would see a consolidated investment of US$47,801 million from 2021 to 2030 to cater to the demand for 600 GWh across all the segments of battery energy storage. Around 63% of this investment portfolio would be covered by the electric mobility segment, followed by grid applications (23%), BTM applications (07%) and CEAs (08%). The price reductions in batteries have been considered as per Bloomberg New Energy Finance (BNEF) estimates, as going from US$128/kWh in 2020 to US$67/kWh in 2030 (a 6.9% reduction annually).

Chapter 4

Battery recycling and reuse

4.1. Need for battery recycling and reuse

Although LIB-based energy storage seems a promising solution to achieve the targets set by India on the global stage, several challenges need to be addressed to make the LIB value chain sustainable. These include limited resources, environmental hazards and geopolitical risks. Promoting recycling can overcome these challenges and also lead to better price discovery of resale value of EVs (also second life of batteries). Therefore, a well-established battery reuse/recycle ecosystem can create a circular economy for LIBs in India.

4.1.1. Limited resource availability

As GoI is pushing for local manufacturing of lithium cells in the country, demand for raw materials is expected to grow significantly. But currently there are no local resources for some of the rare metals required for the cell component manufacturing. Either the cell components or the raw materials must be imported to meet demand if the cell manufacturing takes off in the country.

Recycling of batteries can generate a source for these rare metals. Using recycling technologies, 95% of metals can be recycled for use in manufacturing new batteries.

4.1.2. Environmental hazards

India is not yet prepared for the LIB waste that will be generated by their use in EVs and grid-connected storage applications, which is growing fast.

The pieces of legislation that are in effect – the E-Waste (Management and Handling) Rules 2011, the E-waste (Management and Handling) Rules 2016 and the E-Waste (Management) Amendment Rules 2018 – include a range of materials to be recycled. However, they do not yet include a strict set of rules for the safe disposal of EV batteries. LIBs thus find no mention in any framework for EOL treatment or recycling.[57] The recent draft rules – the E-Waste (Management and Handling) Rules 2020 – include LIBs for recycling under extended producer responsibilities[58] but these are yet to be implemented.

If the increasing amount of battery waste is not handled within a well-established recycling ecosystem, these batteries could end up in landfill. Hazardous heavy metals like nickel and cobalt could leak from the casing of EOL LIBs if left untreated and contaminate soil and groundwater. Also, informal recycling could contribute to environmental hazards since toxic gases are released during pre-treatment and treatment processes. On the other hand, a well-established recycling ecosystem could help in price discovery for EOL

[57] Saha, R. and Dey, S. (2020) Electric Vehicle Battery Recycling in India: An Opportunity for Change. Down to Earth, 3 August.
[58] Battery Waste Management Rules (2020). Ministry Of Environment, Forest and Climate Change notification (2020). https://moef.gov.in/wp-content/uploads/2020/02/BATTERY-RULE.pdf

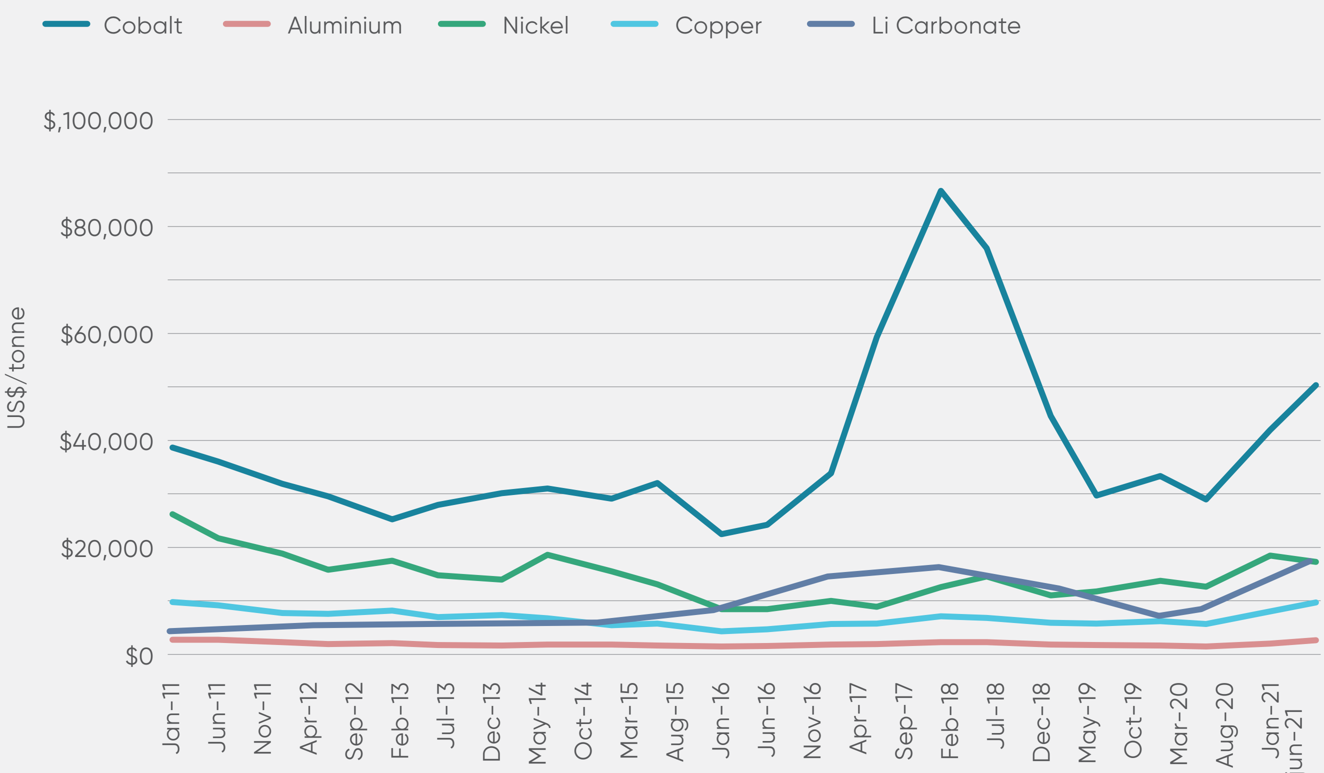
batteries, which in turn will encourage the key stakeholders along the LIB value chain to participate in the recycling and avoid the unsafe disposal of batteries in the country. Thus, battery recycling can help avoid the negative effects of batteries on the environment.

4.1.3. Geopolitical risks

China is the world leader in component manufacturing of LIBs. China leads LIB cell manufacturing with around a 51% share in global cell manufacturing capacity. The country also manufactures 39% (by weight) of the total amount of cathode materials, 27% (by weight) of the total amount of anode materials and 60% (by weight) of the electrolyte materials globally.[59]

Without current manufacturing facilities for cell components, 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. Figure 55 shows the variation of the prices of metals over the years. Cobalt prices have been highly volatile, and a sharp rise and fall can be seen between 2016 and 2019 because of political instability in DRC, where 70% of global cobalt mining occurs.

Figure 55: Price trend of different commodities



[59] Boon-Brett et al. (2017) Lithium Ion Battery Value Chain and Related Opportunities for Europe

The pandemic has also exposed business risks as a result of disruptions in the global supply chain, especially from China, resulting in a long lead time for raw material deliveries. Because of the Covid shock, cargo freight to India from China has also increased by 200% to 300% as a result of operating capacity constraints. This has led to an increase in transportation and other input costs in manufacturing battery packs, thereby putting pressure on profit margins. Recently, China also announced power cuts and several restrictions on the use of power by industries to balance economic growth and tackle climate change.[60] This big decision also affected the global supply chain (thereby increasing product prices) especially from China. India could take advantage of these situations by attracting both global and domestic recyclers to set up LIB recycling facilities in India.

The recent war between Russia and Ukraine has also affected the supply chain of key battery metals like nickel and aluminium, along with crude oil. Russia supplies 10% of global nickel demand. Because of worries about shortages from Russia, nickel prices in the LME have reached a 11-year high price, topping US$100,000 per ton, after gaining about 90% in a day on 8 March 2022.[61] Rusal, a Russian aluminium producer who accounts for about 6% of global supplies, has been shut because of transportation constraints.[62] This may have contributed to the increase in the aluminium price from US$2,500 per ton to an all-time high of above US$4,000 per ton.[63] The dependence on imports for key materials will certainly impact the local supply chain of batteries.

But 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.

4.1.4. Environmental pressure from mineral mining

Mineral mining creates environmental pressure. Metal mining has several negative effects on the environment, like deforestation, GHG emissions, ecological imbalance and water withdrawal. India has reserves of lithium (~1,600 tonnes), nickel (~175 million tonnes) and graphite. There are no primary reserves of cobalt in the country. Two potential secondary sources are nickel ore like laterite and slag from copper extraction.[64]

Mining activities involve land exploitation, which involves deforestation and tends to destroy terrestrial ecosystems, which further leads to loss in the ecological balance at the mining site. Mining is also energy-intensive, which in turn leads to emissions

[60] DW (2021) China: Widespread Power Outages Hit Households, Businesses. 21 January.
[61] Erickson, C. (2022) Nickel Price Spike during Russia-Ukraine Conflict Could Drive up EV Costs. S&P Global Market Intelligence, 3 March.
[62] Desai, P. (2022) Aluminium Nears Record High as Russia-Ukraine Conflict Threatens Supplies. Reuters, 1 March.
[63] Argus (2022) Aluminium Pushes Past $4,000/t on Ukraine Conflict. 7 March.
[64] India Mineral Yearbook, Cobalt 2018. https://ibm.gov.in/writereaddata/files/05102019160003Cobalt_2018.pdf

from use of fossil fuels as an energy source. Production of nickel from its naturally occurring form of oxides needs huge rotary kilns in order to remove the high water content. This involves burning of fossil fuels for energy leading to GHG emissions. The mining of the metals also leads to water withdrawal or consumption, which reduces underground water levels at and around the mining sites.

The environmental impact of metal recycling from LIB waste is thus significantly less than from metal extraction from the mines.

4.1.4. Price discovery

Resale risk is one of the asset risks that is currently hindering the confidence of financial institutions in mobilising finance for EVs[65]. Creating a well-established reuse/recycle ecosystem can help discover the resale value of batteries for reuse/ recycle applications.

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 adoption of EVs.

4.2. Battery recycling market opportunities for India

Today, the recycling market in India is at a very nascent stage, and LIB waste is handled by few organised players. It is expected that the battery recycling market in India will become very attractive by 2025. For many years, LIB waste generated from consumer electronics has been the major source of input streams for recyclers. However, with growing support for and acceptance of EVs among stakeholders, the demand for LIBs is growing fast. This will be also driven by demand for grid storage applications like utility-scale storage, telecom towers, home power backup solutions, etc. It is estimated that annual demand for LIBs for 2021 in India is around 5.2 GWh and this is expected to grow at an annual rate of 35–40% up till 2021.

These LIBs will reach their EOL by 2030 or before. This is equivalent to 43,000 tons of LIB waste every year assuming average energy density at 120Wh/kg. Since most of these EOL batteries will be sourced from EVs, the recycling industry will benefit from organised collection and transportation of these batteries by OEMs to recyclers.

Chapter 3 discussed the estimated annual demand for LIBs and the waste batteries available for recycling in the market for the period 2021–2030.

Nickel, cobalt, lithium, copper and graphite are critical items for battery manufacturing. Battery chemistries will play a decisive role in sustainable LIB recycling. It is expected

[65] RMI (2021) Mobilising Finance for EVs in India. NITI Aayog.

that LFP, NMC and LCO will account for the majority of the market share. Chemistries that contain nickel and cobalt are the most attractive to recyclers. For this reason, battery chemistries such as LFP and LMO may not be very attractive or profitable for recyclers because of their low economic value as they do not contain valuable metals like nickel, cobalt and copper. The down-side risk to the recycling business lies in the expected fall in lithium battery prices from US$140 to US$80 by 2030.[66] However, recovery of critical items will help secure local supply and promote domestic production of cathodes. Today, China controls the majority of cathode production.

4.3. Battery recycling technologies

4.3.1. Overview of existing recycling technologies

The recycling technology of LIBs is a complex process compared with for battery technologies such as LABs, NiCad, 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.

4.3.2.Recycling technology steps

The LIBs recycling is a multi-stage process and the number of steps that will be involved depends on selected recycling routes (called 'recycling plant technologies' (RPTs) in this report), input feedstock varieties (i.e. chemistries) and the quality of the expected output products (metal, salt, etc.). In general, LIBs primarily undergo four steps: preparation (optional); pre-treatment (pyrolysis and mechanical); pyro-metallurgy; and hydrometallurgy.

These four steps in different combinations and intensities define different battery RPTs. Most available technologies for integrated plants carry out a combination of these four steps, commonly referred to as a hybrid (e.g. pyro-hydro, mech-hydro). In some cases, mech-hydro can also be referred to as 'hydro' because this is the prevalent step rather than the pre-treatment step. Standalone plants are commonly referred to as mechanical or pyrometallurgical or hydrometallurgical.

[66] BNEF (2021) Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite. 30 November.

Table 14 shows the different combinations of steps in different RPTs.

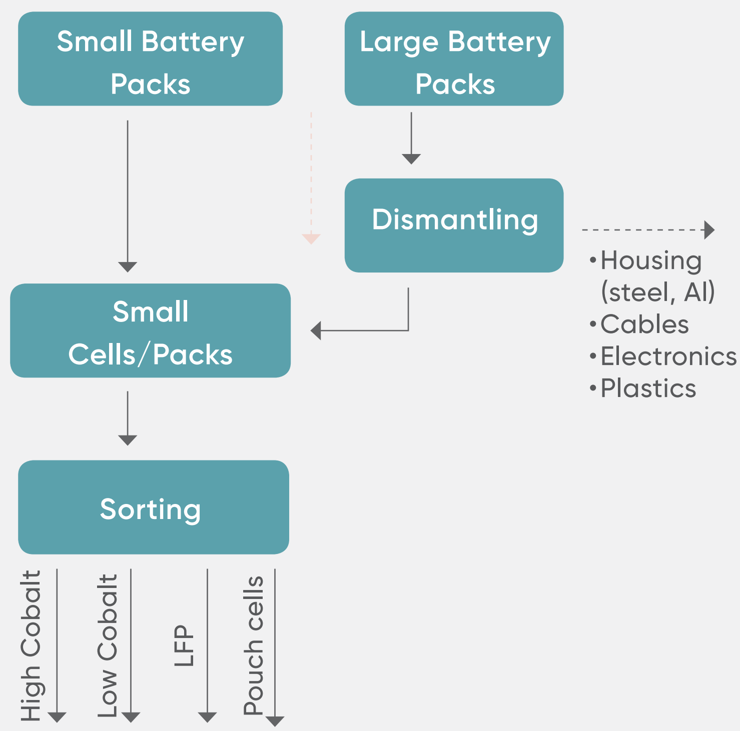
Table 14: Steps involved in different recycling plant technologies

RPT		Combination of steps
Standalone	RPT-1	Mechanical
	RPT-2	Pyrometallurgy (pyro)
	RPT-3	Hydrometallurgy (hydro)
Hybrid	RPT-4	(Mechanical → pyrolysis) pre-treatment → pyro → hydro
	RPT-5	Mechanical pre-treatment → pyro → hydro
	RPT-6	Pyrolysis pre-treatment → pyro → hydro
	RPT-7	(Pyrolysis → mechanical) pre-treatment → hydro
	RPT-8	Mechanical pre-treatment → hydro

Preparation

This step primarily involves discharging, dismantling and sorting of large-size batteries e.g. for E4Ws, e-buses). This step is optional since it is not directly involved in the recycling process. The batteries sourced from SAs and EVs can be quite heavy and large. For ease of handling, they can be dismantled into small cells or module level. As part of the dismantling process, the external periphery materials, such as steel or aluminium housing, plastics, electronics, cables, etc., can be separated. Once this has happened, the sorting process can be carried out for material classification based on cathode type, content weight, etc. Sorting is desirable since it provides better control on input feedstock (by material classification) and can help in planning the subsequent processes of recycling more effectively. The sorting and dismantling process can be either manual or automated.

Figure 56: Preparation process of spent LIBs for recycling



Source: Sojka, R., Pan, Q. and Billman, L. (2020) Comparative Study of Li-ion Battery Recycling Processes. Accurec Recycling GmbH.

It is important to note that some batteries may be partially charged. Since LIBs carry fire and safety risks, which may arise as a result of mechanical damage, or because of the presence of inflammable ingredients and volatile compounds or thermal runaway characteristics, these batteries may be fully discharged (depending on need) before dismantling or processing for the next recycling stage.

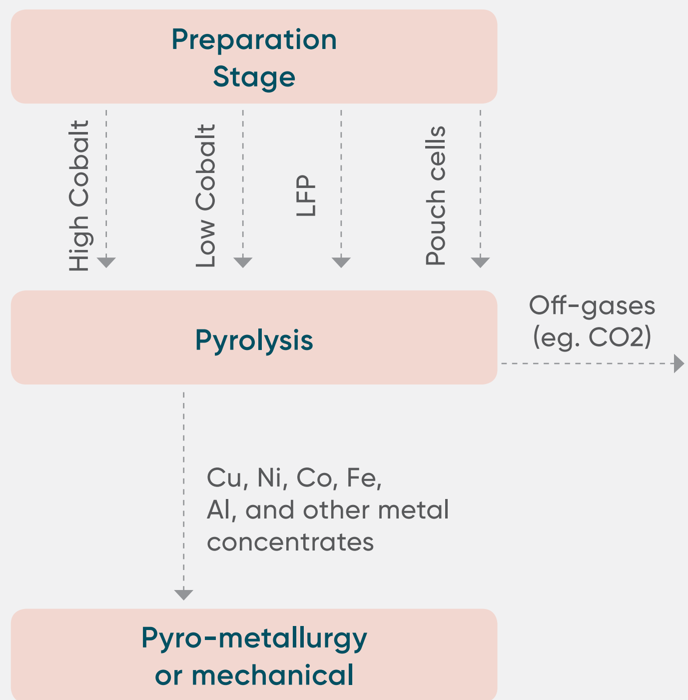
Pre-treatment (mechanical or thermal)

Pre-treatment is an important step for recycling. The objective of this step is to change the composition or physical condition of the LIB cell/pack to such an extent that it can be easily fed into the later-stage processes, such as pyrometallurgy or hydrometallurgy. If this step is not carried out appropriately, performance issues may arise in the next recycling stages (pyrometallurgy/hydrometallurgy) because of high levels of impurity or operational disruptions such as fire and gas explosions resulting from volatile compounds present in LIBs such as electrolytes. Pre-treatment can be carried out through a thermal or a mechanical process or through a combination of both.

Thermal process (pyrolysis)

In this step, sorted LIBs are subjected to low-temperature volatilisation so that their organic components can be decomposed and incinerated in an afterburner. The thermal treatment takes place in a rotary kiln, with the temperature kept up to 120°C to 600°C, to avoid oxidation of metals like aluminium. In this process, binders and electrolytes are burned off. The off-gas is treated by suitable technology and the energy generated from the burning of organic compounds can be used for other industrial processes.

Figure 57: The thermal pre-treatment process



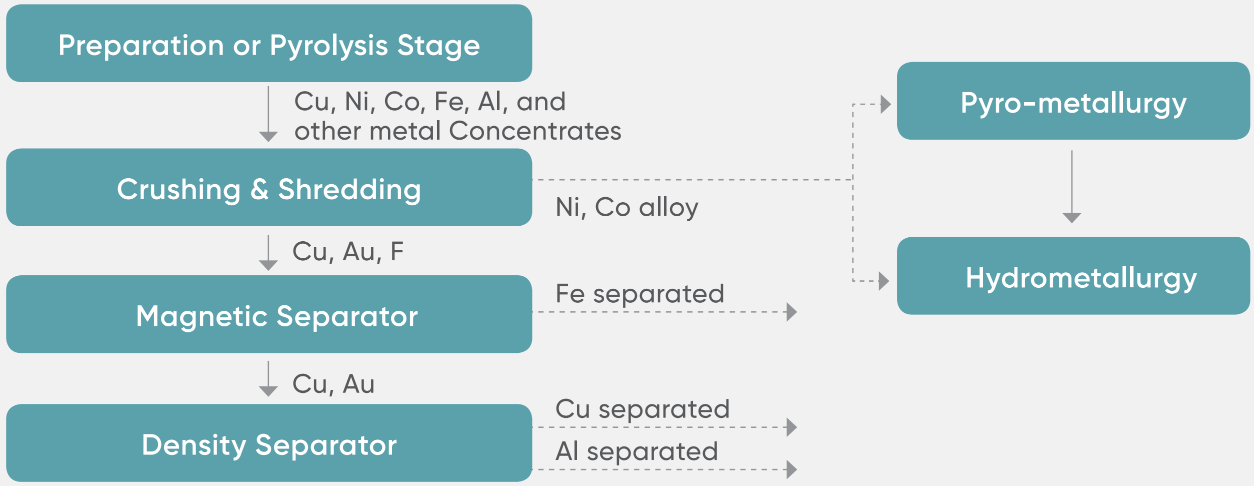
Source: Sojka et al. (2020) Comparative Study of Li-ion Battery Recycling Processes.

The remaining battery metals are subsequently sent to non-dedicated primary metallurgy processors, to recover the cobalt, nickel and copper.

Mechanical processing

In mechanical processing, the input LIB feedstock received from either the preparation or the pyrolysis stage is crushed in two stages. In the first crushing process, a cyclonic air separator removes all the electrolyte and reaction gases, including hydrogen and oxygen, accumulated within the crusher. The gases are subsequently cleaned by the filters. This process may not be required if the input to the crusher is received after thermal pyrolysis pre-treatment.

Figure 58: Mechanical recycling process



Source: Sojka et al. (2020) Comparative Study of Li-ion Battery Recycling Processes.

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. To separate iron from copper and aluminium, the flakes are passed through a magnetic separator. Copper and aluminium are separated using density separator. The steel and copper/aluminium flakes can be delivered to smelting facilities for metal recovery, whereas cobalt and nickel electrode power is forwarded to pyrometallurgy (subsequently hydrometallurgy) or hydrometallurgy facilities for further treatment and extraction of nickel and cobalt salts or metals.

Formation of hydrofluoric acid is possible if the electrolyte is not removed using pyrolysis. The hydrofluoric acid formed can corrosively damage the metals in the black mass. Safety can be improved by shredding the batteries in an aqueous solution/inert gas chamber.

Materials recycled: The primary output is black mass (consisting of cobalt, nickel, copper and lithium) and the secondary output is aluminium, iron, copper and plastics (housing and separator foils). The metals obtained are 90–95% pure and can be used in domestic applications like stainless steel, metal sheds, etc.

Materials lost: No material is lost in this process. However, the cell materials remain in the form of black mass and need further extraction.

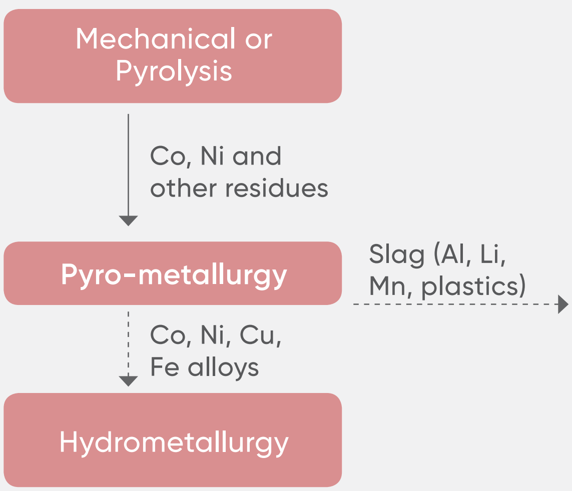
Gases released: If the batteries have not been pre-treated in the pyrolysis step, the highly volatile electrolyte can form explosive gases when combined with oxygen while crushing. Off-gases released during the mechanical process include CO, CO2, H2, HF and CxHy.

Metal recovery efficiency: The iron, aluminium and copper recovered have high recovery efficiency (90–95%) whereas the black mass is either exported or transferred to in-house hydro or pyrometallurgical facilities.

Pyrometallurgy

After the pre-treatment process (pyrolysis or mechanical), the LIB residues can be subjected to a pyrometallurgical process for the extraction of alloys containing precious metals like cobalt, nickel, iron and copper. This is an intermediate process, and the output is further delivered to hydrometallurgy facilities for metal extraction and refining. The output is a metal alloy containing cobalt, nickel, iron and copper.

Figure 59: The pyro-metallurgy recycling process

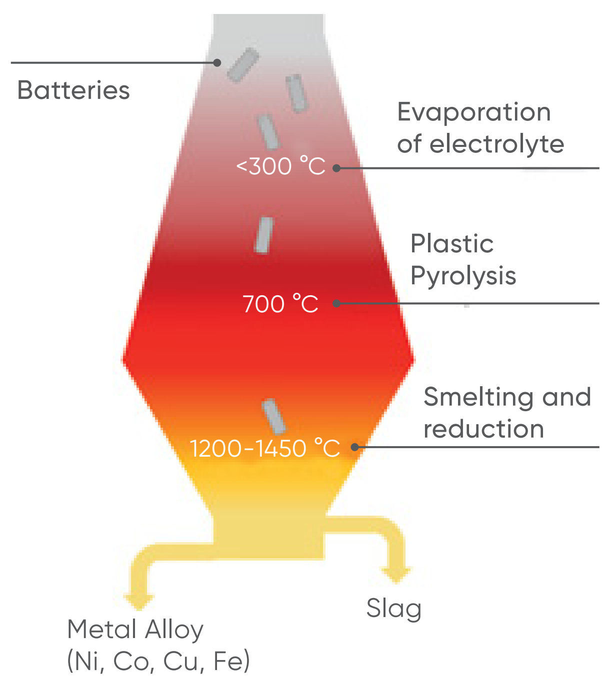


Source: Sojka et al. (2020) Comparative Study of Li-ion Battery Recycling Processes.

The advantage of this stage 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. The raw material required for the hydrometallurgical process must be in the form of fine particles. Thus, this metal alloy is crushed before forwarding to the leaching step in the hydrometallurgical process.

The other materials that are removed in the form of slag cannot be extracted further and are generally used in road construction. Also, some slag can be used within the process acting as a reducing agent (e.g. graphite) for metal oxides. As a result of the high temperature (> 1000oC), some metals, like aluminium, manganese, iron and lithium, are also lost in the process, given their low melting point. It may make economic sense to remove non-precious metals in the form of slag to avoid high chemical leaching and the energy costs incurred in the hydrometallurgical process. However, efforts are being made to establish processes to target the recovery of lithium and graphite as a next step besides cobalt and nickel metal recovery. A review of the literature shows that lithium can potentially be extracted from slag. However, lack of data around lithium extraction means that it is assumed that lithium content is lost.

Figure 60: Furnace used in pyrometallurgy recycling



Source: Sojka et al. (2020) Comparative Study of Li-ion Battery Recycling Processes.

In addition to this, a gas treatment system needs to be installed to decompose the volatile organic compounds (e.g. electrolytes) to limit environmental pollution. The toxic gases that are released in the process contain fluorine, which is captured in the flue dust and generally landfilled. It is also critical to note that LIBs, if not discharged properly but subjected directly to an electric furnace, pose a safety risk because the explosion of cells may result in molten metal splashing out. Therefore, LIBs should be properly discharged before being put into an electric furnace or mixed with other waste in a controlled or lower ratio.

Materials recycled: The primary output is metal alloys containing nickel, cobalt, copper and iron.

Materials lost: Aluminium, graphite, electrolytes, lithium, manganese, silicon and plastics are collected as slag. The energy generated can also be used for burning.

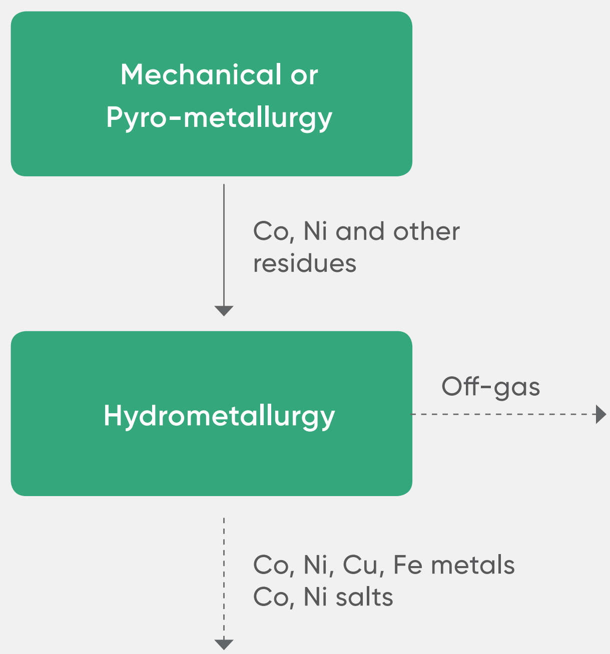
Gases released: Toxic gas containing fluorine is captured in the flue dust and is landfilled. Off-gases released during the process include CO, CO_2, H_2, HF and C_xH_y.

Metal recovery efficiency:[67] This is generally high (>90%) owing to lesser presence of impurities in the metal.

Hydrometallurgy

The hydrometallurgical stage receives battery waste from mechanical or pyrometallurgical plants. 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 solvent extraction chamber (liquid phase synthesis and high temp treatment) to produce cobalt and nickel salts used in battery production. These salts can be further extracted using electro winning and ion exchange process to recover precious metals like nickel and cobalt and other metals.

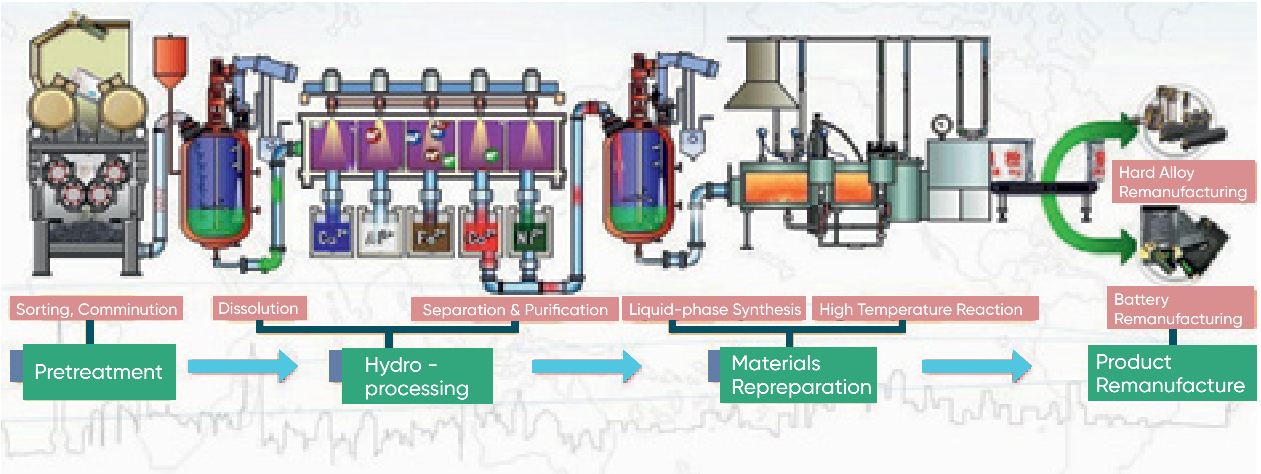
Figure 61: The hydrometallurgy process



Source: Sojka et al. (2020) Comparative Study of Li-ion Battery Recycling Processes.

[65] It may be difficult to prove metal recovery efficiency for LIBs co-processed with other waste like production scraps.

Figure 62: GEM hydrometallurgy process



Source: GEM Co. Ltd, China.

The hydrometallurgical process is sensitive to impurities present in the battery waste. Therefore, pre-treatment using thermal or mechanical processing or pyrometallurgy is an important stage to achieve high metal recovery efficiency (>90%) and reuse for battery cell manufacturing. The effect of the presence of certain materials on the hydrometallurgical process is as follows:

- Silicon-gel formation: increased filtration efforts and disposal cost;
- Plastic residues: additional filter and disposal cost;
- Electrolyte: formation of organochlorine compounds, toxic cases, increased acid consumption;
- Aluminium: increased filtering inefficiencies and operating cost;
- Graphite: foam formation with an impact on plant construction and additional cost of process additives.

The most used leaching agent in hydrometallurgy recycling is sulphate acid.[68] In addition to this, HNO3, organic acids and other mineral acids or alkaline leaching agents are used in leaching. Hydrogen peroxide is the most popular reducing agent, which reacts with cathode materials. The various chemical reactions and the presence of volatile organic compounds (e.g. fluorine in electrolytes) mean that harmful toxic gases are produced (i.e. fluoride emissions). A gas treatment system needs to be installed to decompose the volatile organic compounds (e.g. electrolytes) to limit environmental pollution.

Material recycled:[69] The primary output is metals (copper, iron, aluminium, carbon, cobalt, nickel, lithium) or metal salts (lithium carbonate; nickel, manganese and cobalt sulphates) currently used in the ink, paint, ceramics and cosmetics industries. Lithium is also used in medicines but needs to be refined for high purity. The secondary output is electrolyte solvents and plastics.

[68] Bio-hydrometallurgy proposes the application of bacteria for bioaccumulation and extraction of valuable materials and the use of organic acids or enzymes in the bioleaching process. However, all these projects are lab-scale or under prototype development and, owing to a lack of industrial operation data, are not included in analysis.
[69] The output of the hydrometallurgical stage is dependent on the preceding stages (i.e. pyrometallurgical or mechanical processing) involved before electrode powder was fed into the process.

Materials lost: 50% of plastics and electrolyte is burned for energy whereas graphite and poly polyvinylidene fluoride (PVDF) binder material are landfilled.

Gases released: Toxic gas containing fluorine is captured in the flue dust and is landfilled.

Metal recovery efficiency:[70] Generally high (>90%) provided lesser impurities are present.

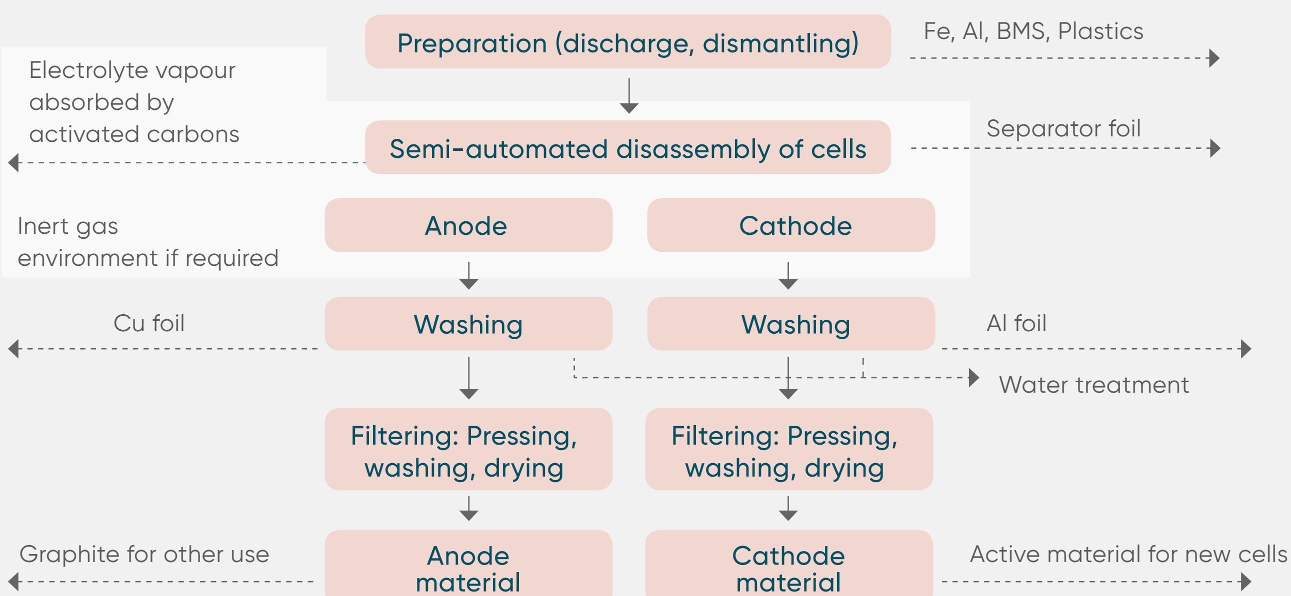
The recycling stages discussed above are well-accepted industry practices among global waste recyclers, including battery recyclers. The number of stages may differ across recyclers, but the defined goal is metal recovery for reuse for battery manufacturing or other applications. However, this technology is still under R&D and commercial feasibility is yet to be proven.

4.3.3. Overview of emerging recycling technologies

Direct recycling

In this method, cathode and anode materials are separated (by mechanical separation), reconditioned and then directly reused for LIB manufacturing.[71] The main recycling steps are 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. There may be several ways to implement direct recycling. Figure 63 shows one such process implemented for LIBs recycling by ERLOS GmbH, a plastic waste recycler located in Germany. This kind of recycling technique is applicable to pouch and prismatic cells but less suitable for cylindrical cells.

Figure 63: Direct recycling process



Source: Mohr, M., Weil, M., Peters, J. and Wang, Z. (2020) Recycling of Lithium-Ion Batteries. In A.J. Bard (ed.) Encyclopaedia of Electrochemistry.

[70] It may be difficult to prove metal recovery efficiency for LIBs co-processed with other waste like production scraps.
[71] Harper, G., Sommerville, R., Kendrick, E., Driscoll, L. et al. (2019) Recycling Lithium-Ion Batteries from Electric Vehicles. Nature 575(7781): 75–86.

In this process, spent LIBs are completely discharged and dismantled to cell level manually.

Subsequently, the cells enter an encapsulated chamber flooded with an inert gas[72] to prevent fire or explosion, where the pouch is automatically opened and separated into anodes and cathodes with the help of robots. This automation is a further safety measure, as compared with manual processing. The electrolyte vapour is collected by an exhaust system with an activated carbon filter that must be exchanged regularly. Beside the electrodes, the separator foils are collected for plastic recycling or for thermal usage in incineration plants.

The cathode and anode electrodes are treated separately in the following washing process. The cathode is treated with water and/or sodium hydrogen carbonate solution at 20–30°C and with a maximum of 90 bar air pressure to separate the aluminium foil and the coating (active mass containing nickel, manganese, cobalt and carbon).

The liquid fraction containing the cathode materials is filtered, pressed, washed and dried in a gas oven, to obtain marketable recycled cathode materials that can be used partially to produce new cells. However, the recycled cathode materials need to be mixed with primary cathode materials. All collected aluminium foils from the cathode are sent to an independent metal recycler.

The anode is treated in the same way, separating and recovering the copper foil and the graphite active mass. However, the recycled graphite material is not used for battery anodes but for other purposes. All collected copper foils from the anode are dried and sold for third party recycling. Because the washing water contains parts of the electrolyte and other contaminants it is treated and cleaned in a sewage treatment plant.

Materials recycled: Most cell materials can be recovered. The poorly characterised feedstock may result in poor quality of output materials and may not meet the required commercial quality for reuse purposes. This process may be more suitable for a single battery type instead of battery mixtures.

Materials lost: Electrolyte is lost.

Gases released: Electrolyte vapour (containing fluorine).

Metal recovery efficiency: No data available and technology yet to be proven at a commercial scale.

[72] Inert gases are noble gases like helium, neon, argon, etc., which do not react with other elements

Table 15: Summary of materials that can be recovered through different recycling steps

	Pre-treatment		Treatment		
	Pyrolysis	**Mechanical**	**Pyro**	**Hydro**	**Direct Recycling**
Copper	In form of battery mass	√	√ (Cu compounds)	√	√
Steel	In form of battery mass	√	√ (Fe compounds)	√	√
Aluminium	In form of battery mass	√	In slag	√	√
Graphite	In form of battery mass	√	√	√	In form of anode material
Cobalt	In form of battery mass	In form of cell (Black mass)	In form of alloy	√	In form of anode material
Nickel	In form of battery mass	In form of cell (Black mass)	In form of alloy	√	In form of anode material
Lithium	In form of battery mass	In form of cell (Black mass)	In slag	√ (Li carbonate)	In form of anode material
Electrolyte	X	√	X	√	X
Plastics	X	√	X	√	√

4.4. Battery reuse

Reuse of batteries is another aspect in the battery supply chain: this can extend the life of batteries through their reuse in the same or other applications through refurbishing. This could reduce the demand for new batteries in certain applications significantly. Among all applications, EV batteries have high scope for reuse. One study shows an EV battery is likely to have around 70–80% of its initial capacity at retirement and its life can be extended about another 10–15 years through use in other applications.[73]

The refurbishing of batteries will involve testing, dis-assembly, grading and refitting into new applications. Although models for estimating battery degradation and battery life are not popular and mature, insights from current research initiatives and pilots show some promising reuse pathways. Table 16 shows some of the pathways for EV battery reuse.

[72] Neubauer, J., Smith, K., Wood, E. and Pesaran, A. (2015) Identifying and Overcoming Critical Barriers to Widespread Second Use of PEV Batteries. NREL.

Table 16: Battery reuse applications

Reuse pathway	Key applications	Expected second life
EV to EV	Processes are being developed to test SoH of individual modules of a battery pack. Modules with low SoH (<80%) are assumed to have achieved first use EOL. These are replaced by new modules along with other older modules having SoH (>80%) for reuse in EVs. Example: Nissan is following one such process with module testing technology developed by Sumitomo, with the LEAF battery modules with 80% or more SoH remanufactured for use in new LEAF models.[74]	5–10 years
EV to other vehicles	With a similar process for detecting module SoH, the battery modules with less than 80% SoH can be used for other vehicle applications like forklifts, airport carts and electric bikes. 1: In the Nissan–Sumitomo process, the lower SoH battery modules are being used in forklifts and golf carts.[75] 2: Renault has partnered with Seine Alliance to use EOL batteries from EVs in boats in Paris.[76]	10–20 years
EV to EV charging	EOL batteries from EVs are being used to power fast-charging stations to avoid augmentation of additional power supply. 1: The US public charging network operator EVgo has repurposed BMW i3 battery packs (two battery packs housed into one providing 44 kWh of storage capacity) to power its DC fast charging station.[77] 2: Renault in collaboration with Connected Energy has developed E-STOR EV second-life energy storage technology to use EV batteries to power fast chargers.[78]	10–12 years
EV to large-scale battery storage[79]	The use of EV batteries for large-scale grid-connected storage is one prominent repurposing route. EOL EV batteries are used for grid-connected storage for renewable integration and power backup for commercial spaces like data centres. 1: Implementation cases include Renault's renewable storage on Port Santo Island, Nissan–Eaton energy storage in Amsterdam, Nissan–Sumitomo in Japan, BMW energy storage in Germany and Florida Power grid management system in Florida. 2: Commercial space backup solutions include Renault power backup for lifts in Paris and Chevrolet's solution for a data centre in Michigan.	10–12 years
EV to small-scale battery storage	EOL EV batteries are also being used for small-scale applications like home storage, solar streetlights, etc. 1: Tesla Powerwall is one of the first applications for reuse for home storage. Nissan's Xstorage and Powervault UK are other players.[80,81] 2: In Nissan–Sumitomo, EV EOL batteries are used to power solar streetlights in Fukushima.[82]	10–12 years

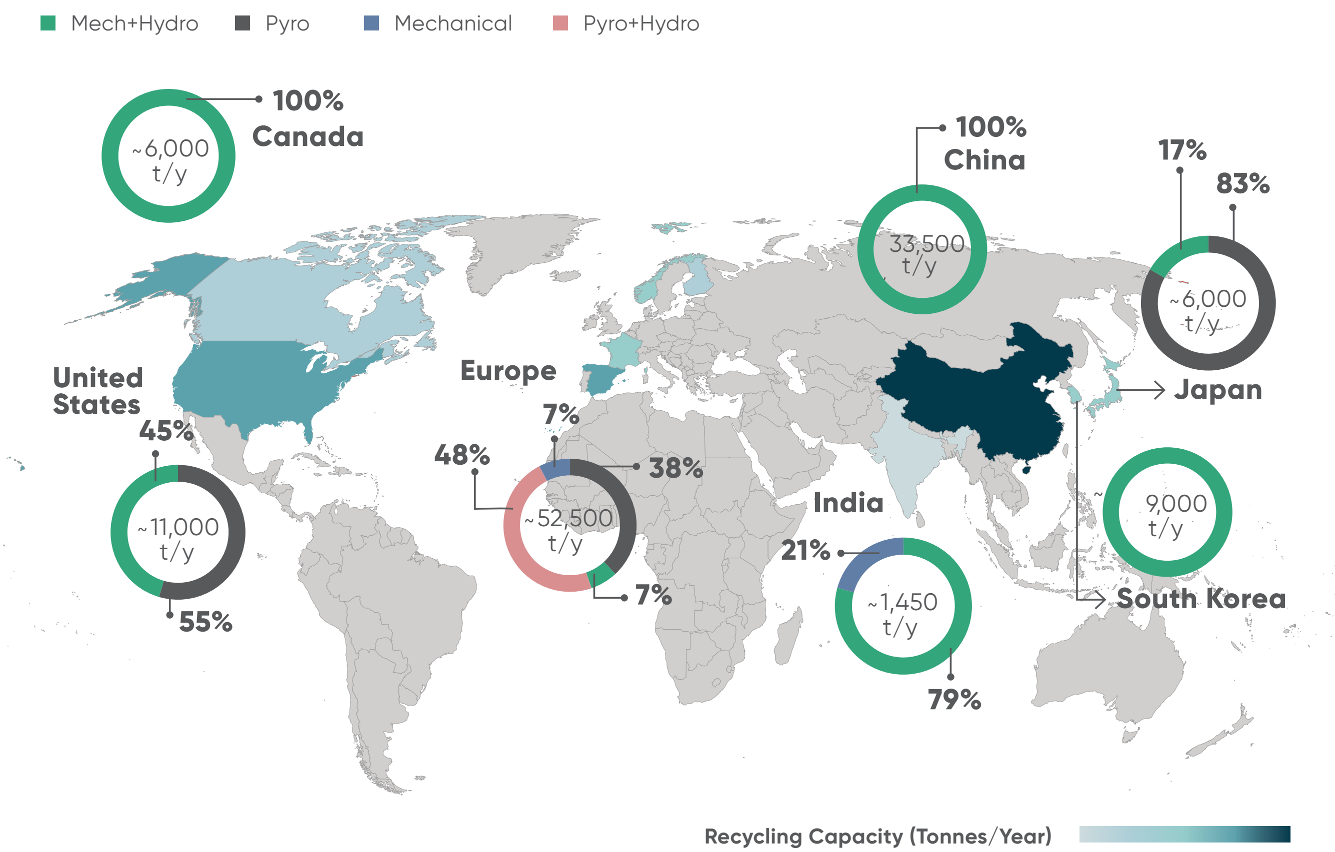
[74] Hanley, S. (2018) Nissan Begins Offering Remanufactured Batteries for LEAF.
[75] REMATEC (2018) Turning Over a New LEAF. 13 September.
[76] Richardson, J. (2022) Electric Tour Boats in Paris to Use Repurposed Renault EV Batteries.
[77] EVgo (2018) EVgo Announces Nation's First Grid Tied Public Fast Charging System with Second Life Batteries.
[78] Ayre, J. (2016) Connected Energy Renault Partner in Second Life EV Battery Energy Storage Tech.
[79] Lovell, J. (2019) Storage: Retirement Home for Old EV Batteries?
[80] https://www.powervault.co.uk/
[81] https://www.nissan.ie/experience-nissan/electric-vehicle-leadership/xstorage-by-nissan.html
[82] Thubron, R. (2018) Nissan Is Repurposing Old EV Batteries for Use in Street Lights.

The reuse pathways presented here are from global practices. For India, as E2Ws and E3Ws currently make up a major share of EVs, the expected second life could be much lower, as these batteries are expected to have a maximum of two to three years of second life compared with six years for E4W batteries. Local environmental conditions like high temperatures and humidity will also have an effect on the second life of the batteries.

4.5. Key battery recycling players: global and India

As per estimates, total global recycling capacity in 2020 exceeds 100,000 tons/year. Europe has the highest battery recycling capacity (>52,000 tons/year) followed by China (>30,000 tons/year). Currently, recycling capacity in India is very low (<2,000 tons/year) but this is expected to increase to 30,000 tons/year in the next two to three years owing to the demand surge from SAs and TAs. Home-grown companies like Attero, Exigo and Tata Chemicals are expected to lead the Indian LIB recycling market.

Figure 64: Mapping of global recycling capacity by technologies, 2020



Source: NREL (2018) The Case for Recycling: Overview and Challenges in the Material Supply Chain for Automotive Li-ion Batteries; Sojka et al. (2020) Comparative Study of Li-ion Battery Recycling Processes; Authors' analysis.

The most prominent multi-stage hybrid technology adopted in Europe is mechanical + pyro + hydro while in China it is mechanical + hydro processing. Renowned global recyclers include Umicore (Belgium), Accurec (Germany), SungEel (South Korea), Kyoei Seiko (Japan) and Brunp (China) among many more. It is important to note that the majority of the state-of-art recycling processes were not initially designed for EOL LIB processing and are used for the recycling of other battery chemistries and production scraps. However, the growing share of LIBs in the battery waste mix and the high value of materials have pushed for a redesign of recycling processes for LIB streams – that is, the diversification of input streams by global players such as Umicore.

As per industry consultations, Indian players seem to be following a similar strategy to China – that is, focusing on hydrometallurgy. The hybrid strategy (mechanical + hydro) makes sense for India because this promotes the idea of a circular economy by allowing metal extraction of a wide range of both valuable and non-valuable metals that are required to produce cathodes. Attero, which is recognised as one of the biggest formal players in the Indian battery recycling space, follows the hybrid (mech + hydro) process. It presently has around 700 tons/year of recycling capacity, which it is planning to augment by another 20,000 tons/year of capacity in the next two years.

Based on our secondary research, it is also understood that some global players, such as SungEel, have set up partial recycling facilities in India.[83] Also, there are global recyclers who have their front offices in India (e.g. Umicore). In addition to global players, some Indian players carry out only mechanical processing and deliver (or export) the black mass to global players. The capacity of such players is unknown.

Table 17 presents a list of both global and Indian recyclers along with their capacities and expansion plans, if any. Some plant capacities in the list may also include recycling of production scrap (iron, copper) and other batteries like NiCad, which requires the same recycling process. The list is not comprehensive and many players, including big ones, may be missing; the list also needs to be continuously updated since the LIB recycling market landscape is evolving rapidly. In the past few years, the recycling industry has also attracted global investor attention and several big announcements are being made in this regard by both existing and new players.

Table 17: List of global and Indian recyclers along with their recycling capacities

Key recycling operator	Operating country	Recycling capacity (tons/year)	Pipeline	Technology	Stages
Accurec	Germany	3,000		Hybrid	Thermal + mech + pyro + hydro
Akkuser	Finland	1,000		Mechanical	Mechanical + unknown
Attero	**India**	**700**	**20,000**	**Hybrid**	**Mech + hydro**
Brunp	China	6,000		Hybrid	Thermal + mech + hydro

[83] EVreporter (2019) Lithium Ion Battery Manufacturing in India – Current Scenario. 24 September.

Dowa	Japan	1,000		Hybrid	Thermal + pyro + hydro
Duesenfeld	Germany	<1,000		Hybrid	Mech + hydro
EDI	France	<1,000		Mechanical	Mech (aqueous shredding) + unknown
Exigo	**India**	**450**	**10,000**	**Hybrid**	**Mech + hydro**
Erlos	Germany	Lab		Hybrid	Mech + direct
Fortum	Finland	3,000		Hybrid	Mech + hydro
GEM	China	2,000		Hybrid	Mech + hydro
Guanghua	China	<1,000		Hybrid	Mech + hydro
Huayou Cobalt	China	>1,000	10,000	Hybrid	Mech + hydro
Ganzhou Highpower	China	>1,000		Hybrid	Mech + pyro + hydro
JX Nippon	Japan	600		Hybrid	Thermal + mech + hydro
Kobar	Korea	1,000		Hybrid	Mech + hydro
Kyoei Seiko	Japan	>1,000		Pyro	Pyrometallurgical
Li-Cycle	North America	10,000	10,000	Hybrid	Mech + hydro
Nickelhütte Aue	Germany	7,000		Hybrid	Thermal + pyro + hydro
Primobius	Germany		18,250	Hydro	Hydrometallurgical
Promesa	Germany	<1,000		Mechanical	Mech (aqueous shredding) + unknown
Recupyl (TA-AMM)	France	<1,000		Mechanical	Mechanical (inert gas)
Redux	Germany	<1,000		Mechanical	Thermal + mech + unknown
Retriev	Canada	<1,000		Hybrid	Mech (aqueous) + hydro
SMCC	USA		5,000	Hybrid	Mech + hydro
SNAM	France	<1,000		Hybrid	Thermal + pyro + hydro
SungEel HiTech	Korea	8,000	16,000	Hybrid	Mech + thermal + hydro
Tata Chemicals	**India**	**0.1 (pilot)**		**Hydro**	**Hydrometallurgical**
Telerecycle	China	<1,000		Hybrid	Mech + hydro
Umicore	Belgium	7,000		Hybrid	Pyro + hydro
Valdi (ERAMET)	France	20,000		Pyro	Pyrometallurgical

Table 18: Quality of output materials of different recycling plant technologies

RPT		Combination of steps	Quality of output materials
Standalone	RPT-1	Mechanical	Recycled material for battery manufacturing: further processing required through hydro process for lithium, nickel and cobalt Downcycled for other use: copper, steel, aluminium
	RPT-2	Pyrometallurgy (pyro)	Downcycled for other use: lithium, cobalt, nickel, copper
	RPT-3	Hydrometallurgy (hydro)	Recycled material for battery manufacturing: cathode precursor materials

RPT		Combination of steps	Quality of output materials
Hybrid	RPT-4	(Mechanical → pyrolysis) pre-treatment → pyro → hydro	Recycled material for battery manufacturing: cobalt (elemental), lithium Downcycled for other use: nickel, copper
	RPT-5	Mechanical pre-treatment → pyro → hydro	Recycled material for battery manufacturing: cobalt (ready for cathode synth.), lithium, nickel Downcycled for other use: copper
	RPT-6	Pyrolysis pre-treatment → pyro → hydro	No details
	RPT-7	(Pyrolysis → mechanical) pre-treatment → hydro	Recycled material for battery manufacturing: cobalt, nickel
	RPT-8	Mechanical pre-treatment → hydro	Recycled material for battery manufacturing: cobalt, lithium Downcycled for other use: nickel, copper

Source: Dominish, E., Florin, N. and Wakefield-Rann, R. (2021) Reducing New Mining for Electric Vehicle Battery Metals: Responsible Sourcing through Demand Reduction Strategies and Recycling.

4.6. Economic assessment of battery recycling

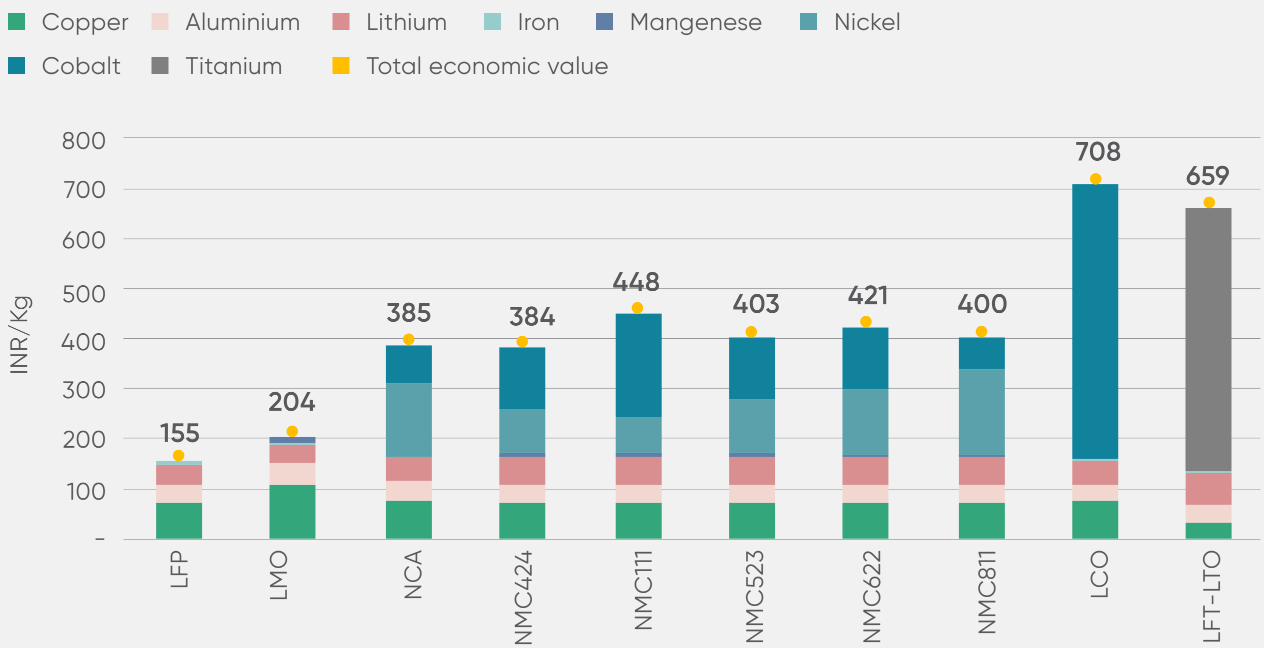
Recycling attractiveness is dependent on the LIB chemistry to be recycled and the steps involved. To evaluate this, an Excel-based data model was developed to undertake assessment of the economic value of recycled battery packs. This model was developed in consultation with industry experts and after extensive literature review.

4.6.1. Economic value of different battery chemistries

The economic value (INR/kg) is defined as the estimated revenue potential for the recyclers by recycling 1 kg of spent LIBs assuming 100% recovery efficiency irrespective of recycling technology. This economic value was estimated for different battery chemistries that are prevalent in the market.

Result analysis: Figure 65 shows the economic value of various battery packs involving various chemistries. Analysis clearly indicates that the economic value of LFP (~US$2/kg) is the lowest among all the battery chemistries. For recyclers, margins involved in taking up LFP recycling may not be very attractive because of the lower economic value and high recycling costs. Also, LFP does not contain any valuable metals except lithium, which is present in a very small quantity. Because of this, many recyclers in Europe and the US are paid a tipping fee by the OEMs to recycle LFP batteries. For example, recycling facilities in California have a gate fee of US$2/kg cells on recycling of LFP batteries[84]. In other words, battery chemistries without cobalt and nickel in the electrode (like LFP and LMO) will generate a lower revenue owing to the low value of recovered materials.

Figure 65: Economic value of recycling of different battery chemistries



Source: Authors' analysis.

For recyclers, chemistries like NMC, NCA, LCO and LTO are very attractive because they contain valuable metals like cobalt, nickel, titanium and lithium. Also, the supply of these resources is limited and concentrated in a few regions. Therefore, it makes more economic and business sense for them to focus on the extraction of these chemistries rather than LFP or LMO. Among NMC chemistries, the highest economic value is for NMC111, given its higher content of cobalt proportionate compared with nickel. As we can see from Figure 65, as industry moves towards NMC111 to NMC811, the economic value will reduce by only 10–12%. Therefore, NMC battery recycling is expected to remain a long-term attractive option for recyclers. However, falling battery prices and fluctuating metal prices may be a matter of concern for the recycling industry. This may make LFP recycling more unattractive.

The other unique LIB chemistry, using LTO as an anode instead of graphite, also seems to be an attractive battery source for recycling. However, this chemistry needs to be evaluated further as there is limited use for the LFP–LTO battery chemistry in EVs. Mitsubishi has used this technology in one of its EV models.

It is important to note that each battery pack contains external casing that uses aluminium or iron. These metals are of low value and

[84] Paul A. Nelson (2019), Modelling the Performance and Cost of Lithium-Ion Batteries for Electric-Drive Vehicles

will not generate much economic value compared with other metals.

The profitability of recycling plants is dependent on several factors. These include:

- Selection of recycling technology and process;
- Cost of technology and process;
- Battery collection and transportation cost;
- Battery chemistry and its acquisition cost;
- Recycling efficiency and price of output product;
- Environmental impact of recycling (water use, off-gas emissions, etc.).

The acquisition cost involved in acquiring waste batteries is location-dependent. Also, lack of knowledge in the value chain means the acquisition cost may vary significantly. This cost is expected to be in the range of 25–50% of total economic value. As per our estimates, because of the lower economic value of LFP and LMO batteries, their acquisition cost is around 40–50%. However, for other batteries, it may be around 25–30%. As the industry matures, this percentage share should go up as a result of increased competition among recyclers and better knowledge of market participants across the value chain. In addition to the waste battery acquisition cost, the operational cost is 30–40% of the estimated economic value, according to industry experts. The profit margin for recyclers is expected to be 10–20%.

The economic value and metal recovery efficiency are dependent primarily on the recycling processes adopted to recycle waste LIBs. For example, lithium, aluminium and manganese are lost in the process if they undergo a pyrometallurgical cycle. Similarly, the energy requirement in pyrometallurgy is higher than in hydrometallurgy but hydrometallurgy requires expensive chemicals for treatment. Therefore, metal recovery efficiency is in the range of 50–95% dependent on the process and the expertise of the recyclers.

Recycling process is dependent on the battery chemistries to be recycled. The recycling process need 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.

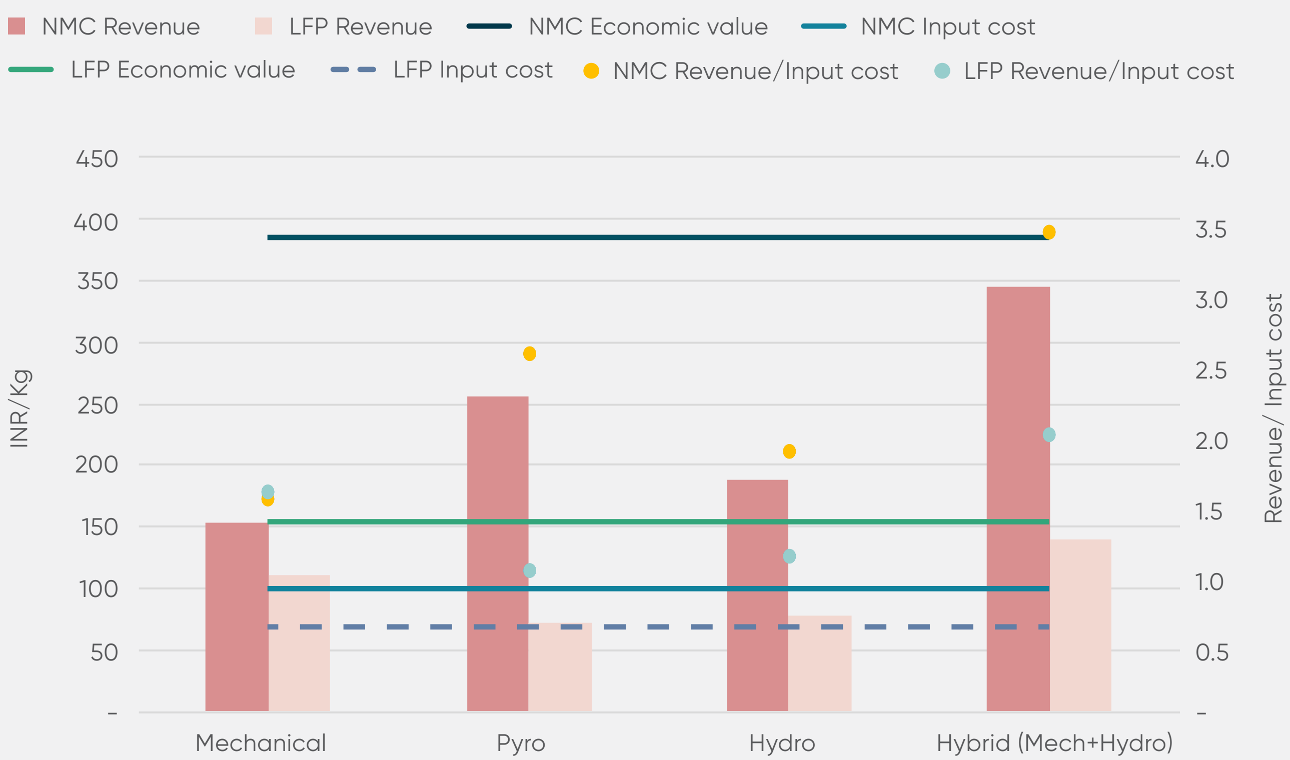
In other words, recyclers need to customise their processes in order to increase their plant productivity and ability to process a variety of chemistries. In discussions, the leading recycler of India said that some advanced chemistries, like solid-state batteries, can be recycled using existing technologies and processes. Solid state batteries are expected to be commercialised soon (probably by 2025) and their EOL is expected around 2030. On the other hand, other advanced technologies (like Na-ion, Al-air and LiS), which are being discussed widely, are still in R&D. It is expected that these technologies will take 7–10 years to commercialise and another 5–10 years to reach their EOL. It is expected that advanced chemistries (e.g. Al-air, Na-ion, etc.) will require additional processes for recycling.

4.6.2. Comparison of different recycling technologies

In addition to comparing the economic value of different chemistries, we compared recycling technologies for two of the prominent batteries, NMC and LFP. Figure 66 shows the revenue that can be generated by recycling these through different recycling steps. We assume recycling efficiencies in the range of 50–90% depending on the recycling technology. In the case of mechanical recycling, most of the cell components cannot be recovered and remain in form of black mass. A value addition for the recovery of materials like nickel, cobalt, lithium and manganese is assumed to be around 20% through mechanical processing.[85]

Mechanical recycling is estimated to have almost the same revenue to input cost ratio[86] – of 1.6 – for both NMC and LFP chemistries. Pyro and hydro have a higher revenue to input cost ratio for NMC as these technologies can recover precious metals like cobalt, nickel and lithium from NMC batteries. On the other hand, this ratio is near to 1 for LFP batteries, indicating that pyro and hydro may not be viable for LFP processing. However, process optimisation may improve viability. For example, mechanical and hydro processing together can improve viability.

Figure 66: Comparison of recycling technologies



Source: Authors' analysis.

[85] Authors' analysis based on the market value of black mass.
[86] This is the ratio of revenue to battery to pack cost (input cost) by recycling 1 kg of spent batteries

The following assumptions were considered for the analysis.

- The anode and cathode (%) of total battery pack weight was assumed to be the same across all NMC chemistries (i.e. NMC111, NMC424, NMC811).

- The cost of EOL batteries is in the range of INR70 to INR100 per kg.[87] The cost assumptions for different chemistries are below:
  - LFP: INR70 per kg;
  - LMO: INR80 per kg;
  - All cobalt chemistries (NMC, LCO): INR100 per kg;
  - LFP–LTO: INR100 per kg.

- The economic assessment includes estimated revenue only from key metal components such as iron, nickel, cobalt, titanium, aluminium, etc. It does not include any revenue or energy savings from plastics, electronic waste, carbon, slag, etc., if any.

- The price assumptions for different metals (for new metals) are given below:
  - Copper: US$9,800 per ton;
  - Aluminium: US$2,700 per ton;
  - Lithium: US$31,500 per ton;
  - Iron: US$675 per ton;
  - Manganese: US$2,100 per ton;
  - Nickel: US$20,000 per ton;
  - Cobalt: US$55,000 per ton;
  - Titanium: Approximately US$73,000 per ton.

- The recycled metal price is assumed to be 90% of new metal price and the US$–INR conversion rate is US$1=INR75.

4.7. Selection criteria for India

A multi-criteria analysis framework was developed to compare the different recycling technology steps that are commercially available on the market today. This framework represents a comprehensive assessment of the recycling technologies across 5 parameters and 16 sub-parameters (see Annexure A.1). The five parameters are applicability; technology performance; market; economics; and process and risks. The assessment involves both qualitative and quantitative parameters, with results derived based on literature reviews, expert interviews and data analysis.

As discussed earlier, the preparation stage is optional. Therefore, the comparison is made primarily of three technologies: mechanical, pyrometallurgy and hydrometallurgy. However, the preparation stage may delivery long-term competitive advantage. For LIB waste recycling, EV batteries are expected to be the major

[87] As per the stakeholder consultation, a price range was provided. In practice, a sampling analysis was carried out to determine the price of EOL batteries.

source for recyclers, followed by grid storage applications. Batteries from both these segments may be designed in such a way that it may be difficult to dismantle them manually or through automation. Also, battery chemistries are expected to continue to evolve over the next 10 years. Therefore, recycling stages should be designed to handle wide varieties of battery chemistries, sizes and forms to achieve optimum performance. As such, it is essential to understand the applicability of the recycling technologies.

For efficiency in metal extraction, one or more than one recycling technology in combination can be selected. In other words, recycling pathways can follow different recycling technologies to extract metals or carbonates. The metal recovery rates for these pathways can vary between 50% and 95%. Depending on the pathway, some metals can be lost in the process or be recovered using additional processes. Therefore, understanding the technical performance of each recycling technology is essential since it will have a direct impact on the economic value of recycled batteries. Market recycling capacity and pipeline data can provide useful insights into recycling technologies and trends observed in leading recycling countries such as the US, Germany, China and others.

The economic viability of the recycling technology (including the lab setup) is crucial to its uptake. The factors that can influence decision-making are minimum plant size, capex and operational costs. The latter include the energy cost, the availability of skilled labour (i.e. the labour cost) and other general costs. Skilled labour and metal extraction expertise can have a strong influence on the economic viability of the recycling unit. For economic viability reasons, LIB waste is often fed as mixture of different chemistries and mixed with production scraps in controlled volumes. Therefore, the technical performance of the recycling stages involved has an impact on the economic value of the recycled batteries. Decisive factors include the recovery of valuable metals like cobalt, nickel and copper. Other metals, like aluminium and iron, may not contribute much in terms of overall economic value of recycled batteries. In general, the capex cost increases with increased complexity of the recycling technology and the metals to be extracted.

Apart from an economic assessment, a process and risk assessment is vital to understand the overall recycling process. Such an assessment will cover the impact on the recycling output of the various preceding stages involved in LIB waste treatment, environmental (e.g. water usage) and health hazard (e.g. skin burns) risks and safety risks (e.g. explosions).

Table 19: Multi-criteria analysis of different recycling technology steps

Parameter	Sub-parameter	Mechanical	Pyrometallurgy	Hydrometallurgy
Applicability	**Able to recycle different chemistries (existing and emerging)**	**Suitable for all** Mechanical processing of all chemistries can be carried out with ease. However, for extraction of precious metals, they need to undergo subsequent stages, i.e. pyro or hydro.	**Suitable for all except LFP** because presence of phosphorous ions can affect the process. Also, commercially may not be viable owing to presence of low-value metals like iron and high energy cost.	**Suitable for all except LFP** because presence of phosphorous ions can affect process and cathode metals recovered are of low value, like iron. To keep recycling cost low, LFP needs to be processed separately, since it does not contain cobalt. Present technology will be able to process solid-state batteries without any changes to the process. Metal hydride, Na-ion, Al-air and LiS are still in R&D. No focus on these chemistries but these would need additional processes for recycling.
	Can recycle different cell types	**Can recycle all cell types**	**Can recycle all cell types**	**Can recycle all cell types**
	Batch process limitations	**No limitations** Mechanical processing stage is simpler and less operationally expensive. Therefore, batch processing can be started with minimal quantity. However, mix of LIB chemistries can affect overall economic value of batch.	**Some limitations** Pyrometallurgy is operationally very expensive since it requires minimum temperature to start smelting and reduction. Therefore, batch processing cannot be started with minimal quantity. Also, mix of LIB chemistries can affect overall economic value of batch.	**Some limitations** Hydrometallurgical processing involves expensive chemicals. Therefore, it may not make economic sense to start batch processing with minimal quanitty. Also, mix of LIB chemistries can affect overall economic value of batch.
Technology performance	**Metal recovery efficiency**	**High**	**High**	**Medium**
		High Copper, aluminium and iron can be recovered with metal recovery efficiency as high as 90%. Impurities level depends on level of automation and processing stages involved. This may affect output of hydro-metallurgical stage.	High Key metals like cobalt, copper, iron and nickel can be recovered in the form of metal compounds. This compound need further processing (i.e. hydrometallurgy) for the extraction of metal or products. Standalone process recovery efficiency for these metals is about 90% and impurities level is very low.	Medium Broad spectrum of metals or sulphates or carbonates can be recovered through hydrometallurgy. The metal recovery rate is sensitive to impurities present in the LIB waste. Additional process may be required to handle impurities. Standalone metal recovery efficiency is about 50%. Recovery efficiency up to 95% is possible with hybrid technology such as. mechanical + hydro processing.

Parameter	Sub-parameter	Mechanical	Pyrometallurgy	Hydrometallurgy
Technology performance	**Other material recovery**	Plastics, black mass containing precious metals like cobalt and nickel.	Slag containing plastics, aluminium, lithium, manganese.	Dependent on the preceding stage, i.e. mechanical or pyrometallurgical.
	Losses	None of the metals is lost.	Aluminium, Manganese, lithium and plastics are lost in form of slag. R&D efforts are being undertaken to recover lithium and aluminium from the process.	Most of the metals recovered are of high quality. If LIB waste is received from the pyro stage then metals like aluminum, manganese and lithium can be lost.
Market	**Existing global deployments**	Europe, US, China, India	Europe and US (>25,000 t/a)	China and India (>50,000 t/a)
	Existing Indian deployments	~1,400 t/a	Almost negligible	~1,200 t/a
	Recycling capacity in pipeline in India	About 30,000 t/a (mechanical + hydro)	Almost negligible	About 30,000 t/a(mechanical + hydro)
	Technology suppliers	NA	NA	NA
Economic	**Minimum plant size for financial viability**	NA	>10,000 t/a	<1,000 t/a
	Capex requirement	**Low**	**High**	**Medium** **India:** US$4-5 million recycling capacity of approximately 1,600 t/a (i.e. US$3,125 per tonne) **Europe:**[88] US$165 million for 18,250 t/a (i.e. US$~9,050 per tonne)

[88] The cost assumption information is not available in detail. The project cost is dependent on several factors such as land, technology, recycling process, level of automation, plant technical performance, etc.

Parameter	Sub-parameter	Mechanical	Pyrometallurgy	Hydrometallurgy
Economic	**Opex requirement**	**Low** Consumes very low energy and technical skill requirement is low compared with other technologies. Mechanical processing is a very simple step compared with other technologies. However, may lead to faster equipment deterioration owing to production of hydrochloric acids.	**High** High energy cost owing to high temperature requirement. Technical skill requirement low compared with hydrometallurgy but high compared with mechanical. Overall, utilities and labour cost have higher share compared with total operational cost.	**Medium** Low energy cost but involves usage of expensive chemicals. Technical skill requirement high compared with pyro and mechanical. Overall, material purchase cost (including chemicals) has higher share of total operational cost. As per estimates, operating cost is about US$1,560 per tonne[89] or 30–40% of estimated economic value.
Process and risks	**Process dependency**	**Low dependency** since preparation or thermal pyrosis stage is an optional stage.	**Low dependency** since preparation or mechanical processing stage is an optional stage.	**High dependency** since presence of impurities can significantly affect metal recovery rates. Pre-treatment or pyrometallurgical steps are important preceding stages. LIB waste received from mechanical processing may require additional processes, a disposal cost and increased chemical consumption to remove impurities compared with LIB waste obtained from pyrometallurgical process.
	Environmental risks	**Less environmental impact** since no chemical reaction steps are involved.	**Medium environmental impact** since LIB materials and their reactions generate environmentally hazardous, human toxic, highly corrosive substances (e.g. HF), as well as explosive gas mixtures. Off-gases need to be treated separately before being disposed of into the environment. Water requirement is about 5–6 litres per kg of battery cells recycled.[90]	**High environmental impact** since off-gas and fluorides produced need to be treated separately before being disposed of into the environment. Also, any chemical leakage in the process may cause noticeable environmental risks. Water requirement is about 13–14 litres per kg of battery cells recycled.

[89] The global recycler Primobius has finalised estimated capex and operating cost of its proposed LIB recycling operation in Germany. As per the estimates, the forecasted capex is US$165 million and average operating costs are at US$1,560 per tonne of batteries processed for a recycling capacity of 18,250 t/a.

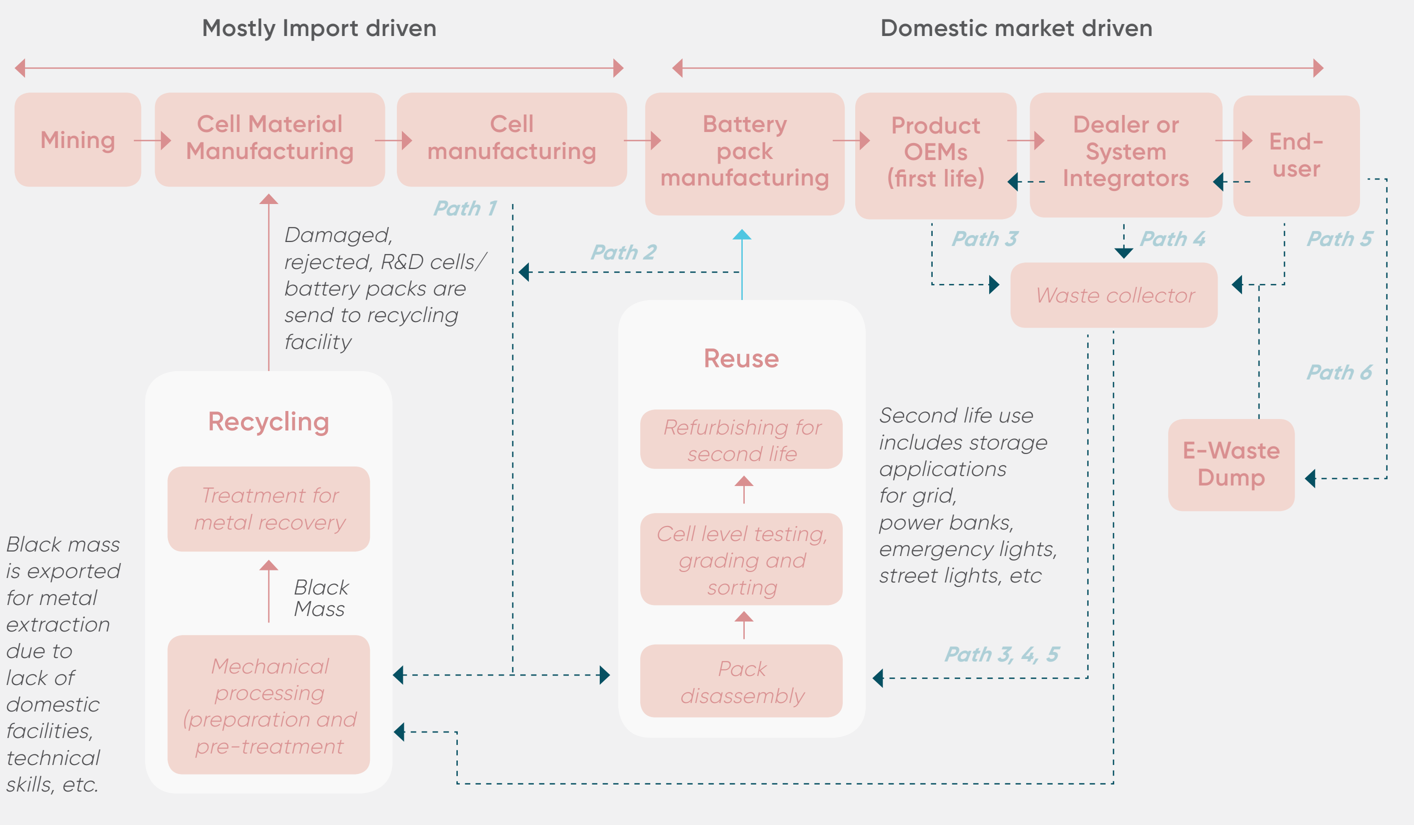
[90] Recycling strategies for EOL LIBs from heavy EVs, KTH Industrial Engineering & Management.

Parameter	Sub-parameter	Mechanical	Pyrometallurgy	Hydrometallurgy
Process and risks	Safety	**Fewer safety risks** such as explosion provided battery is fully discharged (i.e. at preparation stage).	**High safety risks** since operating temperature of furnace is very high (>1000oC).	**Medium safety risks** owing to chemical leaching process involved. Any chemical leakage may cause both environmental and human damage.

4.8. Recycling and reuse pathways

As discussed in Section 2.2, the battery value chain involves different stages. The integration of reuse and recycling in the existing value chain will help in establishing a circular economy for battery recycling. Different possible pathways for reuse/recycling and their characteristics are discussed below.

Figure 67: Recycling and reuse pathways for LIBs



Source: Stakeholder consultations, authors' analysis

Figure 67 presents the ecosystem of battery storage and recycling.

Pathways 1 and 2: During the manufacturing process, a cell or battery pack may need to be recycled because it is damaged during transportation or manufacturing, does not meet performance requirements, was used for R&D, etc. All such cells or packs can be forwarded directly to the recycling or reuse facility.

A cell may be found to be not fit for use for first-use applications (e.g. EVs) because of degradation. Such cells can be forwarded for second use (e.g. solar) after sorting and grading. In other words, a first-use cell is repurposed for second-use application as part of internal quality control and audit by cell or battery pack manufacturers.[91]

Pathway 3: In this pathway, spent LIBs batteries are collected by the product manufacturer and sent directly to the waste collector facility or recycling/reuse facility. In some cases, the waste collector facility can itself act as a recycler. The sources of spent batteries collected for product manufacturers are:

- Directly from the end-user via own service network (e.g. business-to-business);
- Indirectly from the end-user via the dealer network.

Pathway 4: Spent LIBs are collected by dealers (and their own network) from the end-user and sold to waste collector agencies. Collected waste at aggregate level is then forwarded by the waste collector to the recycling/reuse facility. These waste collector agencies can be both organised and unorganised.

Pathway 5: Battery waste is sold directly to the waste aggregator or recycler by the end-user, who may also receive higher pay for their waste in this pathway. For example, the waste aggregator can plan to collect waste from the end-user via a digital campaign.

Pathway 6: In this pathway, the battery waste or electronic waste is still residing with the user despite being of no use. In other words, this waste is stored somewhere to wait for recycling. For example, many smartphones that are not in working condition or damaged are still with the end-user. Even if they have been disposed of, they may have landed in landfill without the adoption of best practices for the safe disposal of batteries.

Pathways summary: Out of all six pathways, Pathways 3 and 4 contribute most to battery waste recycling/reuse sourcing in India, estimated at around 25–30%.[92]

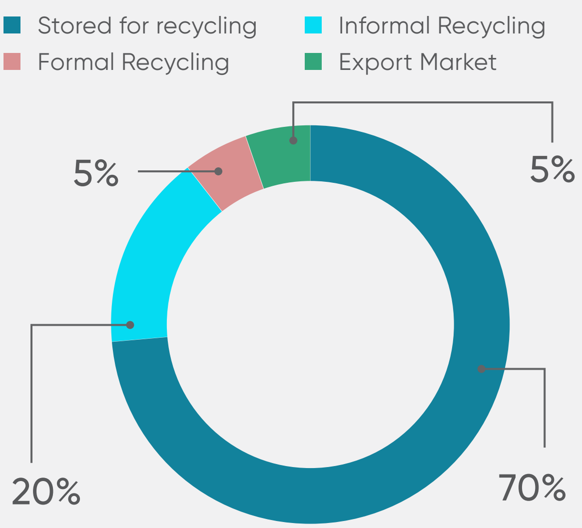
LIB recycling is currently being carried out domestically by either formal or informal recyclers, with an estimated 5% and 20% share, respectively. The other 5% of battery waste (black mass) is generally exported to other countries for recycling. This trend may change going forward, because informal sector players are becoming more educated and may move up the value chain, for example by selling black mass to exporters or domestic players.

[91] According to discussions with cell suppliers in India, the price of a cell fit for second-use application (e.g. solar) is lower by 15–25% compared with cells fit for first-use application (e.g. EVs).
[92] Stakeholder consultations

Also, considering the expected increase in EV adoption, the formal sector share is expected to grow significantly in coming years.

Pathway 6 (which does not participate in either formal or informal recycling) needs to be targeted through appropriate policy interventions and incentives programs. According to the leading recycler in India, about 70% of battery waste is sitting idle (being stored for recycling) and is yet to become part of formal and informal the recycling/reuse industry. The other pathways have their own significance but they may not contribute to overall LIB recycling pathways.

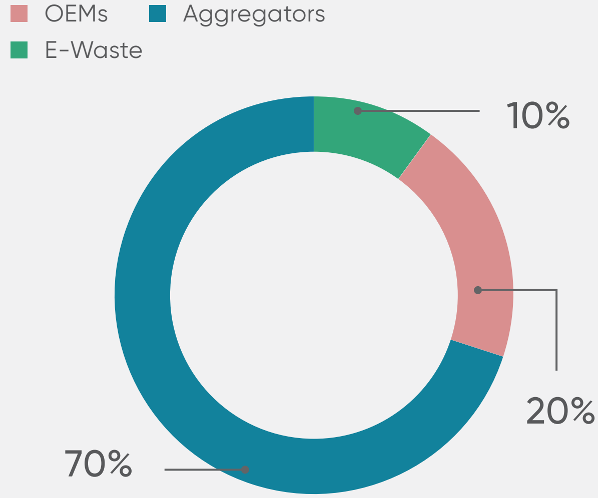
Figure 68: Annual battery waste generation and recycling avenues, 2020



Source: Stakeholder consultations, Authors' analysis.

Battery waste collection channels: Battery waste is channelled in one of three ways before it reaches the recycling/reuse facility – through OEMs, waste aggregators and e-waste. Figure 69 gives the estimated breakdown into these channels.

Figure 69: Distribution of spent batteries by collection channels, 2020



Source: Stakeholder consultations, Authors' analysis.

Today, the majority of battery waste, or 70%, is received from aggregators; 20% is received directly from OEMs and 10% from e-waste facilities. Overall, the formal and informal sectors account for 30% and 70%, respectively. It is predicted that, with any increase in the transport electrification rate, the share of OEMs will increase significantly. The formal and informal shares are expected to swap to 70% and 30%, respectively.

Battery waste collection by application and chemistry: LCO chemistries are sourced from CEAs such as smartphones, laptops, etc. Laptop batteries can be repurposed and used for power bank applications.

SAs like telecom towers are a primary source for LFP and NMC chemistries. Of the two, LFP is expected to dominate the overall stationary storage market.

In the case of TAs, LFP and NMC are expected to dominate the market but

OEMs may also adopt other chemistries, like LTO, NCA, and LMO.

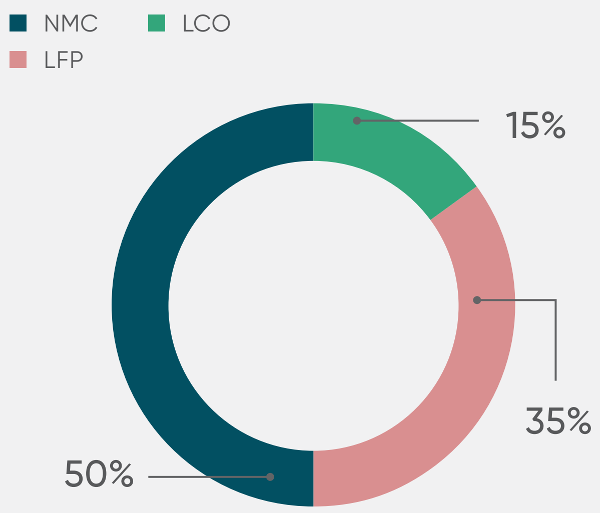
Tesla is using NCA batteries, with demand highly dependent on Tesla sales: this involves very costly battery management systems. However, Tesla has recently announced that it will shift to LFP chemistries for standard range vehicles and NMC for long range vehicles. This is a step towards optimising battery cost, performance, vehicle price and profits. Nissan used LMO in first generation cars; however, there are also reports that it will use NMC and LFP in new generation cars. The adoption of LTO chemistries by any major automobile maker is yet to be revealed. However, there is a chance that Maruti Suzuki, India's larger automobile player, will adopt this technology for its upcoming EVs.

In other words, the souring of LIBs and recycling profitability will be highly dependent on the battery chemistry going forward. Based on several industry consultations, it is understood that LFP recycling is less profitable since LFP does not contain cobalt and nickel, which are high-priced metals. In Europe and the US, OEMs pay a tipping fee to recycle LFP batteries, at about €900/ton. In India, no one pay for EOL batteries.

NMC chemistries are attractive to recycle because of the higher content of nickel and cobalt but a great deal of R&D effort is being undertaken to reduce the cobalt content in NMC batteries. The most used NMC chemistry is NMC111 (one part nickel, one part manganese, one part cobalt); efforts are being made to commercialise NMC811 (eight parts nickel, one part manganese, one part cobalt). This is because cobalt is costly compared with nickel, and nickel usage makes it possible to deliver a higher range. However, lesser usage of cobalt may result in functional instability of the cathode. Therefore, a balance between nickel and cobalt is a must for optimum performance.

In the Indian context, the battery chemistries that are popular are LFP, NMC and LCO. The other chemistries account for a negligible share. The market share (in percent terms) of these three chemistries coming in for recycling by weight is given in Figure 70.

Figure 70: Indian market share by battery chemistry and weight, 2020



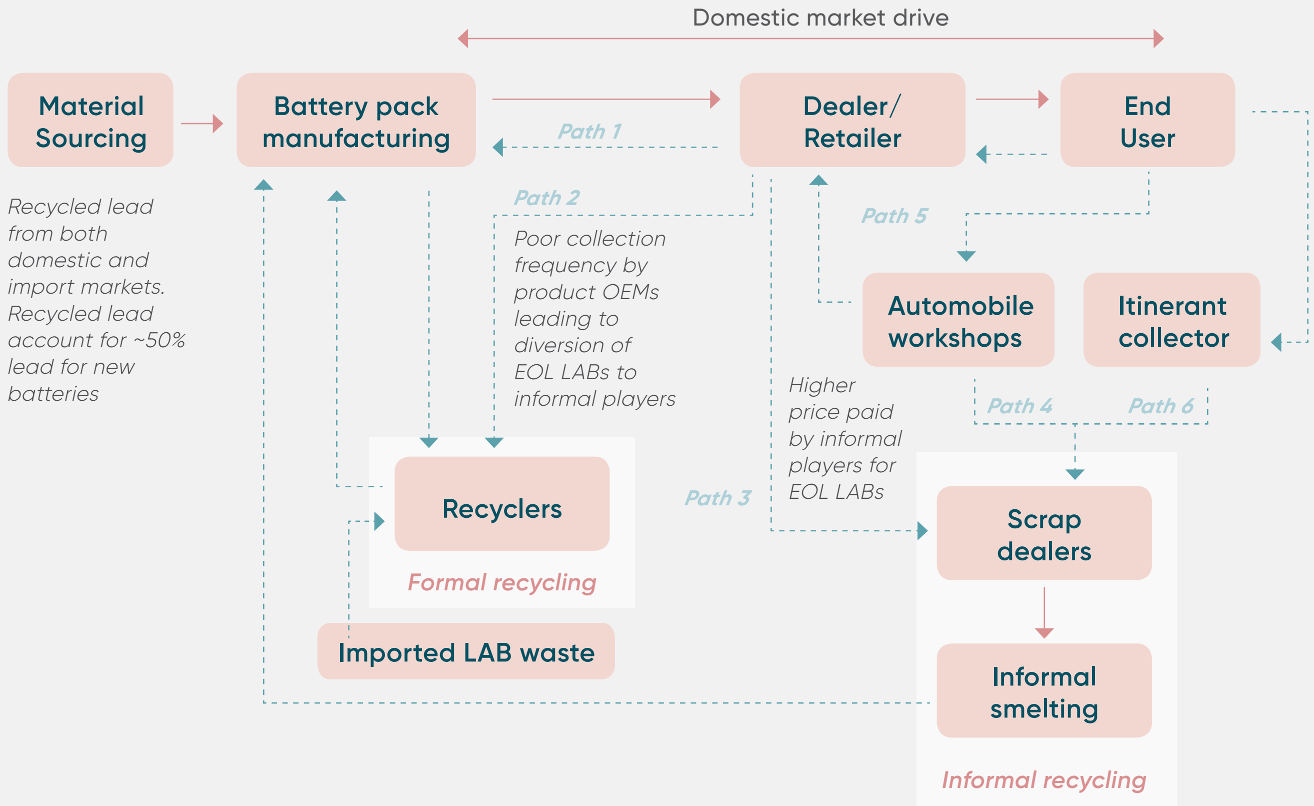
Source: Stakeholder consultations, Authors' analysis.

Therefore, long-term recycling attractiveness will depend largely on the battery chemistry that OEMs adopt. LFP recycling attractiveness will be always lower than that of NCM or LCO. Globally, LFP and NMC chemistries are popular for E4Ws. Annexure A.2 presents a summary of the battery chemistries used by different OEMs across the globe.

4.9. Learning from the lead acid battery market

The LAB supply chain in India is well integrated and circular, with local manufacturing and recycling already well established and most of the lead used for battery manufacturing coming from recycling. According to the CPCB, close to 3 million tonnes/year of LAB recycling occurs in India.[93] Key players in LAB recycling include Gravita, Pilot Industries Ltd, etc. In addition, several battery OEMs, like Exide and Amar Raja, also have their own recycling plants for LABs.

Figure 71: Flow of EOL LABs in India



Path 1: The EOL LABs coming from end-users go through a LAB dealer/retailer or LAB manufacturer to a formal registered recycler. This is the ideal pathway according to the Batteries (Management and Handling) rules (BMHR) set by the Ministry of Environment, Forest and Climate Change (MoEFCC) in 2001. Under the BMHR, retailers are required to sell the EOL LABs only to registered recyclers and the recyclers in turn are required to use technologies that do not have a harmful

[93] Central Pollution Control Board. List of Registered Recyclers of Used Lead Acid Batteries & Lead Wastes /Scraps. https://cpcb.nic.in/uploads/hwmd/List_Used_LA_Batteries_Registered_Recyclers.pdf

impact on the environment. The recycled lead is then used by LAB manufacturers. Manufacturers and importers are also required to buy recycled lead from registered recyclers. This pathway is supported by the Extended Producer Responsibility (EPR) Deposit Refund System (DRS). In DRS, the consumer deposits are added to the price of the LAB and refunded as they return to the retailers. Under this system, a discount is given to the consumer on the purchase of new batteries if old batteries are returned.

Path 2: Like in Path 1, the EOL LABs are recycled with compliance with all environment guidelines through a registered recycler under the BMHR. Here, the EOL LABs are collected directly by registered recyclers from dealers/retailers or bulk end-users through auction.

Path 3: Because of poor collection frequency by battery manufacturers, dealers/retailers tends to sell EOL LABs to informal players who collect on a regular basis to save on the cost of storage.[94] According to a study by Toxics Link,[95] only 20% of batteries are returned by dealers to manufacturers; the rest reach informal recyclers. In informal recycling, scrap dealers and informal smelters are the major stakeholders.

Path 4: The automobile sector accounts for close to 50% of LAB demand.[96] Here, the EOL LABs generally flow through automobile workshops, making these important stakeholders in the EOL LAB value chain. Workshop owners sell the EOL LABs either to retailers/dealers (forming Path 5) or to informal players. According to the Toxics Link study, close to 60% of EOL LABs going through workshops end up in informal recycling.

Path 5: Automobile workshops sell the EOL LABs to dealers and dealers further sell to battery manufacturers. Thus, here, EOL LABs go through a formal recycling process.

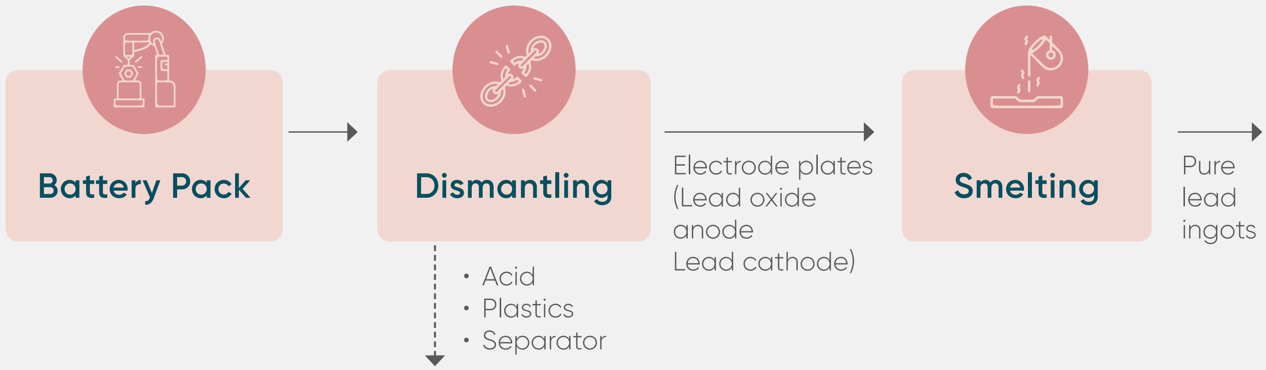
Path 6: In this pathway, the end-user sells the EOL LAB to an itinerant collector who further sells to players like scrap dealers in the informal recycling sector. According to the study by Toxics Link, end-users of LABs prefer itinerant collectors. The main reasons for this include frequent collection by itinerant collectors and monetary gain, especially on small-sized batteries for E2Ws and UPS.

In India, Paths 3, 4 and 6, which lead LABs into informal recycling, account for ~90% of EOL LAB stock.[97] Simple recycling technology and high recovery rate of the recycling process are the key reasons for the uptake of different types of lead recycling in the country.

As Figure 72 shows, LAB recycling involves fewer steps. First, the battery packs are dismantled. In this step, the plastic outer casing, acid electrolyte and separator sheets are taken out. The acid must be treated before dumping. The electrode plates made of lead peroxide and spongy lead and terminals made of solid lead are heated at high temperatures, otherwise called smelting. This process produces lead ingots, which are as pure as virgin lead. The lead dust and lead fumes that are emitted during the dismantling and smelting processes, respectively, are hazardous and need to be treated.

[94] Gupt, Y. (2015) Policy Measures and Incentives for Green Recycling of Lead in India.
[95] Toxics Link (2019) Leaded Batteries: Mapping the Toxic Waste Trail.
[96] Stock Exchange Letters. 2021–22, Amara Raja Batteries.
[97] Toxics Link (2019) Leaded Batteries: Mapping the Toxic Waste Trail.

Figure 72: The LAB recycling process



Because of the simplicity of this recycling process, more than 98% of EOL LABs are recycled and the supply chain is well integrated with recycling. As such, it is pertinent to think how recycling pathways for LABs are different from those of LIBs. The difference between LABs and LIBs pathways is highlighted below in Table 20,

Table 20: Comparison of LAB and LIB recycling in India

	Lead-acid batteries (LABs)	Lithium-ion batteries (LIBs)
% batteries recycled	Today, about 98% of EOL LABs are recycled, according to stakeholder consultations.	As per estimates, less than 1% of LIBs are recycled in India. The market is at a nascent stage.
% metal recovered	70% of battery weight contains lead and 100% of lead can be recovered. New batteries manufactured by leading OEMs contain around 50% recycled leads. This is sourced both domestically and through imports.	The metal weight will depend on the battery chemistry and the recycling technology. Up to 90% of metals can be recovered that can be reused. However, no evidence could be collected to ascertain this.
Technical competence	Less technical skill required.	High technical skills required as the process involved is complex and hazardous.
Supply chain	Most stakeholders understand the price discovery of spent LABs and the ease of technology for recycling LABs.	Only a few stakeholders understand the value chain, which is rapidly evolving with changing battery chemistry technology.
Formal market	Lead recycling is hazardous. The informal market accounts for a 90% share and the process followed may not be safe.	It is likely that many LIBs are recycled by informal actors with limited knowledge and understanding. Their share is estimated to be around 70%.
Ease of setting up recycling plant	Entry barriers are low owing to low capex and limited approvals required to operate. The technology is popular and mature.	Entry barriers are high owing to high capex and operating costs. Also, the approval process may be very tedious.

The key learnings from the LAB supply chain to create a circular economy for LIBs in India would be as follows:

Local manufacturing can aid the recycling industry:
LAB recycling is a well-established practice in India, with 98% of spent LABs being recycled. As a result, locally manufactured LABs use more than 50% recycled lead in the manufacturing process. The demand for recycled lead is met from both local and import markets, with the former occurring because of the increase in local manufacturing of LABs in the country. This has also created a price discovery mechanism for used LABs for all market participants involved in the supply chain. Thus, the LAB recycling market has grown significantly and promoted a circular economy in the country.

Since LIB cell manufacturing is being promoted in India, battery recycling presents an opportunity for cell material sourcing. Therefore, recycling should also be promoted along with manufacturing to create a circular economy in the LIB value chain. However, the technical skills and competencies required are quite different for LIB recycling compared with LAB recycling given the complexity of the processes and the spectrum of metals to be recovered.

Enforcement of regulations is necessary to avoid unsafe recycling that is hazardous to the environment, public health and worker safety:
Currently, a very large share of used LABs (more than 90%) is being recycled by informal recyclers. These recyclers generally do not follow prescribed environmental standards and regulations, which may affect workers' and public health through lead exposure. Informal lead recycling is also having impacts on the environment, as the residue from recycling may be released untreated. The key reasons for the rise in informal recycling of LABs are its simple recycling process and low capex; the higher costs incurred by formal recyclers in adhering to standards, resulting in a lower buying price of LABs compared with for informal recyclers, who save on operation costs; and the low frequency of collection of used LABs by formal recyclers, which leads to the sale of batteries to informal itinerant collectors, who further sell to informal recyclers.

A conclusion thus is that LIB recycling should be supported with the right policy interventions to improve collection efficiency and frequency through formal collection channels and with the enforcement of regulations to avoid growth in unsafe recycling.

4.10. Conclusions

The key take-away points after analysing recycling technologies and recycling pathways and comparing LIB recycling with well-established LAB recycling in India are as follows:

1. Each recycling technology has its own benefits and limitations in implementation and operation. Among all the processes, hydro is a must to extract pure metals from spent batteries.

2. A hybrid strategy (mechanical + hydro) will be more suitable for India because this allows extraction of a wide range of both valuable and non-valuable metals that are required for LIB cell manufacturing.
   a. Recyclers in China and South Korea have opted for mech + hydro to support cell and cell component manufacturing. These countries have a major share in global cell and cell component manufacturing.
   b. A mech + hydro strategy would also facilitate Indian players to import black mass and carry out metal extraction locally, to supply local demand for battery materials.
3. LFP and NMC are expected to take up a major share of the battery market. A mechanical process will be an attractive option for many recyclers, which may lead to growth in the manual dismantling of batteries. Therefore, organised battery collection will be important for LIB recycling.
4. Though battery prices are falling, chemistries such as NMC and NCA will continue to be of good economic value as they contain precious metals. LFP may not be as attractive for recyclers; incentivising recyclers through a tipping fee would make LFP recycling more viable.

4.11. Research and development

To understand the various research efforts being undertaken by Indian industries and academia to develop recycling technologies, we scanned and analysed the patent database. The results indicate that patent filing related to recycling technologies or processes is led by private firms and groups of individuals. These patents focus on pre-treatment (pyrothermal and mechanical), hydrometallurgy and direct cathode recycling. A summary of the patent analysis is in Annexure A.3. Table 21 presents brief abstracts of these patent filings.

Table 21: Some of the patented work on recycling of LIBs in India

01. Systems and Methods for Biological Extraction and Recycling of Lithium Ions From Lithium-Ion Batteries

Owner Type	Owner Name	Record No	Publication/ Issue Date
Individuals	-	IN201811037651A	26-Oct-18

Abstract: A method for biological extraction and recycling of lithium ions from lithium-ion batteries using microorganisms of the species Candida guilliermondii includes the steps of: physically grinding the lithium-ion batteries to smaller pieces in air free environment such that any lithium is prevented from exploding; removing the mixture, the carbon pieces and outer shell pieces that are non- metallic; mixing the bacteria grown in a big drum previously for 3 days leaving it overnight; and, separating the microorganisms and mixing the microorganisms with calcium carbonate and water

02. A Method of Roasting Lithium Batteries and Apparatus Thereof

Owner Type	Owner Name	Record No	Publication/ Issue Date
Firm	Attero Recycling Pvt. Ltd.	IN201711000131A	06-Jul-18

Abstract: The present invention relates to a method and apparatus for roasting the spent lithium batteries. Said apparatus involves a roasting mechanism that utilizes minimum amount of heat energy for roasting the lithium batteries. To achieve low heat energy based roasting process, the batteries are first punched to create holes or apertures on the outer surface and thereafter, kept inside the apparatus. In the roasting method, holes created on the battery surface assist in heat penetration that causes organic matrix to burn. Initially, the batteries are exposed to an initial temperature in the range of 250-300 °C that allows the organic matrix to catch fire. The energy released from the organic matrix is utilized to maintain temperature in the roasting apparatus. The temperature of the apparatus is kept within a range in between 400-600 °C that helps to reduce the necessity external heat energy required for a roasting process.

03. Process for Recovering Pure Cobalt and Nickel From Spent Lithium Batteries

Owner Type	Owner Name	Record No	Publication/ Issue Date
Firm	Attero Recycling Pvt. Ltd.	IN201711000131A	06-Apr-18

Abstract: An improved method and process for recovery of valuable metals from spent lithium batteries in highly purified and saleable form. The spent lithium batteries are shredded in a wet environment and wet screened to separate coarser particles containing copper, iron, aluminium, shredded plastic contents, and finer particles containing valuable materials like lithium, cobalt, nickel, and manganese wherein cobalt and nickel are recovered in saleable form using a selective adsorption technique. The finer particles obtained are passed through a resin column filled with adsorbents or resins for selectively loading the particular type of metals. The present invention provides benefits including low processing costs, recovery of nickel and cobalt in pure and saleable form, thereby producing greater social and economic benefits.

04. Process For The Recovery Of Lithium From Lithium Ion Batteries Using Acetic Acid

Owner Type	Owner Name	Record No	Publication/ Issue Date
Govt.	CSIR	IN201611030993A	06-Apr-18

Abstract: Disclosed is a process for the recovery of lithium and other metals i.e., manganese and cobalt from spent lithium ion batteries using CH3COOH (2M). Leaching efficiency of 2M acetic acid at 80°C for 80min (300rpm stirring) for cathode materials are 99% Lithium, 100% Manganese and 80% Cobalt. Ammonium sulphide (NH4)2S (0.2 wt. %) was used to precipitate cobalt as cobalt sulphide at the pH3 and separated from the leach liquor and manganese was precipitated as manganese sulphide in the pH7-9. After the separation of manganese and cobalt, the leach liquor was concentrated and evaporated to precipitate lithium as lithium carbonate. 90% lithium was recovered as a lithium carbonate with 96% purity.

05. Apparatus For Automatic Segregation Of Spent Lithium Ion Batteries And Method Thereof

Owner Type	Owner Name	Record No	Publication/ Issue Date
Firm	Attero Recycling Pvt. Ltd.	IN201611020384A	16-Feb-18

Abstract: The present invention provides an apparatus and a method for automatic classification and segregation of spent lithium ion batteries based on the eddy current generated by each battery depending on the composition at pre-treatment stage is used before metal recovery process. The present invention discloses a hopper to receive batch of batteries for classification and segregation; a conveyer belt that moves over magnetic drums that create a variable magnetic field capable enough to induce eddy current in the lithium ion batteries; a deflector plate that is located on one side of conveyer belt to determine the type of battery based on induced eddy current by each battery; and a plurality of chambers wherein the batteries and other materials fall over the deflector plate into the assigned chambers with variable angle ranging from 40 to 60 degree.

06. Process For Recovery Of Pure Cobalt Oxide From Spent Lithium Ion Batteries With High Manganese Content

Owner Type	Owner Name	Record No	Publication/ Issue Date
Firm	Attero Recycling Pvt. Ltd.	IN201611006457A	26-Jan-18

Abstract: The present invention relates to a process and method of recovering electrode materials like cobalt and graphite along with other valuable metals from used lithium-ion batteries having high manganese content. The valuable metals include lithium, manganese, copper, iron, aluminium etc. In this method, lithium ion battery used as a raw material that undergo through unit operations like shredding, sieving, filtration, precipitation, leaching, magnetic separation etc. The method of the present invention provide benefits including low processing costs, high recovery of copper and nickel-cobalt-manganese, thereby producing greater social and economic benefits.

07. Process For Recovering Metal Values From Spent Lithium Ion Batteries With High Manganese Content

Owner Type	Owner Name	Record No	Publication/ Issue Date
Firm	Attero Recycling Pvt. Ltd.	IN201611000739A	19-Jan-18

Abstract: The present invention relates to an improved process and method of recovering metals of value from used Lithium batteries (hereinafter LiBs). More particularly, the invention provides a method for recovering cobalt, lithium, manganese along with other metals of value from used LiBs rich in manganese content. The method includes combination of chemical and physical processes for separation, limiting the use of chemical for removing minor impurities. The invention provides for a cost effective, economic and environmental friendly process for recovering metals of value. The method comprises the following major steps of wet shredding, filtration followed by electrolysis in preferred conditions, density and magnetic separation procedures. The purity of metals obtained by using the proposed process is more than 99%.

08. Regeneration Of Cathode Material Of Lithium-Ion Batteries

Owner Type	Owner Name	Record No	Publication/ Issue Date
Academia	Calcutta University	IN-KOL-2013-00962A	27-Feb-15

Abstract: Lithium metal oxides may be regenerated under ambient conditions from materials recovered from partially or fully depleted lithium-ion batteries. Recovered lithium and metal materials may be reduced to nanoparticles and recombined to produce regenerated lithium metal oxides. The regenerated lithium metal oxides may be used to produce rechargeable lithium-ion batteries.

09. A Method Of Recovering Metals From Spent Li-Ion Batteries

Owner Type	Owner Name	Record No	Publication/ Issue Date
Firm	Attero Recycling Pvt. Ltd.	IN-DEL-2015-02048A	13-Jan-17

Abstract: The present invention relates to an improved process and method of recovering metals of value from used Lithium Ion batteries. More particularly, the invention provides a method for recovering cobalt and lithium along with other metals of value wherein the method majorly includes physical processes for separation, in particular wet screening a slurry, limiting the use of chemicals for removing minor impurities. Majority of elements were separated by physical process instead of chemical process which gives the benefit of cost saving in chemical treatment of liquid and solid effluents. Chemicals are used to dissolve only minor impurities from electrolyte which lead to the process economically attractive. This makes the method of recovering metal values is environment friendly. The invention provides for a cost effective, economic and environmental friendly process for recovering metals of value.

10. Recovery Of Cobalt From The Spent Lithium-Ion Battery Through Chemical Extraction And Precipitation

Owner Type	Owner Name	Record No	Publication/ Issue Date
Individuals	-	IN-CHE-2013-02997A	02-Aug-13

Abstract: We have successfully recovered the cobalt from the cathode active material of spent Li-ion battery (LIB). For this, we had chosen a leading commercial battery wherein cobalt based cathode material are used. After careful dismantling of the spent LIB, the cathode material coated on Al-foil was collected by scrubbing and analysed by using XRD, SEM/EDX, etc. It was found to be LiCoO2, and the same was subjected for chemical dissolution in environmentally benign aqueous mixture of citric acid and ascorbic acid at 80 °C for 6h. From the dissolved solution of cobalt and lithium, we have separated cobalt as cobalt oxalate through selective precipitation. During this study, we have also followed the dissolution kinetics of Li and Co ions by estimating their concentration using AAS. Furthermore, the formation of Li- and Co-complexes with citric acid was evident from UV-Vis spectra and cyclic voltammetric studies of the dissolved solution.

11. Smart Recycle Lithium Ion Battery Technology For Electric Vehicle

Owner Type	Owner Name	Record No	Publication/ Issue Date
Individuals	-	IN202141034488A	06-Aug-21

Abstract: To extract valuable components Co (cobalt), Ni (nickel), Al (aluminium) and Mn (manganese), Cathode materials made from spent lithium-ion batteries are dissolved in a solution for the production of active cathode materials for new batteries. The solution contains chemicals dissolved from exhausted cathode material from the wasted cells of valuable material such as cobalt, nickel, aluminium and manganese. To get the appropriate commingled compounds ratio for recycled cathode material for new cells, raw materials are added, depending on the desired ratio of the desired materials or ratios. Without significant heating or separation of desirable materials, the required materials precipitate off solution into compounds or elements. The resultant active cathode material has the default ratio for new cells. Generally, it prevents excessive heat needed to separate the necessary components since the right ingredients are still mixed into the solution.


LIGHTING A BILLION LIVES

Chapter 5

Policies and regulations for recycling in India

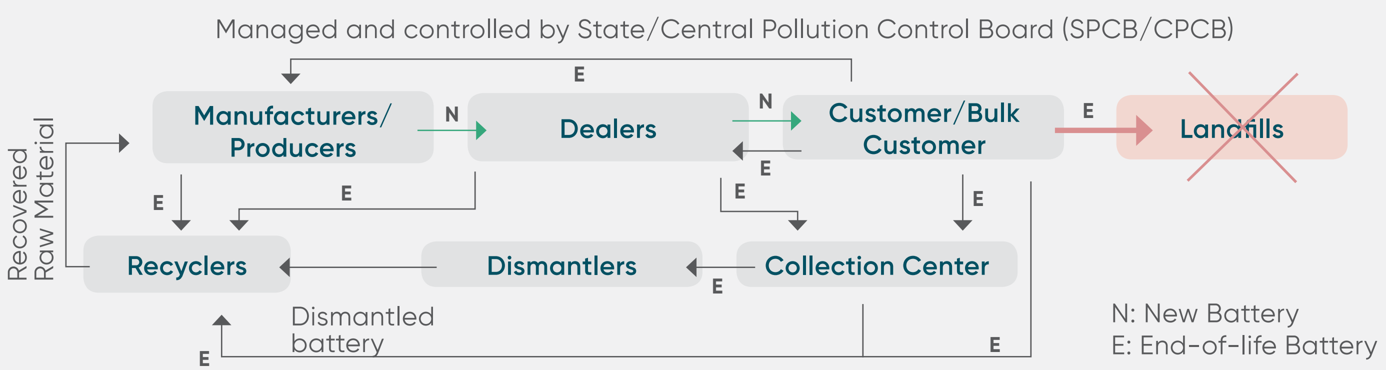
5.1. Key policies and regulations for recycling in India

India, in acknowledgment of the importance of battery recycling, has come up with a few policies, including the BMHR 2001 (applicable only for LABs) and E-Waste (Management and Handling) Rules 2011, 2016, and finally an amended version in 2018. The E-Waste management rules were first introduced in 2011 to enable the recovery and/or reuse of useful material from e-waste, thereby reducing the hazardous wastes destined for disposal. In 2016, the manufacturers, dealers, refurbishers, and Producer Responsibility Organisations (PRO) were also brought under the ambit of these Rules. Furthermore, the applicability of the Rules was also expanded to cover components, consumables, parts, and spares of EEE in addition to the equipment covered under the Rules. Finally, in 2018 the E-Waste Rules were amended by the Ministry of Environment, Forest and Climate Change (MoEFCC) to formalize the e-waste recycling sector by channelizing e-waste generated in the country towards authorized dismantlers and recyclers. Under the new amended Rules, the PROs had to register with Central Pollution Control Board (CPCB) to carry out their prescribed activities, ensuring that they are accountable and continuously monitored by CPCB.

In 2020, MoEFCC published the draft Battery Waste Management Rules under the Environment (Protection) Rules 1986 in order to establish a regulatory framework to strengthen the ecosystem for handling batteries across India while ensuring safe disposal and recycling. The draft covers all battery types including all primary (rechargeable) and secondary (non-rechargeable) cells, regardless of their shape, volume, weight, material composition or use. Batteries used for military purposes, space exploration, emergency and alarm systems, emergency lighting and medical equipment are not covered.

Under the draft rules, all stakeholders, including manufacturers, importers, assemblers, dealers and recyclers, have specific responsibilities. The aim is to ensure safe and formalised recycling of batteries that are in use with an emphasis on tracking batteries that have completed their useful life through online records and data management. The rules are designed to establish a circular and sustainable ecosystem where all stakeholders are environmentally aware and obligated to dispose of batteries in the right way. Figure 73 summarises the flow of battery throughout its lifecycle.

Figure 73: Circular supply chain of batteries



Source: Authors' analysis

The rules primarily introduce the concept of EPR, which gives the manufacturer additional responsibility for dealing with batteries efficiently throughout their lifecycle. Basically, the EPR regulations are designed to ensure that batteries are collected at the end of their lives and are recycled by registered recyclers. It is also possible to meet this responsibility through a collection agency known as a producer responsibility organisation. Apart from EPR, specific responsibilities are laid down in the regulation, aiming to streamline the process of collection, transport and recycling of batteries. The draft lays out the following responsibilities:

- Responsibilities of manufacturer, importer, assembler and reconditioner: Collect spent batteries of similar types and specifications against new batteries sold as per schedule; create public awareness on improper recycling of batteries and use international recycling signs on batteries; set up collection centres by themselves or jointly; ensure safe transportation from collection centres to registered recyclers with no damage to the environment; recycle and procure recycled lead through registered recyclers; notify authorities on violations; and file annual returns of sales and buy-back to the State Pollution Control Board (SPCB).

- Responsibility of dealer: Collect battery waste from consumers directly or through a take-back system on behalf of the producer; ensure annual submission of details of battery waste collected to the SPCB; and maintain records of battery waste handled and registered with the SPCB.

- Responsibility of consumer: Ensure EOL batteries are disposed of to a manufacturer, authorised dealer, collection centre or licensed recycler; and keep records of recycled batteries deposited with registered recyclers.

- Responsibility of collection centres: Ensure compliance with standards and guidelines of facilities and safe storage and transportation of battery waste; and maintain records of battery waste handled and of verification and discharge of discarded batteries with residual charge

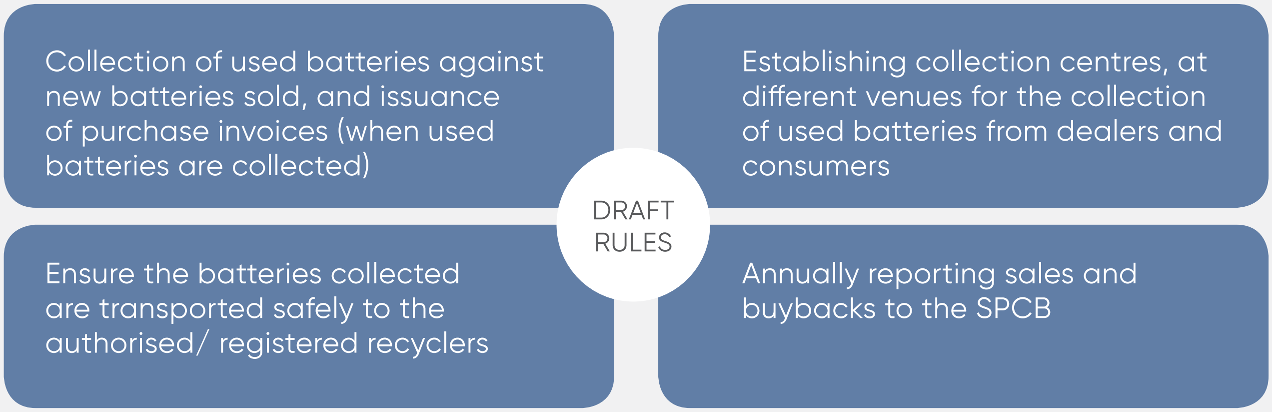
- Responsibility of pollution dismantler: Maintain records of battery waste collected, dismantled and sent to the authorised recycler and ensure that dismantled battery waste is segregated and sent to the registered recycling facilities for recovery of materials.

- Responsibility of recycler: Central recycling facilities to be developed with a capacity greater than 10,000 tons/year to ensure adequate pollution control that is cost-effective.

- Responsibility of pollution control authorities: Periodically monitor all recycling facilities; prepare guidelines/standard operating procedures (SOPs) for battery recycling facilities; standardise technologies for all types of battery recycling; and establish R&D facilities.

The responsibilities of manufacturers and dealers under the draft rules can be summarised as in Figure 74.

Figure 74: Summary of Battery Waste Management Rules 2020



The proposed rules when enforced will ensure accountability to ensure that batteries are recycled through formal channels. The draft also sets battery waste collection targets along with the framework for collection and channelisation of waste batteries at EOL.

However, there are also some potential problems in the implementation of the aforementioned rulings:

1. The draft rules fails to establish any regulatory standards for testing and classifying used batteries that have a secondary life and could still be used in other applications such as in households or energy backups.
2. The draft rules do not mention anything about labelling of the batteries in the battery packaging that would help not only in segregation of batteries but also in identification of the appropriate disposal method.
3. The incentive to follow the rules is not explicitly mentioned, and neither is the penalty for breaking the rules.
4. There is no provision for a separate licence for handling only LIBs, separate from electronic waste, and as such there is no reduced minimum requirement for entry into the recycling of LIBs.

5.2. Standards for recycling lead acid batteries

MoEFCC has set the SOPs for secondary lead recycling units. According to these guidelines, any person wishing to set up a lead-bearing waste recycling unit should submit an application to the SPCB along with a list of documents such as proof of installed capacity; membership of a treatment, storage and disposal facility for the final disposal of slag; a flow chart of recycling process; details of the air pollution control system and effluent treatment plant installed; and details of on-site storage for slag generated and raw material.

According to MoEFCC, the minimum required facility, operating practices and standards for secondary lead recycling plants have been defined. According to these:

- The furnace installed must have the minimum required air pollution control system.
- Dedicated covered storage space with required protection must be available for both raw materials and residue generated in the recycling process.
- The effluent treatment plant should be based on physic-chemical treatment of wastewater.
- The facility must have adequate provision for battery dismantling, storage and emission control.

The minimum standards set by MoEFCC ensure that pollution levels are within the permissible limits set by the CPCB.

5.3. Relevance of regulations for recycling of batteries and recommendations for India

In the next five years, it is anticipated that India's LIB industry will develop considerably, and the limited life of these batteries means that an efficient recycling or reusing procedure is the need of the hour. Recycling batteries would not only solve battery manufacturing issues, through ensuring less waste, avoiding environmental pollution and reducing costs, but also bring down dependence on imports for raw materials that are needed for battery manufacturing. In an economic sense, the best way to recover value from used batteries is to set up the infrastructure for recycling and to enable policies with the help of GoI. However, to successfully implement battery recycling in India, it is imperative that everyone involved in the supply chain take responsibility for awareness creation and the implementation of the laid-out battery management rules. To boost the participation of customers in recycling processes, innovative business models are required. Systems such as buybacks and deposit refunds will enable remuneration for participation. It is likely that contracts or leases signed with bulk users will increase the recycling rate at the EOL of the batteries. The battery recycling market associated with solar PV and RE in general will involve consumers in addition to bulk buyers.

Some recommendations for battery recycling are as follows:

[65] RMI (2021) Mobilising Finance for EVs in India. NITI Aayog.

Government should promote closed-loop recycling, whereby spent batteries are recycled directly, thus reducing energy use and waste by eliminating mining process.

Research organisations can be funded to come up with a commercially viable recycling process with a high recovery rate to make the recycling market a reality.

Battery manufacturers can forge recycling partnerships as they deploy batteries in EVs to streamline operational processes for collection, testing and recycling.

Incentives for manufacturers to meet recycling regulations, such as green taxes, in order to enforce EPR, will help in attaining a higher recycling rate.

The upcoming battery management rules must explicitly state the responsibilities of corporates and repercussions of their inability to achieve these.

Design for Environment guidelines and standards should be established to minimise environmental impacts and promote seamless battery recycling.

Disposal of batteries in landfill should be made illegal and an effective mechanism developed for batteries to undergo proper disposal through recyclers.

A Deposit Refund System can provide incentive to customers to return batteries thereby ensuring collection of batteries by the manufacturers.

Establishment of a separate collection agency by GoI will help in streamlining both the collection of batteries and recycling in formal smelters.

Battery recycling activity should be included as part of a typical operations and maintenance contract of solar projects in which large battery is associated.

Specific recommendations pertaining to LIBs are as follows:

- Standardisation of LIBs: For the establishment of recycling centres, standardisation of the battery chemistry is needed, as well as standardised battery forms based on the application, to streamline the dismantling process.

- Labelling system for LIBs: LIBs should have labels on their covering based on the recycling process to be used, making it easier to segregate them.

- Secondary life of LIBs: As the National Mobility Mission targets 6–7 million EVs on the roads by 2020, the number of LIBs in EV applications is expected to increase substantially. These LIBs in mobility applications are disposed of once they reach 80% capacity. These discarded batteries can be used in stationary storage applications combined with solar PV systems. Rooftop solar PV installations provide an ideal market for LIBs with an extended life. However, it has to be ensured that the battery quality, safety and performance standards are met. This makes it necessary to establish regulatory standards for testing and classifying used batteries that are being planned for a second life in energy storage.

- Licensing: There should be a separate licence for handling only LIBs, separate from electronic waste. This will reduce the minimum requirement for entry in the recycling of LIBs.

All these above measures, if implemented, would help India streamline the processes to ensure the proper disposal and recycling of LIBs in a cost-effective and sustainable manner. Additionally, building a collaborative ecosystem for EV battery reuse and recycling will lay the groundwork for a smart, safe and sustainable future.

It is projected that the consumption of metals used in LIBs, such as lithium, copper, cobalt, etc., will increase globally as a result of the rapid growth in demand for batteries. For India, most of the raw material stocks and supplies come from outside the country. Therefore, it is essential that the minerals recovered from battery recycling to go into cell manufacturing, so that there is a lesser dependence on imports of critical metals.

Moreover, the varying political relationships with countries that own natural reserves of these primary metals, as well as fluctuating raw material prices on global markets, may affect India's battery prices. For example, Russia accounts for about 11% of the global supply of nickel ore, and as such nickel prices have roughly doubled to unprecedented highs as the war with Ukraine has fuelled concerns of supply disruptions. Therefore, it is of the utmost important to create a closed-loop or 'circular economy' when it comes to the battery value chain in the country wherein the raw materials recovered from battery recycling are again used in the cell industry. To conclude, using the recovered minerals from battery recycling for cell manufacturing can not only reduce our dependence on imports but also help meet the demand for the manufacturing of new batteries.

Chapter 6

Case study

Battery-as-a-Service (BaaS) is an effective business model to maximise the value of batteries. Using the circular economy model,[99] BaaS is maximising asset efficiency and connecting the transport and energy sectors simultaneously. Under this model, manufactured batteries are leased to end-users such as vehicle owners and energy storage projects. When nearing the EOL of a battery, the provider of BaaS refurbishes the battery and makes it suitable for applications such as energy storage or BTM use. Batteries can also be recycled by extracting the raw material to manufacture new batteries.

The process is shown in Figure 75.

Figure 75: Integrated value chain – BaaS

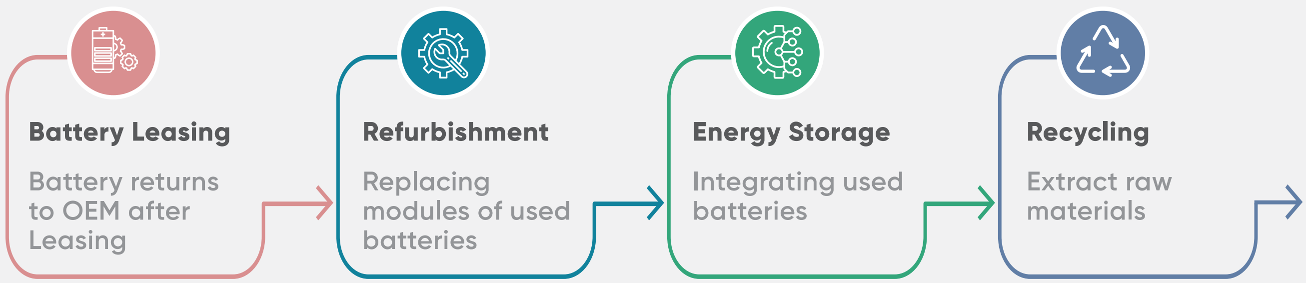


Table 22: Case study – Nio Battery as a Service with CATL

The Chinese automaker Nio, in partnership with CATL, a leading battery manufacturer, aims to separate the cost of the battery from the price of the vehicle purchase by 2020 through the BaaS business model. As a result of Baas, Nio has been able to reduce its vehicle prices by 70,000 yuan (~€8,530).

For the BaaS project, Nio, CATL and two other partners established the Battery Asset Company. Each partner invested 200 million yuan in the company (~€25 million). The Battery Asset Company is set up to buy batteries, and to lease them out using a BaaS model through CATL, which will supply the batteries.

EV-Urjaa is central India's first BaaS provider, which offers IoT-enabled smart LIB packs for E3Ws and electric bicycles. Lithion Power is India's largest BaaS provider, offering LIBs for e-bikes and E3Ws.

[17] Report by Ronald Berger.

Annexures

Annexure 1:
Multi-criteria analysis of battery recycling technologies

Level-1 (L-1)	Level-2 (L-2)	Description	Data type
Applicability	**Able to recycle different chemistries (existing and emerging)**	Ability to recycle a) Existing chemistries (all LIBs, NiMH, NiCd and b) Emerging chemistries (Na-ion, Li-S, Li-air, Solid state batteries, Thin film batteries)	Qualitative
	Ability to recycle different cell types	Ability to recycle different cell types (Cylindrical, prismatic and pouch cells)	Qualitative
	Batch process limitations	Operational or economical limitations in processing mix batches of a) Different battery chemistries, b) Different cell types, c) Different sizes of battery	Qualitative
Technology performance	**Metal recovery efficiency**	Recovery efficiency of technology for key metals contained in the battery like Co, Ni, Cu, Al, Fe and Li	Qualitative
	Other material recovery	Recovery efficiency of technology for other materials contained in the battery like plastics & graphite	Quantitative
	Losses	Any metals that are either lost or cannot be recovered or needs additional processes for complete recovery	Qualitative
Market	**Existing global deployments**	Cumulative recycling capacity (approx.)	Quantitative
	Existing Indian deployments	Cumulative recycling capacity (approx.)	Quantitative
	Recycling capacity in pipeline in India	Estimated upcoming recycling capacity in India	Quantitative
	Technology suppliers	Availability of technology within India	Qualitative
Economics	**Minimum plant size for financial viability**	Minimum recycling capacity required for financial viability	Quantitative
	Capex Requirement	Expected capital expenditure to setup recycling plant	Quantitative
	Opex Requirement	Expected operational expenditure for successful running of the plant including energy, additives, and man-power costs	Quantitative
Process and risks	**Process dependency**	Process dependency (if any) for carrying out smooth operation	Qualitative
	Environmental risks	Off-gas emissions, water requirement, etc.	Qualitative
	Safety	Safety risks such as fire, skin burns, skin reaction, etc.	Qualitative

Annexure 2:
Summary of different OEMs and the batteries used in their E4Ws

Brand	Pack size	Chemistries[100]	Remarks
BAIC	16 to 55 kWh	NMC	
BYD	37 to 88 kWh	LFP	
Changan	17 to 31 kWh	NMC	
Chery	22 to 49 kWh	LFP/NMC	Low battery pack size uses LFP
Denza	63 kWh	LFP	
Dongfeng	18 to 49 kWh	LFP	
GAC	63 kWh	NMC	
Geely	14 to 41 kWh	LFP/NMC	
Hawtai	21 to 50 kWh	NMC	
JAC Motors	22 kWh	LFP	
JMC	15 to 20 kWh	NMC	
Kandi	20 kWh	LFP/NMC	
Zotye	18 to 25 kWh	NMC	
BMW	33 kWh	NMC	
Chevrolet	60 kWh	NMC	
Fiat	24 kWh	NMC	
Ford	34 kWh	NMC	
Kia	27 kWh	NMC	
Mercedes	32 kWh	NCA (NMC)	
Mitsubishi	16 kWh	LMO	Anode is lithium titanium
Nissan	40 kWh	LMO/NMC	
Tesla	90 kWh	NCA/LFP	LPF for std. range vehicles
Volkswagen	36 kWh	NMC	

Source: The Lithium-Ion Market and the EV market, BMO Capital Markets, Authors' analysis

[100] The NMC cathode chemistries i.e. NMC111, NMC424, NMC821, etc. used in the LIBs was not available

Annexure 3:
Summary of patent filing by Indian industries and academia

Record Number & Publication/Issue Date	Register Legal Status	Title	Recycling technology/ process	Owners Type	Inventors
IN201811037651A **(26-Oct-18)**	FER[101] Issued, Reply not Filed	Systems And Methods For Biological Extraction And Recycling Of Lithium Ions From Lithium-Ion Batteries	Bio-hydrometallurgy	Individual	1) Dr Suhasini Bhatnagar 2) Mrs Manju Bhatnagar 3) Mr Prem Swaroop Bhatnagar
IN201711000131A **(06-Jul-18)**	FER Issued, Reply not Filed	A Method Of Roasting Lithium Batteries And Apparatus Thereof	Recycling Process (pyro-thermal)	Firm (Attero Recycling Pvt. Ltd.)	1) Nitin Gupta 2) G Prabaharan 3) Smruti Prakash Barik 4) Khadak Singh 5) Anuj Tyagi
IN201611031052A **(06-Apr-18)**	Application referred u/s 12 for examination	Process For Recovering Pure Cobalt And Nickel From Spent Lithium Batteries	Recycling Process (Mechanical + Hydro)	Firm (Attero Recycling Pvt. Ltd.)	1) Nitin Gupta 2) G Prabaharan 3) Smruti Prakash Barik
IN201611030993A **(06-Apr-18)**	FER Issued, Reply not Filed	Process For The Recovery Of Lithium From Lithium Ion Batteries Using Acetic Acid	Recycling Process (Hydro-metallurgy)	Govt. (CSIR)	1) Hari Chand Bajaj 2) Noon Ul Hasan Khan 3) Arvind Kumar Balvantrai Boricha 4) Subramanian Natarajan 5) Krishnan Muthukumar
IN201611020384A **(16-Feb-18)**	Application referred u/s 12 for examination	Apparatus For Automatic Segregation Of Spent Lithium Ion Batteries And Method Thereof	Apparatus (Mechanical)	Firm (Attero Recycling Pvt. Ltd.)	1) Nitin Gupta 2) G Prabaharan 3) Smruti Prakash Barik 4) Nitin Kumar 5) Shakil Ahmed Shabbir Shekh
IN201611006457A **(26-Jan-18)**	Application referred u/s 12 for examination	Process For Recovery Of Pure Cobalt Oxide From Spent Lithium Ion Batteries With High Manganese Content	Recycling Process (Mechanical + Hydro)	Firm (Attero Recycling Pvt. Ltd.)	1) Nitin Gupta 2) G Prabaharan 3) Smruti Prakash Barik
IN201611000739A **(19-Jan-18)**	Application referred u/s 12 for examination	Process For Recovering Metal Values From Spent Lithium Ion Batteries With High Manganese Content	Recycling Process (Mechanical + Hydro)	Firm (Attero Recycling Pvt. Ltd.)	1) Nitin Gupta 2) G Prabaharan 3) Smruti Prakash Barik

[101] FER refers to First Examination Report

Record Number & Publication/Issue Date	Register Legal Status	Title	Recycling technology/ process	Owners Type	Inventors
IN-KOL-2013-00962A **(27-Feb-15)**	Application Published	Regeneration Of Cathode Material Of Lithium-Ion Batteries	Direct Cathode Recycling Technology	Academia (Calcutta University)	1) Deb Nilanjan
IN-DEL-2015-02048A **(13-Jan-17)**	FER Issued, Reply not Filed	A Method Of Recovering Metals From Spent Li-Ion Batteries	Recycling Process (Mechanical + Hydro)	Firm (Attero Recycling Pvt. Ltd.)	1) Nitin Gupta 2) G Prabaharan 3) Smruti Prakash Barik 4) Bhuvnesh Kumar
IN-CHE-2013-02997A **(02-Aug-13)**	Application Published	Recovery Of Cobalt From The Spent Lithium-Ion Battery Through Chemical Extraction And Precipitation	Recycling Process (Hydro-metallurgy)	Individual	1) Dr Jayappa Manjanna 2) Mr Girish P Nayaka India
IN202141034488A **(06-Aug-21)**	Awaiting Request for Examination	Smart Recycle Lithium Ion Battery Technology For Electric Vehicle	Recycling Process (hydro-metallurgy)	Individual	1) Dr S Prabhu 2) Mr Sudhakar Murugesan 3) Mrs Evangelin Jeba J 4) Mr Deepak Sharma 5) R Mohammed Abdullah 6) Dr S Vijayarajan 7) Dr Bikram Jit Singh 8) Dr Rajeshwar Rao Kodipaka 9) Mr B Subrahmanyam 10) Dr R Karthick 11) Mrs P Meenalochini

Annexure 4:
List of authorised dismantlers/recyclers under E-Waste Rules 2016

List of Dismantlers/Recyclers as per the authorisation issued by SPCBs/PCCs under E-Waste (Management) Rules, 2016 (As on 06-12-2021)

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	State-wise capacity
1	Andhra Pradesh	8	1	M/s. Green Waves Environmental Solution, Sy. No. 43/1, Mindi (V), Gajuwaka (M), Visakhapatnam District.	480	32122.5
			2	M/s. Apna Bhoomi E-Waste Management Services, Sy. No. 119, Near Bharat Junction, Kusalapuram (V), Etcherla (M), Srikakulam Distric. - 532005	300	
			3	M/s. Veera Waste Management Systems, Plot No. 42, Block-D Extension, IDA, Autonagar Visakhapatnam District.-530012,	5820	
			4	M/s. Binbag Recycling Services Pvt. Ltd,Anatapur District	300	
			5	M/s. Clean Earth Green Earth Solutions, Krishna District	22.5	
			6	M/s. E-Parisaraa Pvt. Ltd,Anantapur District	300	
			7	M/s. World Scrap Recycling Solutions (P) Ltd Plot No 50,Chittor District	6,900	
			8	M/s World Scrap Recycling Solutions Pvt Ltd., Shed No 10 11 12,Chittor District	18000	
2	Assam	1	1	M/s. United Global Trust, F-5, Zoo Road, S enduri Ali Path, Guwahati, Dist. Kamrup (M) Assam	120	120
3	Chhattisgarh	2	1	M/s. ADV Metal Combine Pvt. Ltd., Shed No. -25, Borai Industrial Growth Center, Rasmada, Dist.- Durg (C.G)	750	6750
			2	M/s. Star E-Processors, Village-Baktara, P.O.-Godi, Tehsil-Arung, District- Raipur, Chhattisgarh	6000	
4	Delhi	2	1	M/s Fozia Traders, Khasra No.13/1, Saboli Mandoli Industrial Area, Delhi-110093	90	120
			2	M/s Muskan Technologies, B-96,Okhla Industrial Area,Phase-1,Delhi- 110020	30	
5	Gujarat	33	1	M/s. E-coli Waste Management P. Ltd, Plot No.-90 TO 92 Sabar Industrial Park Pvt. Ltd Vill-Asal Ta-Bhiloda Dist-Sabar kantha	7227	84301.92
			2	M/s. ECS Environment Ltd, ECS House, 11-12 Garden View, Opp. Auda Garden, Sindhu Bhawan road, Off SG Highway-Pakwan Circle, Bodakdev, Ahmedabad 380054	4999.92	
			3	M/s. Pruthavi E-Recycle Pvt. Ltd., Plot No.- 31/32 Golden Industries Area Near Rolex Industries Vill- Kothariya Rajkot -360002	3000	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
5	Gujarat	33	4	M/s. E-Process House, Plot No. 136/F-1. 2nd Phase, GIDC, Dist Valsad VAPI – 396195	350	
			5	M/s. Earth E-Waste Management Pvt. Ltd., Block No. 63, Sagun Ind. Estate, Type-A Paiky 11-A, Plot No. 1 to 5 & 10-D, Plot No. 1 to 5, Vill-Altodara, Tal. Opad, Dist. Surat – 394130	6000	
			6	M/s. Recotech E-Waste Management, Plot No. 36-37, Aashirwad Industrial Estate, Udhana-Sachin Road, GIDC Naka, Sachine, Surat	4500	
			7	M/s. E-Front Line Recyclling Pvt. Ltd., Shed No. C1B-905\9, GIDC, Panoli, Tal: Ankleshwar, Distt: Bharuch, Gujarat- 394116	2700	
			8	M/s. Dron E-Waste Solution, Plot No. 56, G.I.D.C., Gozariya, Tal & Distt; Mehsana, Gujarat- 382825	975	
			9	M/s. Eximo Recycling Pvt. Ltd., Plot No. 5/3, Raj Industrial Estate, Tal: Savli, Vadodara	900	
			10	M/s. Galaxy Recycling, Sr. No. 36/P1, P2, 37/P2, 38/ P2, Plot No. 52 &53, Near Tirth Agro. Pvt. Ltd., At: Bharudi, Tal: Gondal, Rajkot	521	
			11	M/s. Basant Clean Enviro Ltd., Plot No. 67, G.I.D.C., Kadi, Distt: Mehsana, Gujarat- 382715	7200	
			12	M/s. Eco Green Recycling, Plot No. 4, Near-Dynamic Textile, Ozar Road, Mota Ponda, Kapaada, Distt: Valsad, Gujarat	500	
			13	M/s. Unicare E-Waste Recycler, Plot No. 9/1, Raj Industrial Park-III, Jarod-Savali Road, Karachiya, Tal: Savli, Distt: Vadodara- 391520	1500	
			14	M/s. Surbine Recycling (P) Ltd., Plot No. 765, GIDC Phase-II, Dared- 361004, Distt: Jamnagar	1500	
			15	M/s. Greentech Recycling, Plot No. 5&6, Maharaja Estate, B/H: Ananad hotel, Sarkhej-sanand Road, Ahmedabad	702	
			16	M/s. Dinesh Appliances, Plot No: 10, R. K. Ind Estate, Rakhiyal, Ahmedabad	360	
			17	M/s. Mahammad Salim & Brothers Near Umiya Weigh Bridge, GIDC- Sachin, Tal: Chorasi, Dist: Sachin-394230	600	
			18	Electro Waste Solutions Plot no: 631, GIDC-Halol, Dist: Panchmahal	480	
			19	Felix Industries Pvt Ltd, Plot No:123, Devraj Industrial Park, 200 ft Ring Road, Piplaj-Pirana Road, Piplaj-382405, Dist: Ahmedabad	375	
			20	Ecotime Industries, Plot No: 98 & 99, Sparkle Industrial Estate, Tal: Jalalpor, Dist: Navsari-396436	144	
			21	Sharda Copper, Plot No: SME-06, Bardoli-2, (Miyawadi) Industrial Estate, Bardoli, Surat-394601	300	
			22	Bharuch Enviro Infrastructure Ltd (Beil), Plot no: 9701-16, 9801-28, 9901-28, 9601-04, 10001-10008, G-7 & 8, 7924- 27, 9401-9412, 9501-9506, 7905 E to H, GIDC, Ankleshwar-393002, Ta: Ankleshwar, Dist: Bharuch	700	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
5	Gujarat	33	23	Star Recycling, Survey no: 44 P1P1 44P1P2 & 46, Plot no: 45, R K Industrial Zone-09, Kuwadva-Wankaner Road, Ranpur360023, Tal & Dist: Rajkot	400	
			24	R Planet Integrated Solution Pvt. Ltd Plot no: 201, 202 (old block no. 264,265 paiki 1), Village: Zak-382330, Tal: Dahegam, Dist: Gandhinagar	11450	
			25	Payas Recyclers, Survey No.2139, Plot No.28, Parshwa Industrial Park, B/H. Sandvik Asia, Ahmedabad-Mehsana Highway, Rajpur-382740, Tal:Kadi, Dist: Mehsana	1158	
			26	ID Technocom, Plot No.C1-414/P, GIDC Estate Mansa, Visnagar Road, Vill- Mansa, Mansa382845, Dist: Gandhinagar	240	
			27	M/s. Unity E-Recycling Co, Sr. No: 310/p, Plot No: 4, Danilimda, Ahmedabad-380028	383	
			28	M/s. Mahaarana Industries Pvt. Ltd., Survey No. 466 & 475, Village: Timba, Ta: Daskroi, Dist; Ahmedabad	16585	
			29	10. M/s GL Recycling LLP, Survey No. 108, Village: Soliya, Ta.:Kotda Sangani, Dist.: Rajkot-360030	6026	
			30	M/s. Electro Alloys Recycling And Transformation HUB, Plot No. 301/13, GIDC Palej-392220, Bharuch	750	
			31	M/s. Reart Recycling Private Limited., Plot No.365, Survey No.111p1, Golden Green Industrial Park (phase-D), Khambha-360311, Tal:Lodhika, Dist:Rajkot	300	
			32	M/s. Tvarita Phones Pvt. Ltd., Plot No.171, Survey No. 846, N. H. 8, Vapi, Valsad-396191	600	
			33	M/s. Kalpana E-Recyclers, Plot No. 2486, Madhuban Industrial Park, Village: Kuha, Ta: Daskroi, Dist: Ahmedabad	876	
6	Goa	1	1	M/s Global E Waste Management Systems Plot No: Shop No 729/s-1 to 729/s-5, Sonum Township Nessai Salcete – Goa	103	103
7	Haryana	42	1	M/s Honey Disposal Store, Plot No. 67-68 Jarrout Road, Village Mandour Industrial Area Ambala city.	300	124281.6
			2	M/s. Makol Enterprises, Vill. Vasudev Nagar, Nr. Saunda Village, Ambala. (Not available on website)	300	
			3	M/s. Thapar Disposal Industries, 902A/5/6, Chara Mandi Road, Ambala City	1825	
			4	M/s. Mittal Battery, plot No. 349, Indl-Area, Ph-1, Panchkula. (Not available on website)	3600	
			5	M/s. Exigo Recycling Pvt. Ltd., G. T. Road, Samalkha Panipat	6000	
			6	M/s. Exigo Recycling (P) Ltd., Barsat Road, Panipat	18000	
			7	M/s. JLB Recycling Industries, Plot No.23/1 (20//21/1/2) HSIIDC, Industrial Area Road, Samalkha, Panipat (Not available on website)	1140	
			8	M/s. Adinath Recyclotronix (P) Ltd., Plot No.#361, Industrial Estate, HSIIDC, Panipat(Not available on website)	1080	
			9	M/s Earth Waste Management Pvt. Ltd. Vill-Ismaila, Distt. Rohtak	600	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
7	Haryana	42	10	M/s. Giriraj Metal, P. No. 39 HSIIDC, IE, Kutana, Rohtak	300	
			11	M/s. Green World International, Pvt. Ltd., GR 60-61 Ganpati Industrial Dham Industrial Area Bahadugarh Haryana	5000	
			12	M/s. R. K. Enterprises (P) Ltd., Vill Lohari, Distt, Jhajjar	14640	
			13	M/s Renu Recycling Company, Plot No. 1257, MIE-B, Bahadurgarh (Not available on website)	1800	
			14	M/s. A 2 Z E-Waste Management ltd., P No. 14 and 15 -Roz Meo Indusrial Area, Nuh Mewat	2000	
			15	M/s AMN E-Waste Management Pvt Ltd., Plot No. 171, Sector-59, Industrial Area, Faridabad (Not available on website)	290	
			16	M/s Endeavor Re-processor and Recyclers India, Plot no. 323, Sec-24, industrial Area, Faridabad (Not available on website)	365	
			17	M/s E-waste Solutions, Industrial Shed, 1A, Industrial Estate, Sec-6, Faridabad	1000	
			18	M/s V S Enterprises, Plot no. 9, Pragati Vihar, Sector-59, Faridabad (Not available on website)	300	
			19	M/s Dotline Informatics Pvt. Ltd., Plot No. 302, Ph-V, HSIIDC, Indl. Estate, Rai, Distt. Sonipat	350	
			20	M/s Bluend Technology Pvt. Ltd., Plot No. 149, Phase-IV, Sector-57, HSIIDC Industrial Estate Kundli, Sonipat (Not available on website)	3650	
			21	M/s RBH E-Waste Recycle Hub Pvt. Ltd. (old name M/s Satellite Vision India), Plot No. 130, HSIIDC, Rai, Distt. Sonipat	912.5	
			22	M/s Global Waste Solution, Village Ram Nagar, Tehsil Ganaur, Distt. Sonipat	9490	
			23	M/s Global Waste Solution Unit-II, Village Dhaturi Tehsil Ganaur, Distt. Sonipat	8249	
			24	M/s Tes Amm (India) Pvt. Ltd., Village Wazidpur Saboli, Distt. Sonepat	12000	
			25	M/s Bluenvir, 81, HSIIDC, Rai, Distt. Sonipat	435	
			26	M/s. EARTH SENSE RECYCLE PVT LTD, Plot No. 100, Sector - 5, IMT Manesar, Gurgaon	2160	
			27	M/s. Nirvana Recycling Pvt. Ltd., Plot No. D-6, Udyog, Vihar, Phase-VI, Sector-37, Gurugram	6030	
			28	M/s. Green Vortex Waste Management Pvt Ltd.Plot No 177, Sector 7, IMT Manesar	1500	
			29	M/s. SMS ENTERPRISES, Plot No. 544- D, First Floor, Sector -37, Pace City - II, Gurgaon (Haryana)	360	
			30	M/s. Dlila Systems, 1st Floor, Plot No.61, Sector-8, IMT Manesar, Gurugram	474	
			31	M/s. Apicem Recyclers Pvt. Ltd., Plot No. 359, Sector-8, IMT Manesar, Gurugram, Haryana	510	
			32	M/s. KM Global E-Waste Private Limited, Ground Floor Plot no. -359, Sector- 8, IMT Manesar, Gurugram, Haryana	510	
			33	M/s 3 R Recycler, Plot No. 392, Sector-8, IMT Manesar Gurgaon	2994	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
7	Haryana	42	19	Deshwal Waste Management Pvt Ltd, plot No-116, Sec-8, IMT Manesar, Gurgaon, Haryana	4652.1	
			35	Deshwal Waste Management Pvt Ltd, plot No-292, Sec-7, IMT Manesar, Gurgaon, Haryana	10000	
			36	Deshwal Waste Management Pvt Ltd,Plot No 215, Sec-4, IMT Manesar, Gurugram	1800	
			37	M/s. Namo E-Waste Management Ltd., 14/1, Mathura Road, Faridabad Haryana	5796	
			38	M/s. E Waste Recyclers India, Shed no. 15 Roz Ka Meo Industrial Area Nuh.	667	
			39	M/s. United Waste Solution India Private Limited Plot No. 38 & 57, Rozka Meo Industrial Area, Nuh, Haryana	262	
			40	M/s. EcoFriendly MetalPvt.Ltd., PlotNo.A- 7,Ind. EstateNo.1, Near MR,Faridabad(15 00MTA)	1500	
			41	M/s Radhey Steel Traders, Vill. PatviBarara Road, Shahabad, Distt. Kurukshetra	600	
			42	M/s Adlib E- Waste Recycling, Plot No.433, HSIIDC, Barhi, Sonipat	840	
8	Himachal Pradesh	2	1	M/s. Shivalik Solid Waste Management Ltd., (Unit –II), Village-Shabowal, Tehsil Nalagarh, District-Solan HP	1000	1500
			2	M/s Ortech India Corporations, Plot No. 67-B, Industrial Estate, Lodhi Majra, Baddi	500	
9	Jammu & Kashmir	3	1	M/s. VRG Groups, Gangyal	135	705
			2	M/s. Bashir Ahmad Babdemb, Srinagar	285	
			3	M/s. Bashir Enterprises Noorbagh, Srinagar	285	
10	Jharkhand	2		M/s. Meliorate Lubes Pvt Ltd, Plot No. 606/A, Ward No. 4/34, Vikas Nagar, hesal Piska More, Ranchi Jharkhand - 834005	300	660
				M/s. Simran Infotech, Vill & P.O Kanak Chas, P.S. Chandan Kiari dist. Kokaro Jharkhand- 828134	360	
11	Karnataka (Not updated)	2	1	M/s. Meliorate Lubes Pvt Ltd, Plot No. 606/A, Ward No. 4/34, Vikas Naga, hesal Piska More, Ranchi Jharkhand - 834005	300	660
			2	M/s. Simran Infotech, Vill & P.O Kanak Chas, P.S. Chandan Kiari dist. Kokaro Jharkhand- 828134	360	
		71	1	M/s. Ash Recyclers, No. 94, Thimmaiah Road, Bangalore- 01	NA	52842
			2	M/s. Eco-E-Waste Recyclers India Pvt. Ltd., No. 41/1, 42/2, 19&20, 2nd Cross, Muthachari Industrial Estate, Hanumanthappa Layout, Mysore Road, Bangalore - 560039	300	
			3	M/s. Sriram Eco Raksha Computer Services Pvt. Ltd. No. B-29, KSSIDC Indl. Estate, Bommasandra, Hosur Road, Anekal Taluk, Bangalore – 560 099	500	
			4	M/s. E-Friendly Waste Recyclers, First Floor, No. 17 1st, Cross, Azeez Sait Industrial Town, Nayandahalli, Bangalore-560039	600	
			5	M/s. Green Globe Enterprise, No. 108/7, 5th Cross, Singasandra Industrial Area, Hosur Road, Bommandahalli, Bangalore-68	948	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
11	Karnataka (Not updated)	71	6	M/s. Shobith Industry –Unit II, Survey No. B-4/1, KSSIDC Industrial Area, Nanjangud – 571302, Mysore District	300	
			7	M/s. Sai Shaakti Chemicals, No. 1/8, Kodipalya Road, CVR Main Road, Kengeri, Bangalore- 560060	120	
			8	M/s. Eco Globe E-Waste Recyclers, Plot No. 87, 2nd Phase, 2nd Sector, Bidadi Industrial Area, Bidadi Hobli, Ramanagra Taluk and District	300	
			9	M/s. E-Hasiru, No. 168/B, 1st Floor, 7th Main Road, 3rd Phase, Peenya Industrial Area, Bangalore – 558	300	
			10	M/s. Green Enabled IT Solutions Pvt. Ltd., No. 2/1, 27th Cross, Behind Krishna Grand Hotel, Banashankari 2nd Stage, Bengaluru	360	
			11	M/s. Coral Waters, No. 8E, KIADB Industrial Area, Hoskote Taluk, Banglaore Rural District	1440	
			12	M/s. Royal Touch, No. 3/2, 2nd Cross, Ezakiel Industrial Estate, K. G Halli, Nagawara Main Road, Banglaore	1080	
			13	M/s. Pharmateck Consultancy, Sy. No. 40/1, Mangammanapalya, Bommanahalli	300	
			14	M/s. Digicomp Complete Solutions Ltd., or Regenersis (India) Pvt. Ltd., No. 86, Grond Floor, 3rd Cross, New Timber Yard Layout, Mysore Road, Bangalore- 560026	180	
			15	M/s. Cerebra Integrated Technologies Ltd., Plot No. 41 to 46, Appasandra village, KIADB Indl. Area, Narasapura Hobli, kolar Taluk and District	2076	
			16	M/s. Lube Tech Petro Chemicals, Plot No. 08-A, Bidadi Industrial Area, 2nd Phase, Sector-1, Bidadi Hobli, Ramanagara Taluk and District	300	
			17	M/s. AGK Enterprises, Unit-I, No 33/A, Industrial "A" Layout, Bannimantap, Mysore - 570015	360	
			18	M/s. Aptus Recycling Pvt. Ltd., Sy No. 241/4B, Magnur Village, Kirgavalu Hobli, Malavalli Taluk Mandya District- 571430	300	
			19	M/s. Premier Comprint, No. 33/3, abigere Pipe Line Road, Hanumanthaih Industrial Area, chikkabanavara Post, Bangalore- 560090	300	
			20	M/s. E-Parisara Pvt. Ltd., No. 30-P3, Dabaspet Bangalore	8820	
			21	M/s. Tech Logic, Unit-2, Shed No. 36, 2nd Main, Ranganathapura, Bangalore - 560 044	240	
			22	M/s. E-Scrapy Recyclers, No.106, Andrahalli Main Road, Byreshwara Industrial Area, Peenya 2nd stage, Bangalore - 560 058	720	
			23	M/s. R. N. Traders, Plot No. 101 Kumbalgodu village, Bengeri Hobli, Bangalore	300	
			24	M/s. KH E-Waste Recyclers, No. 104, 1st Main Road, 4th Cross, Azeez Sait Industrial Area, Nayandahalli, Bangalore – 39	300	
			25	M/s. RPN Industries, Plot No B2, KSSIDC Industrial Area, Kumbalgodu, Mysore Road, Bangalore-74	300	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
11	Karnataka (Not updated)	71	26	M/s. Macro Engineering Services, No. 427-E2, Hebbal Industrial Area, Mysore-570018	300	
			27	M/s. I Seven, # 9/4, Kachohalli Industrial Estate Kachohalli, Near Saibaba Temple, Laxmipura Post, Bengaluru- 562123	300	
			28	M/s. SLV Enterprises, The Gachaguppe Village Kumbalagodu Post, Kengeri Hobli, Bangalore	300	
			29	M/s. XL Engineering and Fabricators, No. B-188, 5th Main, II Stage, Peenya Industrial area, Bangalore- 58	408	
			30	M/s. Greenscape Eco Management Pvt. Ltd., Plot No. R-12, Veerasandra Indl Area, Anekal Tq, Bangalore Urban District – 100	600	
			31	M/s. Just E-Care, No Indl estate Station back road, Bijapur	NA	
			32	M/s. Trishyirya Recycling India Pvt. Ltd., No. 315, 4th Phase, Peenya Industrial Estate, Bangalore - 560 058	900	
			33	M/s. E Pragathi Recycling Plot No. 66, Road No. 18, Anthaasanahalli Indl. Area, IInd Phase, Tumkur	300	
			34	M/s. Ingram Micro India Pvt. Ltd., I Floor, Plot No. 1-4, Sy No. 5/2, 15th Km, Singasandra Post, Baretena Agrahara, NH-7, Hosur Main Road, Bangalore-560100	720	
			35	M/s. Vans Chemistry, Plot No. 94/5, Shed NO. 13R14, SRRLayout, Kannalli Village, Bangalore- 560094	720	
			36	M/s. Intro Tech Recyclers, No. C-50/1, First Floor, KSSIDC Industrial Estate, Kumbalgodu, Bangalore-560060	300	
			37	M/s. Nobel Technology, No. 46, 14th Cross, 4th Phase, Peenya Industrial Area, Bangalore - 596058	300	
			38	M/s. E-Parisara Pvt. Ltd., Unit -2, No. P-10, (a), 3rd Stage, Peenya industrial Area, Bangalore – 560058	300	
			39	M/s. Moogambigai Metal Refineries, Unit (3), Plot No. 174, Industrial Area, Baikampady Mangalore- 575011	2400	
			40	M/s. Sogo Synergy Private Limited, Shed No. A-57, KSSIDC Industrial Estate, Bommasandra, Hosur Road, Anekal Taluk, Bangalore Urban District – 560099	600	
			41	M/s. Trishyraya Recycling Indi Pvt. Ltd., No. 315, 4th Phase, Peenya Industrial Area, Bangalore	300	
			42	M/s. MKK E-Waste Enterprises, Shed No. 292, Belur Industrial Area, Belur, Dharwad Dist- 580011	750	
			43	M/s. BSMR Metals, No. R. O 7, KSSIDC Industrial Estate, Veerasandra II stage, Attibele Hobli, Bangalore Urban District	300	
			44	M/s. Newtek Recyclers, No. 124, Byreveshwara Industrial Estate, Andhrahalli Main Road, Peenya 2nd Stage, Bangalore - 560091	300	
			45	M/s. Mak Technology Industrial, Shed No. SP-5, Veerasandra KSSIDC Industrial Estate, Phase 0-11, 3rd Cross, Huskur Min Road, Electronic City Post, Bengaluru	350	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
11	Karnataka (Not updated)	71	46	M/s. Earth Sense Recycle Pvt. Ltd., Industrial Plot No. spl. 14, Jigani 2nd Stage, Jigani Village and Hobli, Bangalore - 560105		
			47	M/s. General Eco Transtech Private Limited, shed No. B-15, KSSIDC Industrial Area, Tamaka, Kolar	300	
			48	4R Recycling Pvt Ltd, Shed No A-5, Industrial Estate, Peenya 3rd Stage Industrial area, Nallakadirenahalli Village, Yeshwanthpur Hobli, Bangalore North Taluk, Bangalore.	600	
			49	M/s. Prakruthi Recycling Pvt. Ltd., Sy No. 22, Flat No. 103, 5th Block, 5th Cross, SSI Area, Rajajinagar, Bangalore- 560010	600	
			50	M/s. Puthur Infortech pvt. Ltd., No. 55, 1st Floor 5th Cross, Banaswadi Main Road, Bangalore- 560043	150	
			51	M/s. SA Ewaste Recyclers, B-4, KSSIDC Indl Estate, Yellapura Village, Doddaballapura Taluk, Banglaore	360	
			52	M/s. Elxion Pvt. Ltd., P. No. 24, 23rd A. Main Road, J.P Nagar 2nd Phase Indl Bangalore- 560078	360	
			53	M/s. K. G. Nandini Enterprises, No. 46/4, 46/5, Billakempanahalli Village, Bidadi Hobli, Ramanagaram District.	360	
			54	M/s. Eco Bird Recycling Company Pvt. Ltd., No. 185, Azeez Sait industrial Area, Nayandahalli, Mysore Road, Bangalore -39	7200	
			55	M/s. Ameena Enterprises Shed No. C-199, KSSIDC Industrial Estate, Hebbal,	350	
			56	M/s. E-R3 Solutions Pvt. Ltd., No. C-430, 1st Cross, 1st Stage Peenya Industrial Area, Bangalore - 560058	560	
			57	M/s. Afeefa Spectro Alloys, Sy No. 289/1, Nagaragere village, Gauribidnur Tq.	290	
			58	M/s. Rashi E-Waste Solutions Pvt. Ltd., SW-51, Shed No. 26, Phase II, Apparel Park, Doddaballapura, Bangalore Rural District	300	
			59	M/s. Coral Communication and Networks Pvt. Ltd., No. 52, Hoskote Industrial area, Bangalore Rural District	300	
			60	M/s. Ash Recyclers, No. 3, KSSIDC Ind Estate, Hoskote, Bangalore Rural District	300	
			61	M/s. Vans Chemistry Pvt. Ltd., Plot No. 47 & 48, of Narsapura industrial Area 1st Phase, KIADB Narsapura Industrial Area, Narsapura Hobli, Kolar Taluk & District	720	
			62	M/s. E Pragathi Recycling, Plot No. 66, Road No. 18, Antharasanahalli Indl Area, IInd Phase, Tumkur	300	
			63	M/s. E-Green Recycling, Plot No. 86-B, Jigani 1st Phase, Anekal Taluk, Bangalore	500	
			64	M/s. Sri Vasavi Recyclers India Pvt. Ltd., P. No. 57 & 58, KIADB Indl Area, 1st Phase, Harohalli, Kanakapura Taluk, Ramanagara District	1080	
			65	M/s. Excel Recycling P. No. 212/2, Tippu Town, Rammanahalli village, mysuru Taluk & District	720	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
11	Karnataka (Not updated)	71	66	M/s Sheltron Digital systems Pvt.Ltd No.27, maney estate, Sy.no.121, Kumbalgodu, Bengaluru-560074	360	
			67	M/s Tes-Amm, India pvt. Ltd. Sy. No. 118, Site. No. 8, Mookambika Temple Road, Machodalli Forest Gate, Magadi Road, Bangalore	3240	
			68	M/s Sonal Metacop, No.5, Sy No.5/1, Kachohalli Industrial Estate, Kachohalli, Laxmipura Post, Bangalore-562123	720	
			69	M/s E-Ward & Co. No.11, Mutthachari Industrial area, Nayandahalli, Mysore road, Bangalore-560039	600	
			70	M/s Trackon E-waste Recyclers Pvt. Ltd, No.28, Gerupalya, 2nd Phase, Kumbalgodu Industrial Area, Benglore-560074	300	
			71	M/s. Moogambigai Metal Refineries, No. 89 & 90 Industrial Area, Baikampady Mangalore-575011	1080	
12	Kerala	1	1	M/s. Kerala Enviro Infrastructure Ltd, Infrastructure Ltd E Waste Dismantling Facility, Common TSDF project, Inside Fact-CD Campus, Ambalamedu, Kochi 682303	1200	1200
13	Maharashtra	116	1	M/s Eco Recycling Ltd. Eco House, Near Top Glass Enclave, Bhoj Pada, Sativali Road, Vasai (E) Dist: Thane	7200	106280.5
			2	M/s Ecocentric Management Pvt. Ltd. Plot No.17, Universal Industrial Estate, Vill. Sajgaon, Tal. Khalapur, Distt. Raigad	2500	
			3	M/s. ECO Friend Industrial, Plot No. A-205, TTC Industrial Area, MIDC Pawane, Navi Mumbai- 400710	1000	
			4	M/s. Evergreen Recyclekaro (I) Pvt. Ltd., S. No. 63/4, Vill: Varle, Tal: Wada, Dist: Thane	2400	
			5	M/s. Arihant E- waste Recycling Pvt. Ltd. Gat No. 307/1, Shada Road, Dodaiacha Tal: Sindkheda Dist: Dhule	2000	
			6	M/s. E-incarnation Recycling Pvt. Ltd., Plot No. J-56, MIDC Tarapur, Dist: Thane	950	
			7	M/s. High-Tech Recycling Pvt. Ltd., Gut No. 42, Plot No. 657, A/P. Bhukum, Ta.. Mulshi, Distt. Pune	1000	
			8	M/s. TTCWMA, Plot No. P-128, TTC MIDC Indl. Area, Near LFT Infotech Shil Mahape Road, Mahape, Navi Mumbai- 400710	300	
			9	M/s. Green Enviro Management Solutions LLP, Plot No. 51, Gat No. 376, Kanhe, Tal: Maval, District: Pune	594	
			10	M/s. Earth Sense Recycle Pvt Ltd, A-7, Gala no: 1, 2 & 3, Ground Floor, Prena Complex, Anjur Phata, Vill: Val, Tal: Bhiwandi Dist: Thane	360	
			11	M/s. Just Dispose Recycling Pvt Ltd, A-103,104,110,119, Arvind Industrial Estate, Navghar, Tal: Vasai, Dist: Thane	500	
			12	M/s. Mercury Metal industries, Plot no. D-48, MIDC Mahad, Tal: Mahad, Dist: - Raigad, Maharashtra	500	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
13	Maharashtra	116	13	M/s. Green World Recycling Vill: Val, Pritesh Complex, Building No; B-12, Gala No. 7,8 Anjur Phata, Village: Val Tal: Bhiwandi, Dist: Thane	1000	
			14	M/s. Suritex Pvt. Ltd., Plot No. B-111, MIDC Butibori, Dist, Nagpur	360	
			15	M/s. CBS E-Waste Recycling Ind. Gut No. 18/63/2, At. Khnapur, Tal. Alcole, Distt. Ahmednagar	450	
			16	M/s. Nagraj E-Waste Recycling S. No. 41/2, Village Asoli, Mouza Mahalgaon, Tal. Kamptee, Distt. Nagpur	2000	
			17	M/s. R. T. Corporation S. No. 377, Hissar No: 2, Ambisi Ganeshpuri Road, Village: Palsai, Tal: Wada, Dist: Thane	7500	
			18	M/s. Environcare Recycling Pvt. Ltd., Unit No. 8/C-1, Actual Indusrial complex, Uchat Road, Vill. Nagothane, Tal. Wada, Distt. Thane	7500	
			19	M/s. AQSA Stamping 55, Rangara, Industrial Estate, 33/35, Kirwali (Adivali), Old Thane-Pune Road Tal: Panvel Distt: Raigad	300	
			20	M/s. Green Valley E-Waste Management Pvt. Ltd., Pritesh Complex, Bldg No: A- 7, Gala No:7, Anjurphata Dapoda Village: Val, Tal: Bhiwandi Distt.	240	
			21	M/s. Go Green Recycling Unit No. 75/66, Hasti Industrial Estate, TTC Industrial Area, Mahape, Navi Mumbai	150	
			22	M/s. Indian Scrap Traders, Ghusia Market, Gala no: 661 Vill: Pimpari, Post: Dahisar Dist: Thane	200	
			23	M/s. Clean Tech B/8, Gala no: 3, Parasnath indl Estate, Anjurphata Road, vill: Val, Tal: Bhiwandi Dist: Thane	360	
			24	M/s. Mahalaxmi E-Recyclers Pvt. Ltd., Plot No. J-5, (part), Gokul Shirgaon MIDC Area Dist: Kolhapaur	720	
			25	M/s. R. K. E-Recycling International LLP, Gala No. 2, Tirupati Industrial Park, Sativali Road, Waliv, Tal. Vasai, Distt. Thane	300	
			26	M/s. Shree Mohantara Solutions, G. No. 1290, 10th Mile Pune- Satara Road, Wadki, Tal. Haveli, Distt. Pune	450	
			27	M/s. Anand Computer Systems, 2160 B, Sadashiv Peth, Swamipuram Building Shop No. 7, 8, 9 Pune	500	
			28	M/s. E-Waste Recycling, Nicholas Compound, Near Agarwal Naka, Sativali Road, Valiv, Vasai, Distt. Thane.	500	
			29	M/s. Krishna Metal Refinery, (Unit-2) Plot No. 2/143, Sapronde Vill., Tal. Wada Distt. Thane	750	
			30	M/s. Eco-Tech Recycling, C/6 (5), Sagar Industrial Estate, S. No. 46/4, Bhunal Nagar, Vasai, E, Distt. Thane	450	
			31	M/s. Green India E-Waste & Recycling OPC Pvt. Ltd., S. No. 74, H. No. 1/A, at. PO Dahisar, Tal. & Distt. Thane	300	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
13	Maharashtra	116	32	M/s. Green IT Recycling Centre Pvt. Ltd., D-222, MIDC Ranjangaon, Tal. Shirur, Dist. Pune	600	
			33	M/s. Shree Recyclers S. No. 208-2, Ap. Bhori-Bhotak, Chandarwadi, Tal. Daund,Dist. Pune	180	
			34	M/s. S. K. Enterprises, Plot No. 134, Ahmednagar Indl. Co-op. Society Ltd., Nashik	2000	
			35	M/s. Spas Computers Pvt. Ltd., 7 &12, Hema Industrial Estate, Premises, Cos Ltd., Sarvodaya Nagar, Rajmata Jijai Road, Josheshwari E Mumbai	500	
			36	M/s. Pakeaza Traders, Plot No. 406, 407, 408, At. Soyapur, Tal. & Distt. Aurangabad	720	
			37	M/s. Computronics Solutions Gut No. 679/2/2, Kuruli, Chakan, Tal. Khed, Distt. Pune	1200	
			38	M/s. Kalko Recycling Plot No. 144, Ganesh Nagar, Phursungi, Tal. Haveli, Dist. Pune	180	
			39	M/s. Solapur Eco Recyfine Plot No. K-47, MIDC Chikholi, Tal. Mohol, Dist. Pune	750	
			40	M/s. Recycling Future, S. NO. 169, Bhangarapada, Post Kundevahll, Tal. Panvel, Distt. Raigad	500	
			41	M/s. JRS Recycling Solutions Pvt. Ltd., Gala No. 428, S. No. 74, Hissa No. 2A, Garib Nawaz Estate, old Mumbai Pune Road, Dahisar, Distt. Pune	300	
			42	M/s. Bharat Steels, S. No. 154, Hissa No. Vill. Dhansar, Tal. Panvel, Distt. Raigad	300	
			43	M/s. Sahara Enterprises, G. No. 65, Dehu Alndi Road, Tal. Haveli, Distt. Pune	1000	
			44	M/s. Green E-Bin Electronic Solutions, Plot No. 18 MIDC Chikalthana, Aurangabad	500	
			45	M/s. Sahyadri E-Recycler Plot No. 108, 5 Star MIDC Kagal, Hatkanangale, Tal. Kagal, Distt. Kogal, Distt. Kolhapur	300	
			46	M/s. J. S. Enterprises, G. No. 132, Khalumbare, Tal. Khed, Distt. Pune	150	
			47	M/s. Sabbir Traders Plot No.999 (7), Karivali Narayan Kutir Udyog Mandal, Village Adivali, Tal. Panval, Dist. Raigad	300	
			48	M/s. Greenbay Enterprises, 4550, S. No. 13, H No. 3A, Behind star Weigh Bridge, Mantawadi, Urali Devachi, Pune - 412203	600	
			49	M/s. E-Waste Global, Gate No. 2, Near Theur Phata Lonikand, Pune Nagar Road, Tal. Haveli, Distt. Pune-412216	240	
			50	M/s. Reteck Envirotech pvt. Ltd., Plot No. 4A, MIDC Taloja, Tal. Panvel, Distt. Raigad	2500	
			51	M/s. Mukesh Metal, Sr. No. 93, Hissa No. 1, Behind Deepesh Lodge Gotegar Uttarshiv, Mumbra Road, Distt. Thane.	400	
			52	M/s. Green Tech Solution Industries Gat No. 83/1, A/P. Wakhari, Tal. Pandharur, Distt. Solapur – 413304	250	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
13	Maharashtra		53	M/s. Lilashana Sales, Ramdas company, Nandra Road, Khamgaon, Distt. Buldhana	360	
			54	M/s. Sayma E-Waste Solutions, S. No. 323, Hissa No. 3, A Plot No. B-27, Urali Devachi, Tal. Haveli, Pune	335	
			55	M/s. Pranam Enterprises, Sr. No. 286/116, Next to Badhe, Vill. Urali Devachi, Tal. Haveli, Distt. Pune	1000	
			56	M/s. Kuldeep E-Waste Disposals, S No. 50, Wadhyai Nagar, Anbegaon, Khed, Katraj, Pune	240	
			57	M/s. Sigma E nterprises, Plot NO. 5 & Gut No. 54/0, Adiwali, Tal. Panvel, Raigad	350	
			58	M/s. Pune Greens Electronic Waste Recycler Pvt. Ltd., SR. No. 63/1, B-4/1, Handewadi Road, Hadapsar, Pune	500	
			59	M/s. Kohinoor E-Waste Recycling Pvt. Ltd., Gut No. 205/1 and 205/2, Opp., Gurudatta Washing Centre, Dhekhu, Khalapur, Distt. Raigad	240	
			60	M/s. S. S. E-Waste Recyclers, Gut no. 442, Village Usar, Kondla Road, Tal. Wada, Distt. Palghar – 421312	1500	
			61	M/s. Aman Trading Co. F/1, Annasagr Market, Behind Forooqi Hotel, Kurla Andheri Road, Jarimari, Kurla (W) Mumbai- 400072	100	
			62	M/s. Poona E-Waste Solutions, 1/1009, Gat No. 2334/4, Wagholi, Pune - 412207	250	
			63	M/s. AG Enterprises, Gat No. 815 (1), Kudalwadi, Chikhli, Pune-411062	365	
			64	M/s. Eco Tantra LLP, M-365, Raviwar Peth Bohari Lane, Tal & Distt. Pune	160	
			65	M/s. E- recon Recycling Pvt. Ltd., Gut No. 94, Chitegaon, Tal. Paithan, Distt. Aurangabad	500	
			66	M/s. Amiable Electroning Pvt. Ltd., Plot No. D-141, Shirawane, TTC Industrial Area MIDC shiewane, Nerul, Navi Mumbai-	750	
			67	M/s. Eco Layer E-Waste Recycling S. No. 11, H. No. 1/1, PT-8, S. K. Indl. Estate, Choudhary Compound, Vasai E, Palghar	110	
			68	M/s. Ambar Enterprises, Awutade, Handewadi, Tal. Havali, Distt. Pune – 4110028	250	
			69	M/s. National Traders S. No. 103/1/2, Undri-Saswad Road, Autade, Handewadi, Tal: Haveli, Distt: Pune	250	
			70	M/s. Sultan Disposal Stores, S. No. 28/2A/B, Undri, Opp R Point, Pune Saswad Road, Undri, Tal-Haveli, Distt Pune	600	
			71	M/s. Baban Plastic, Gut No. 1, At. Sajapur, Tal. & Dist. Aurangabad 401136	500	
			72	M/s. Kalawishwa Electrical, B-47 (Sub letting), MIDC Waluj, Dist. Aurangabad 431136	300	
			73	M/s. E Refine Corporation, Gut No. 24, Dargah Road, Abdimandi, Daultabad Plot No. 2, Tal & Distt: Aurangabad	260	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
13	Maharashtra		74	M/s. J Choudhary & Company, Survey No. 67/3, Pipewal Lane, Mohammadiya Estate, Pimpri, Old Mumbai Pune Road, Tal. Thane	500	
			75	M/s. Maharashtra Enterprises, Plot No. 17, RAngara Industrial Estate, Kiravalli (Adivali), old Thane Pune Road, Tal-Panvel, Distt-Raigad	500	
			76	M/s. Prabhunath Traders, Sr. No. 314, H. No. 2, uril Devachi, Tal. Haveli, Dist. Pune	1680	
			77	M/s. Royal Scrap Traders, Gut No. 23 Plot no. 8, Mayurnagar, Naregaon Tal & Distt; Aurangabad	230	
			78	M/s. Harshita Green Recyclers, Gat No. 452, Urse Talegaon Dhabade, Tal. Maval, Dist. Pune	500	
			79	M/s. Navkar Recycling Sr. No. 69, Hissa No. 15, Mahamadiya Estate, Mumbai Panvel Road, Post. Dahisar, Dist. Thane	1000	
			80	M/s. Vora Computers Pvt. Ltd. 1B, Lara Apartments, Sadhu Vaswani Chowk, Hotel Woodland Lane, 1/D/3, Tal. & Dist. Pune	50	
			81	M/s. New India Scrap Traders, Plot No. 31/E, Ashok Nagar, Dist. Aurangabad	150	
			82	M/s. Hari Om Scrap Traders 957/43, K.P. 2nd Lane, S. P. Road, Opp. Om Namahshivaya Bldg. Mumbai Central, Mumbai	49.5	
			83	M/s. Saani Enterprises, Gut No. 64, Plot No. 65, Mahal Pimpri, Dist.Aurangabad	1200	
			84	M/s. Bombay Recyclers Pvt. Ltd. Gala No. P-17-18, S. No. 121/2, Balaji Industrial Park, Behind Hindalco Co. MIDC Taloja, Panvel, Dist. Raigad	200	
			85	M/s. Techeco E-Waste Namo LLP, Gat No. 155 B/2, Village Dhakambe, Tal. Dindori, Dist. Nashik	9360	
			86	M/s. Manihar Enterprises, Survey No. 74, Village Goteghar, Tal. Thane, Dist. Thane	1000	
			87	M/s. Green IT Recycling Centre Pvt. Ltd. Gat No. 207, Plot No. 3 & 4, Near Scienunero Company, Near PMT Depot, Shindewadi, Tal. Bhor, Dist. Pune	1000	
			88	M/s. Avis Technologies Plot No. A-58, MIDC Osmanabad, Dist. Osmanabad	500	
			89	M/s. Bhavesh Enterprises, Sr. No. 225/11, Hissa No. 23, Gausiya Compound, Gate No. 1, Vill. Pimpri, Tal. & Dist. Thane	200	
			90	M/s. Om Recycling 19/2 Mangalwa Peth,19/2 mangalwar peth pune., Peth, Dist. Pune	100	
			91	M/s. Wonder Print Technologies Plot No. M-36, MIDC Ambad, Dist. Nashik	300	
			92	M/s. Process Recycling Gala No,2, S.No 302, Richard Compound Near Maharashtra Vajan Kata, umang pharma road vasai phata, Dist. Palghar	125	
			93	M/s. Shivam Enteprises, Gala No. 326, At. Post. Khandale, Near Suruchi Dairy, Dist. Pune	4800	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
13	Maharashtra		94	M/s. Mahesh Traders Plot No. 316, Shree Shahu Market Yard, Tal. Karveer, Dist. Kolhapur	107	
			95	M/s. Asquare Industrial Solutions Gala No. 3, Plot No. 35, Mulgaon, MIDC Khopoli, Tal. Khopoli, Dist. Raigad	300	
			96	M/s. Map Trading Company Gat No. 670, Villoli, Tal. & Dist. Nashik 422010	500	
			97	M/s. Environment Exports, Gala No. 11, Lane, J. K. Compound, Opp. Roshan Comp. Kherani Road, Sakinaka, Mumbai	350	
			98	M/s. Green Enviro Services, 118/1, Wasali, Tal. Khed, Dist. Pune	700	
			99	M/s. Bsqaure E-Waste Recyclers, Gala No. 800, Survey No. 69/3, Siddhivinayak Market, Mohammadia Estate, Pimpri, Thane, Dist: Thane, Maharashtra		
			100	M/s. Mahalaxmi E- Recyclers Pvt. Ltd.Plot NO.77 & 78, Sub Plot No. 3A, Ramtekadi, Indl. Area, Hadpsar, Tal: Haveli, Dist: pune	525	
			101	M/s. E-Waste Recycling Nirhsas Compound, Near Agarwal Naka, Sativali Road, Waliv, Vasai, Dist. Thane	500	
			102	M/s. Green India E-Waste & Recycling OPC Pvt. Ltd. S. No. 74, H. No. 1/A, At. Po. Dahisar, Tal. & Dist. Thane	300	
			103	M/s. Green Tech Solution Industries Gat No. 83/1, A/p. Wakhari, tal. Pandharpur, Dist. Solapur 413304	250	
			104	M/s. Hi-Tech Recycling Pvt. Ltd. Plot No. 193, Gut No. 89, Jai Ganesh Warehousing, Shindewadi, Pune.	1410	
			105	M/s. Progressive Recycler LLP. MIDC Chakan Industrial area (PH-II), D-45, Tal:- khed, Dist:-Pune	295	
			106	M/s. Bombay Metal Works, Sr. 54, Hissa No. 4, Dahisar Road, Pimpri, Tal & Dist: Thane	1000	
			107	M/s. Ecostar Recycling, Survey No.94 Hissa No.12 Mahadev Industrial, Near Ladi Company, Mumbra, Dist:- Thane-400612.	275	
			108	M/s. R T Corporation, S.No.377, H.No.2, Ambisi Ganeshpuri Road, Village- Palsai, Tal: Wada, Dist- Palghar	3000	
			109	M/s. Threco Recycling LLP, Survey No. 153-3 & 149-1,Hedavli, Dist- Raigad	3500	
			110	M/s. Eco Tech Recycling, C/6, (5), Sagar Industrial Estate, S. No. 46/4, Dhumal Nagar, Vasai (E), Tal: Vasai, Dist: Palghar.	450	
			111	M/s. CPG Shell Mould & Casting, Plot No. W-39, Additional MIDC, Satara	1000	
			112	M/s. SKE Waste Disposal, Gat No. 116, Fine Weight Bridge, Jadhavwadi, Chikhali, Tal: Haveli, Dist: Pune.	250	
			113	M/s. Kapila Enterprises, Gat No. 46/3, At. Post. Supa, Tal. Parner, Dist: Ahmednagar	250	
			114	M/s. Rolex Entrprises, Survey No. 218, Hissa No. 4/1, Dahisar, Navi Mumbai	500	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
13	Maharashtra		115	M/s. Ancus India Reprocessing Pvt. Ltd., shop No. 2, Bldg. No. 1, Tiwari Estate, Vill:-Dhaniv, Nalasopara€, Vasai	450	
			116	M/s. Justdispose Recycling Pvt. Ltd., Sr. No. 42/5, Kaddu Industrial Estate, Near Jasraj Ind. Estate, Sativali Fata, Vasai (E), Dist. Palghar.	1200	
14	Madhya Pradesh	3	1	M/s. Unique Eco Recycle, Plot No. 26, Industrial Area, Palda, Indore (Madhya Pradesh)	6000	9600
			2	M/s. Monnstar Enterprises Pvt. Ltd., Plot No. 24/A, 24/D, 24/A-1, 21/D, 21/E, 21/E-1, Sector-B, Sanwer Road, Industrial Area Indore (MP)	3600	
15	Orissa	5	1	M/s. Sani Clean (P) Ltd., Tangiapada, Khurda	3000	5690
			2	M/s. Varun infra Steel Pvt. Ltd. Dismantler	730	
			3	M/s. Jagannath E-Waste Recyclers, Berhampur	500	
			4	M/s. P K Enterprises, Plot No.293/525, Khata No.127/4 At /P.O. Kalunga,Dist- Sundargarh	730	
			5	M/s Mirtunjai Udyog(Dismantler), At-AA/2, Civil Township, Rourkela Distt- Sundargarh	730	
16	Punjab	7	1	M/s Ramky Enviro Engineer Ltd., Vill. Nimbuan, Tehsil Dera Bassi, District SAS Nagar.	1200	9492
			2	M/s Spreco Recycling, D-45, Industrial Area, Focal Point, Raikot, District Ludhiana.	240	
			3	M/s K.J. Recycler, C-38, Sanjay Gandhi Nagar, Industrial Area, Jalandhar	600	
			4	M/s Black Diamond Cements Pvt. Ltd., (E-Waste Dismantling & Recycling Facility), Village Humayunpur, Nariangarh Road, Tehsil Dera Bassi, District SAS Nagar	2400	
			5	M/s.Cosmos Recycling Grewal Nagar, Street No. 2, VPO Hambran Jagroan, Ludhiana	450	
			6	M/s. Stellar Recycling LLP Village Lakhowal (H.B.No.190), Tehsil & District Ludhiana	3600	
			7	M/s Kumar Enterprises, Malerkotla Road, village dulladi, teh nabha, Distt. Patiala	1002	
17	Rajasthan	23	1	M/s. Dhruv Techengineers Pvt. Ltd., G-1209, Rampur mandana, Industrial Area, Bhiwadi, Alwar	2575	83254
			2	M/s. Shri Krishna Additives Pvt. Ltd., F-105, Matasya Industrial Area, Alwar	1200	
			3	M/s Greenscape Eco Management Pvt.(Unt-II), F-588 & 591 MIA Alwar	41400	
			4	M/s ETCO E-waste Recycler pvt. ltd, SB-23, Shilp Bari Road, 1415 VKI Area, Jaipur	1446	
			5	M/s. Universal E-Waste Recycling, G1-117 (B), RIICO Industrial Area, Alwar	450	
			6	M/s Green Leaf Recycling Industries, G-166-167, West part, RIICO Ind Area Bagru Jaipur	1380	
			7	M/s Shukla E-Waste Processors, H-309 (B) RIICO Industrial Area, Bhiwadi, Tijara, Alwar.	480	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
17	Rajasthan	23	8	M/s Vasoo Metals, (Division-III) G-287, MIA, Alwar	825	
			9	M/s. Vinay Traders, F-241-242, RIICO Ind. Area, Palra, Ajmer	9000	
			10	M/s. Greenweb Recycling, Web Plaza, 84-85, First Floor, Shyam Nagar, Benar Road, Jhotwada, Jaipur	2000	
			11	M/s. GS International, G1-101, Shri Khatu Shyam Ji Ind. Complex, Ringus, Sikar	2000	
			12	M/s. Rohit Pigments industries Pvt. Ltd., B-81/B, RIICO Ind Area, Dholpur	705	
			13	M/s K.G. Metalloys, F-37,38, RIICO Industrial Area, Ondela Road, Dholpur	1800	
			14	M/s. Adatte E-Waste Management Pvt. Ltd., C6/23, Opposite to Post Office, Safdarganj Development Area, New Delhi	1825	
			15	M/s. Green Recycling Waste Management, J-983, RIICO Ind. Area, Chopanki, Tijara, Alwar	303	
			16	M/s. PWL Ventures, B137, Queen Road, Vidyut Nagar B, Jaipur	5000	
			17	M/s. H. M. Traders	720	
			18	M/s. Green India Waste Management, G-1/565, RIICO Ind. Area, Khuskhera, Tapukaa, Bhiwadi, Alwar	1200	
			19	M/s. H.M.E-waste Management G1-226, RIICO Ind. Area, Kehrani Bhiwadi (Extn.) Tijara Distt- Alwar	895	
			20	M/s EPRAGATHI Recycling Pvt. Ltd., P.No. 29, SKS Industrial Area Ringus, Tehsil- Srimadhopur, Distt- Sikar- 332404	2400	
			21	M/s Hydro Engineers, H1-929, RIICO Industrial Area, Chopanki, Bhiwadi, District- Alwar	450	
			22	M/s Abhinav Enterprises Khasara no. 9669 Village Thok maliyan 3 Gyanoday Nagar Naka Madar, Ajmer (P.No. H1-15 RIICO Ind. Area, Ajay Meru Palra Ajmer Tehsil: Ajmer, District: Ajmer)	4000	
			23	M/s Greenscape Eco Management Pvt Ltd F- 584-585, MIA, Alwar	1200	
18	Tamil Nadu (Not updated)	32	1	M/s. Tritech Systems, No.165/3, Porur, Chennai- 116	3900	132049
			2	M/s. R. M. Comptuers, 405/6, T. H. Road,, G. C. K complex 1st Floor Ambattur Chennai – 600098	9	
			3	M/s. Genbruze Solutions Pvt. ltd., S. F. No. 9.28, 29pt, Athipattu Village, Ambattur Taluk, Chennai District	1100	
			4	M/s. Ecosible Recyclers Pvt Ltd, No.154A/B,8th Mahatma Gandhi Road, Tass Industrial Estate, Ambattur, Chennai – 600098.	6000	
			5	M/s. Green Era Recyclers 37, Sivanandha Industries Estate, Dr. M.S. Udhayamurthy Nagar, Thadagam Road, Edayarpalayam, Coimbatore District -641025	146	
			6	M/s. Green India Recyclers, SF. No. 26/1B, Kovilpalayam Road, Soolakal Village, Coimbatore District.	3000	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
18	Tamil Nadu (Not updated)	32	7	M/s. A. K. Enterprises, No:12, Chakarapani St, Velacherry, Chennai-32.	300	
			8	M/s. Shri Raaam Recycling, No. DP-29, SIDCO Industrial Estate, SIPCOT Industrial Complex, Gummidipoondi- 601201	504	
			9	M/s. JADG India E-Waste Recyclers Pvt. Ltd., SF No. 256/1A1, Kollur Village, Kilikodi Post, Ponneri Taluk, Tiruvallur- 601206	730	
			10	AER Worldwide India Pvt Ltd, No.774,Elandandheri,sadayankuppam village, near andar kuppam Check Post, Manali New Town, Chennai – 600103.	12000	
			11	M/s. Abishek Enterprises, SF No. 2G, 2nd Ambattur, Chennai-600098	6000	
			12	M/s. Virogreen India Pvt. Ltd., No. 297/1B2, No. 49, Pappankuppam Village, SR Kandigai Road, Gummidipoondi Taluk, Tiruvallur-601201	15000	
			13	M/s. Earth Sense Recycle Private Limited, S.F.No. 247, Thenmelpakkam Village, Chengalpattu Taluk, Chengalpattu District.	4248	
			14	M/s. Envirogreen E waste recycling Solutions, S.F.No. 2134, Plot No. 65, Palur Village, Chengalpattu Taluk & District	1900	
			15	M/s. K. S. Traders, Thiruneermalai Village, Alandur Taluk, Kancheepuram Ditt.	15000	
			16	M/s. Leela Traders., Plot No. C-15/1, CMDA Industrial Complex Maraimalai Nagar, Kancheepuram District	2640	
			17	M/s. SEZ Recycling, TP-7, IVth Avenue, mahindra World City Developers Limited, Industrial Estate, SEZ Area, Thenmelpakkam Village, Chengalpattu Taluk, Kancheepuram District	1500	
			18	M/s Trishyiraya Recycling India Pvt. Ltd., Plot No.A-7, Phase-I, MEPZ-SEZ, Tambaram, Chennai-600 045	3100	
			19	M/s. S. P. P. Enterprises, S. No. 184-4C, Mambakkam Village and Post Sriperumbudur Taluk Kanchipuram District	1080	
			20	M/s. RBIA Minerals and Metals Pvt. Ltd., S. F. No. 205-1B2A, Knadur Village, Sriperumbudur Taluk, Kancheepuram District	720	
			21	M/s. Punithan Enterprises Unit –II, No. 113/19 part, Rajiv Nagar, Peinjambakkam, Gundu Perumbedu Post SPR Talu, Kancheepuram Dt- 601301	6000	
			22	6. M/s. K. P. P Enterprises, No. 535-3C, Santhavellore Village, Sunguvarchatram Post, Sriperumbudur Taluk, Kancheepuram District	720	
			23	M/s. G S ENTERPRISES S.F NO:254/2A2A, evalurkuppam Village, Sriperumbudur Taluk,Kancheepuram Dist 602105.	6000	
			24	M/s. Enviro Metals Recyclers Private Limited Pvt Limited Aluminium Division S.No. 104 and 106, Ezichur Village,Sriperumbudur Tk,Kancheepuram District.	1200	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
18	Tamil Nadu (Not updated)	32	25	M/s. World Scrap Recycling Solutions Pvt. Ltd., S. No. 351/7, Beemanthangal Village, Sriperumbudur Taluk, Kancheepuram District	720	
			26	M/s. Green E Waste Private Limited, S. F. No. 294/ pt, Ayanambakkam Village, Poonamallee Taluk, Tiruvallur District.	468	
			27	M/s. Southern Alloys, DP No. S-105 and 106, SIDCO Industrial Estate, Kakallur Village Taluk and District	600	
			28	M/s. Micro E-Waste Recyclers, SF No. 301/3, Varaganeri Village, Trichy East Taluk, Trichy District.	900	
			29	M/s. M. G. Traders, No. 86, Nehru Street, Teachers Colony, Ambattur, Chennai - 600053	600	
			30	M/s. Udhaya Traders, No. 242, Tiny Sector Ambattur Industrial Estate, Chennai – 600058	84	
			31	M/s Victory Recovery & Recycle Technologies India Pvt.Ltd., 672/2, Doubal Dragon Industrial Park, Kannur Village & Post Kottaiyur, Thiruvallur, District - Tamil Nadu - 602 108	5880	
			32	M/s. TES AMM Private Limited, Plot No.A-18, SIPCOT Industrial Growth, Centre Oragadam, Panruti 'A' Village, Sriperumpudur, Kanchipuram District Tamil Nadu – 630 304	30000	
19	Telangana	16	1	M/s Earth Sense Recycle Pvt.Ltd., Plot No.37, APIIC Industrial park, Mankal (V), Maheswaram (M), Rangareddy District.	22775	91563
			2	M/s Z Enviro Industries Pvt. ltd., Pulimanmidi (V), Kandukur (M) Rangareddy District.	20000	
			3	M/s Silicon Planet Recycling Pvt. Ltd.,Sy. No.811/A, Ankireddypally (V) &Grampanchayat Keesara (M), Medchal Malkajgiri District	1000	
			4	M/s Enviro Collection Centre (Dismantling Unit), Plot No.1-185/2/A, Sy. NO.298 part, Phase-I, IDA Jeedimetla, Medchal-Malkajgiri District.	720	
			5	M/s Ramky E-Waste Recycling Facility, Hardware Park, kancha, Imarat of Raviryal (v), Maheswaram (M), Rangareddy District.	7840	
			6	M/s Earthbox Ventures (p) Ltd., (E-waste Dismantling Unit), Sy. Nos.29, 30, & 85, Uddemarri (V), Shamirpet (M), Medchal-Malkajgiri, District.	3600	
			7	M/s NAP Recycling, Sy. No.3, Kethireddypally (V), Balanagar (M), Mahaboobnagar District.	2592	
			8	M/s Sasi E Recycling Solutions (Dismantling Unit), Sy. No. 152 part 157,160 & 165, IDA, Pashamailaram (V), Patancheru (M), Sangareddy Sistrict	900	
			9	M/s Bellus E Waste, Sy.No.4-120, Ramachandra Puram (GP), Kondurg (M), Rangareddy District.	3600	
			10	M/s Shreem Mythri Enterprises, Plot No.50, phase-III, IDA Cherlapally, kapra (M), Medchal-Malkajgiri District.	600	
			11	M/s TES-AMM India Pvt. Ltd Plot no 79, Sy no 847, IDA Medchal, Medchal (M), Medchal-Malkajgiri District	1800	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
19	Telangana	16	12	M/s. Earthbox Recycling Private Limited Sy No 114/1, plot no s-2/12, Raviryala Grampanchayat, Maheshwaram (V & M), Rangareddy District	2340	
			13	M/s. Green Wave E-waste Recycling, Sy. No. 1880E, 1880EE, Nandigama (V&M), Rangareddy District	8388	
			14	M/s Kamal Electronics Refurbishing of E-waste Solutions,Sy No: 227/LU, 227/E1m 227/E2, 227/E/2/1 Atmakur (V) Sadasivpet (M), Sangareddu District.	5400	
			15	M/s. Chilkuri Enterprises, Sy No.14, Keesara (M), Medchal-Malkajgiri District	540	
			16	M/s. Reboot Resources Private Limited Sy. NO.113	9468	
20	Uttar Pradesh	89	1	M/s. Auctus – E Recycling Solutions Pvt. Ltd., F-637, M. G. Road, Industrial Area, Ghaziabad	1800	494042.7
			2	M/s. Mahaluxmi metal Alloys (India) Pvt. Ltd., Modinagar, Ghaziabad	30000	
			3	M/s. N.K. Products, 58-59, M. G. Road, Ghaziabad	9000	
			4	M/s Bharat Oil Co.E-18, Site – IV, Sahibabad, Industrial Area, Ghaziabad	4000	
			5	M/s Plant Green Recycling Pvt. Limited, G-129, Phase – I, M.G. Road, Ghaziabad	1500	
			6	M/s. Rocket Sales, Plot No. 1-12, I/A, M. G. Road, Hapur	300	
			7	M/s. Ariglonton Information System Pvt. Ltd., Plot No C-13, Site-4 Sahibabad Industrial Area Ghaziabad	40000	
			8	M/S Fiz Trading Company, C55, Sector-B-3, Trans Delhi Signature City Tronica City, Loni, Ghaziabad	365	
			9	M/S. Tele Supar Electronics India Pvt Ltd, B-15, Roop Nagar Industrial Area, Loni Ghaziabad,201102	730	
			10	M/s R.R. Recycler Pvt. Ltd., Khasra No.-115, M, Vill-Achraunda, Tehsil & District- Meerut Meerut	8000	
			11	M/s. 6R Recycling, Plot No-272, MG Road industrial area, Hapur	12000	
			12	M/s 3R Recycler Pvt Ltd. Unit 2, Plot No. A-61/2, UPSIDC Industrial Area, Sikandrabad, Bulandshahar, Buland Shahar- 203202 Uttar Pradesh	25000	
			13	M/s Circularity Solutions PrivateLimited (M/s. Karo Sambhav Pvt.Ltd.,) Khasra 95-96, Village - Sikhera,Hazazari Industrial Area, Modinagar, Ghaziabad	30000	
			14	M/S Ozone Waste Llp Plot No.- C-25, Upsidc, M.G. Road, Industrial Area, Hapur	500	
			15	M/s. Arsh Recycling Pvt. Ltd., Plot No. 203, UPSDIC, I/A, M/G. Road, Ghaziabad	15000	
			16	M/s. Auctus Recycling Solutions Pvt. Ltd, Habibpur, Greater Noida	20000	
			17	M/s. Khan Traders, B-5, Site No. 4, Panki Ind. Area, Kanpur	7190	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
20	Uttar Pradesh	89	18	M/s. Green Tech Recycling, Khasra No. 645, Acchraunds, Bahdurpur Road, Partapur, Meerut	9000	
			19	M/s. Narora Atomic Power Station, Narora, Bulandshahar	10	
			20	M/s Metal Alloys, E-46, Industrial Area, Ramnagar, Varanasi	1825	
			21	M/s Comwen Information Technologies Pvt.Ltd., 127/35B, ChakRagunath, Naini, Allahabad.	300	
			22	M/s. Dasia Eco E-Waste Recyclers E-160, Industrial Area, Khalilabad, Sant Kabairnagar.	3000	
			23	M/s. Sims Recycling Solutions Plot No. 1, Udyog Kendrall Ecotech-III, Greater Noida	1250	
			24	M/s J.A.O. E-Waste Recycling Co, Vill- Jaitpur,Distt-Moradabad.	720	
			25	M/s. HIN Green E-Waste Recycling Co. Vill-Jaitpur, Distt-Moradabad	750	
			26	M/s S.R. Metcast India (P) Ltd 11.8 Km.Agra Mathura Road, Agra.	600	
			27	M/s K.M. Metals Suppliers 9/270,271,Mathura Agra.	5000	
			28	M/s Prakash Metal House 39/223, Karwan Lohamandi, Agra.	1500	
			29	M/s Shree MahaveerJi Trading Company, 30/127, Chippitala, Agra	375	
			30	M/s. E-Waste Recyclers India, E-50, UPSIDC Industrial Area, 98Km Stone, NH-2, Kosi Kotwan, Mathura	6000	
			31	M/s E-Waste Recyclers Industries K40, UPSIDC Industrial area, NH-2 Kosikalan, Mahura	150	
			32	M/s Supar Trading Company, Plot No.-3 Govt. Industrial Estate, Talkatora Road, Lucknow	365	
			33	M/s. V. R. Techno Enviro Services Pvt. Ltd., Khasra No. 440, Indira Priyedarshni Ward Jarhra Indira Nagar Lucknow	365	
			34	M/s Greenzon Recycling Pvt. Ltd., R 30, UPSIDC, Industrial Area, Sikandrabad, Bulandshahar.	6022	
			35	M/s Sachin Enterprises, 123/751, block-T 74 Pratapganj Gadariyan Purwa, Fazalgang, Kanpur	2500	
			36	M/s Greeniva Recycler Pvt. ltd., Plot No. G-284, M.G. Road, Industrial Area, Hapur	780	
			37	M/s S. Malik Traders, plot No.93, 94 vill-Budhera jahidpur, Meerut	365	
			38	M/s Royal Faiz Recycling (P) Ltd, I-22, I.A.M.G. Road, Hapur	12000	
			39	M/s 3 C Recycler, F-326, I/A, M. G. Road, Hapur	720	
			40	M/s Life E-Recycling (p) Ltd., F-435, UPSIDC I/A, M. G. Road, Hapur	9000	
			41	M/s Hind Recycler (p) Ltd., Plot No.F-203, M.G. Road, Hapur	9000	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
20	Uttar Pradesh	89	42	M/s Hayat Recycler, F-53,54 I/A, M.G. Road, Hapur	1728	
			43	M/s B.R.P. Infotech Private Limited, F-394, Phase-1, M. G. Road, Industrial Area, Hapur	9000	
			44	M/s Sky Green Waste Recycling, Management, Khasra No.174, Alipur Jijmana, Meerut, U.P	5475	
			45	M/s Swachh Bharat Recycling Company, Gali No.4, 2083, Saipuram Industrial Area, Delhi Road, Meerut, U.P.	4800	
			46	M/s Rudra Interprises, Plot No.A-96, Sector A-4, Tronica City, Loni, Ghaziabad	500	
			47	M/s Avgree Recycling Pvt.Ltd. KH No.549, Vill-Tiyala, Meerut-Bulandshahar Road, Hapur Bypass, Hapur	11000	
			48	M/s Faiz Recycling, G-235, MG Road, Industrial Area, Hapur	36.67	
			49	M/s Malik Recycling, 25-A, Anand Ind. Estate, Mohan Nagar, Ghaziabad.	10000	
			50	M/s U.W.M. Recycling Pvt Ltd. Plot No.-F-331, UPSIDC, M.G. road, Ind Area, Hapur.	12	
			51	M/s Safdar E-Recycling Pvt Ltd. Plot No.H-69, M.G. road, Ind Area, Hapur	12000	
			52	M/s Horizon Recycling Pvt.Ltd., Khasra No.35, Kumarhera, 7th km Dehradun road, Saharanpur, U.P.	12000	
			53	M/s Golden E Waste Recyclers Pvt. ltd., Plot No.-12A, Gagol Road, Behind Sophia School, Udyog Puram, Partapur, Meerut Sophia School, Udyog Puram, Partapur, Meerut	9600	
			54	M/s R.D Recylers khasara no-46 village- shakharpur Hapur road Meerut	300	
			55	M/s Earth Zone Recycling Plot no-11 pargana-Hazipur Hapur road meerut	2400	
			56	M/s Making India E-waste recycling management plot no-50 sector-3 Shatabdi nagar industrial Area meerut	1080	
			57	M/s Indian Recycler Khasra No338 Vill- Wazidpur Kavali Jansath Muzaffarnagar	3500	
			58	M/s Greentek Reman Pvt Ltd. Plot No-B-2/12,Site-B Inds Area Surajpur, Greater Noida	9000	
			59	M/s Clean Waste managemnet. Plot No-131, Udhyog kendra Second, Ecotech-3, Greater Noida	100	
			60	M/s El green Recycling Pvt ltd.G-33, Sec-63, Noida	100	
			61	AIMS Technologies Pvt Ltd.G-256, MG Road Inds area, Hapur	1500	
			62	M/s Future Web, 48-A, Harthala Inds Area, Kanth Road, Moradabad	750	
			63	M/s Buddha Industries, Behind vision Exports Faridpur Sambhal Road, Moradabad	250	
			64	M/s Latoori Shah Traders,Gata No1396, Bhojpur, Dharampur, Moradabad	1200	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
20	Uttar Pradesh	89	65	M/s Shoeb Waste solution, Gata No250, Vill-Fazalpur, Near Hindoli, Chadausi, Sambhal	600	
			66	M/s NR E-Waste Company, Gata No235,237,245, 250K Vill-Sirsa, Inayatpur, Moradabad	750	
			67	M/s Eco Trader, Plot no.454, Rooma, Kanpur	100	
			68	M/s Aseries Envirotek India Pvt, Ltd, Plot no. B-10 Industrial area, Salon, Raebareli.	3600	
			69	M/s Electronic Waste India VillKhujnawar Chutmalpur, Kalasia Road Teh.- Behat, Saharanpur	9000	
			70	M/s ATR Traders Private Limited, G380, M.G.Road, Industrial Area, Hapur Ghaziabad 2400 MT/A	9000	
			71	M/s Eco Green India, Khasra no.-447, Vill-Ghosipur, Hapur Road, Meerut	365	
			72	M/s S.D. Recycling Process Industries, Khasra no.-51, 52,, Vill- Shakarpur,, Hapur Road, Meerut	4800	
			73	M/s HIN Green E-waste Recycling (P) Ltd, Khasra no.-733,737, Vill.- Baral, Partapur, Meerut.	12000	
			74	M/s J I ScrapTraders, Plot no. 418/12, Shastrinagar, Meerut	240	
			75	M/s E Tech Interprises, Plot no.- E- 26,Phase-I/ G322 Phase-II, M.G.Road, Industrial Area, Hapur	960	
			76	M/s Habib Trading Company, Khasra no- 28, Village- Alipur, Jijmana,Pargana & Tehsil- Meerut	5400	
			77	M/s B.R.P. Infotech Private Limited,F- 381, Phase-I, M.G.Road, Industrial Area, Hapur	6000	
			78	M/s Recology Recycling India Pvt. Ltd., Khasra no.-69, 70,71, Vill-Piple Kheda,, Sargana Sarawa Meerut, Meerut	13764	
			79	M/s Bright E-Waste Recycling India, Village-Ganeshpur, Mawana, Meerut	3240	
			80	M/s Sheetala Waste Management Project Plot no.-D-26, Sikandrabad Indl. Area, Tehsil-Sikandrabad, Bulandshahar	3000	
			81	M/s Spreco Resource Recyclers, Khasara no.- 235,Vill-Abdulpur, Block- Khekra, Baghpat, Meerut- 250101	3000	
			82	4. M/s Hind Recycling Pvt. Ltd., G- 460, UPSIDC, Industrial Area M.G.Road, Hapur	960	
			83	M/s Eco Fly E-Waste Recycling Pvt. Ltd., Khasara no-26, Piplikhera, Bhamanpur Road, Indl. Area, Meerut	7800	
			84	M/s Green Earth E- Recycling, F-95, UPSIDC, Industrial Area, Gopalpur Sikandrabad, Bulandshahar	6000	
			85	M/s Waste Tech Recycling Company, Plot no HD-7, UPSIDC, Industrial Area, Sikandrabad, Bulandshahar	1800	
			86	M/s LIMR Recycling Pvt. Ltd., G- 256, Industrial Area, M.G.Road, Hapur	600	

Sl. No	State	Number of Authorised Dismantlers/ Recyclers		Name and Address	Installed Capacity Metric Tons per Annum	Inventors
20	Uttar Pradesh	89	87	M/s Sky Green Waste Recycling Managememt , Khasra No.- 51, 53,54,66,20,21, Vill.- Piplikhera, Hapur Road, Indl. Area, Meerut	9000	
			88	M/s D M Recyclers Vill.- Phaphunda, Hapur Road, Meerut	750	
			89	M/s Global Green E-Waste Recycling, Khasra No.- 57, Indl. Area, Udhyogpuram, Partapur, Meerut	18000	
21	Uttarakhand	6	1	M/s Attero Recycling Pvt. ltd. Kh. No.117, Raipur Industrial Area, Bhagwanpur	144000	147305
			2	M/s Bharat Oil & Waste Management ltd. Mauja Mukimpur, Laksar, Haridwar	325	
			3	M/s Resource E-Waste Solution Pvt.Ltd. F-97, Industrial area, Bhadrabad, Haridwar	180	
			4	M/s Anmol Paryavaran Sanrakshan Samiti, Daulatpur Hazaratpur urf, Budhwasahid, Daulatpur	600	
			5	M/s. Scarto Metal Recycle plant, Kh. No-314 Kh, village –Mehvar Khurd, Roorkee	1000	
			6	M/s. Nayak Enterprises, Village Dhakia, No. 1, Post Kundeshwari, Tehsil Kashipur, District Udham Singh Nagar, Kashipur, Uttrakhand, 244713, India	1200	
22	West Bengal	4	1	M/s J.S. Pigments Pvt. ltd, Vill.+ P.O.-Jarua, P.S.- Polba, Hoogly-712138	600	1950
			2	M/s Lubrina Recycling Pvt. ltd., P.O. Bakrahat, P.S. Bishnupur, Distt.-24 Pgs(S), Pin-743377.	1080	
			3	M/s. P. U. Steel and Electro Process pvt. Ltd., Ruiya Industrial complex P.O. Patuliar PS-Khadar Distt. 24, PGS (N), West Bengal - 750119	180	
			4	M/s Old N Furniture 323, K.P. Mondal Road, PO & PSBudge Budge, Dist-24 PGS(S), Pin-700137	90	
	Total	**468**				**1385932.2**