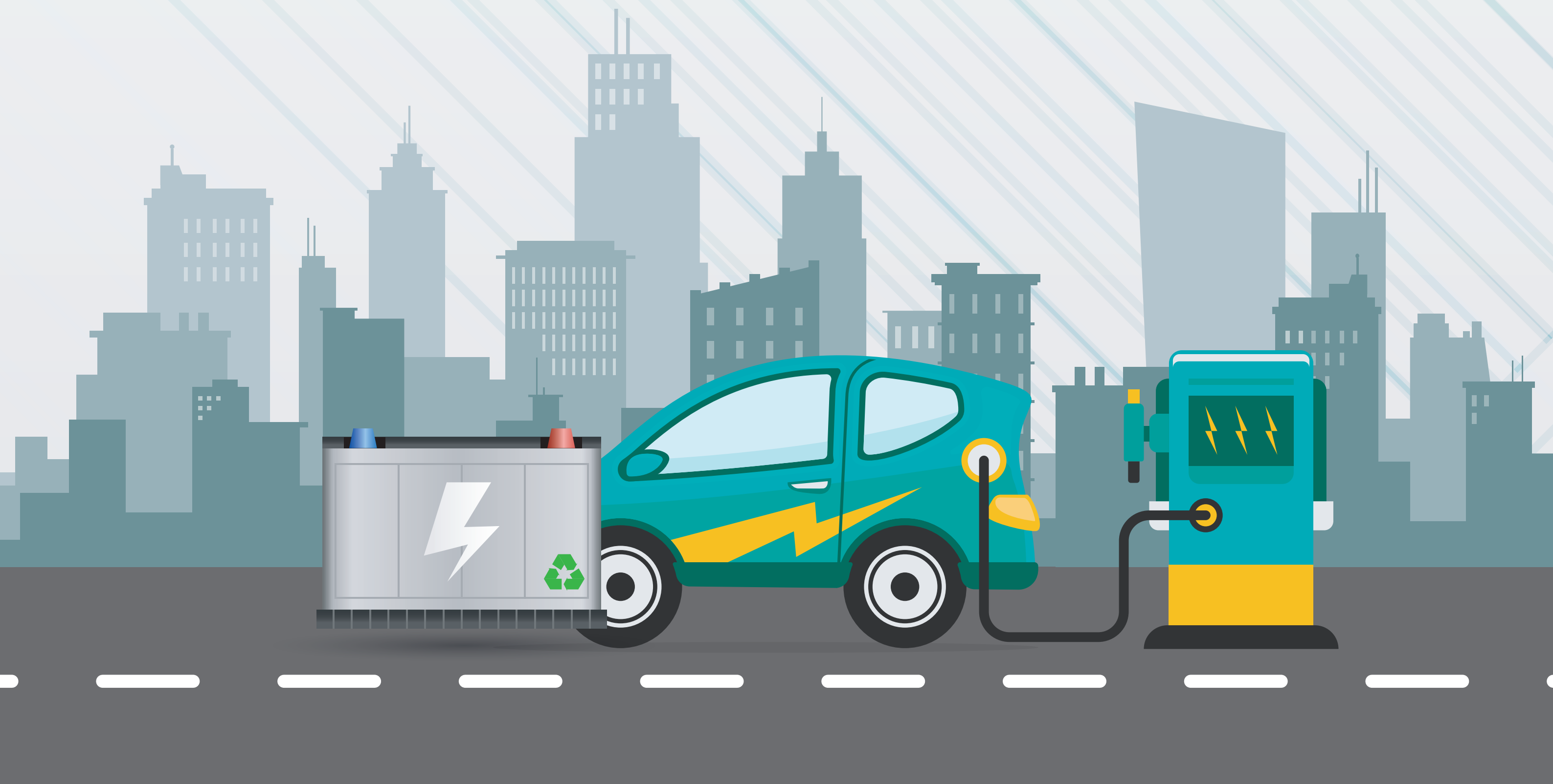
JMK Research & Analytics

Recycling of Lithium-ion batteries in India

- $1,000 million opportunity

October 2019



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JMK Research & Analytics is a boutique consultancy for all kinds of research and advisory services for Indian and international clients focusing on Renewables, Electric mobility and storage markets. We employ our interdisciplinary team, strong industry network, existing databases as well as vast project experience in the Indian power sector to create substantive business value for our clients. Our subscribers include, equipment suppliers, investment agencies, multi-lateral and bilateral agencies, project developers, government authorities.

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Abbreviations

B2B	Business to Business
B2C	Business to Customer
C&I	Commercial & Industrial
CAGR	Compound annual growth rate
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric Vehicles
E-waste	Electronic Waste
GHG	Green House Gases
JBRC	Japan Portable Rechargeable Battery Recycling Centre
LCO	Lithium Cobalt Oxide
LFP	Lithium Iron Phosphate
LMO	Lithium Manganese Oxide
MTPA	Metric Tonne per annum
NCA	Lithium Nickel Aluminium Cobalt Oxide
NMC	Lithium Nickel Manganese Cobalt Oxide
PMP	Phased Manufacturing Program
SDG	Sustainable Development Goals

Introduction

In the year 2030, the annual recycling market is expected to be around 22 - 23 GWh, which is a $1,000 million opportunity.

The lithium-ion batteries market in India is expected to grow significantly in the next five years. Some of the important initiatives by the Government of India that will accelerate the growth of this market are National Electric Mobility Mission Plan 2020, with a projection of getting 6-7 million electric vehicles on Indian roads by 2020 and target of 175 GW installation of renewable energy by 2022.

JMK Research estimates the annual lithium-ion battery market in India to increase from 2.9 GWh in 2018 to reach 132 GWh in 2030 at a CAGR of 37.5%. The increase in volume of lithium-ion batteries would, in turn, lead to a rise of 'spent' batteries in our ecosystem which if left untreated would become a health and environmental hazard. Also, the precious metals comprising these batteries would be lost forever. The best way to treat such batteries is to recycle the metals and other natural resources from a spent battery using different mechanical and metallurgical processes. These precious extracts can be re-used to manufacture more batteries. Since, the natural reserves of most of these metals are outside of India, the Indian battery manufacturers are heavily dependent on imports. This dependence can be reduced only by recycling of spent batteries.

The heavy reliance on imports of these metals is one of the main reasons why India is still not a scale manufacturer of lithium-ion batteries. To bring down the imports and make battery manufacturing sustainable it is necessary to invest early in large scale recycling infrastructure.

The Indian Government has set up an ambitious electric mobility target. The only hindrance for the EVs is high prices, 40-50% of which is constituted by the batteries only. With recycling being a probable solution the government should focus on regulations for certified and sustainable ways to reclaim the materials from used lithium-ion batteries. To ensure this, in October 2019, Government announced that it is in the process of framing a recycling policy for lithium-ion batteries under which tax sops would be considered for the recyclers. The proposed policy also imposes liability on battery producers to collect spent batteries under the Extended Producer Responsibility (EPR) norms.

With this report, JMK Research is highlighting the current state of the lithium-ion battery market in India, potential of recycling and the associated opportunities and challenges. The report focusses on recycling mechanisms followed worldwide along with the benefits of recycling. Last but not the least the report analyses the regulatory frameworks of international markets regarding recycling and management of lithium-ion battery waste and provides the Indian government with a few regulatory recommendations which would boost the battery recycling industry.

Lithium-ion battery technology

Lithium-ion batteries are energy storage devices that convert chemical energy into electrical energy. Each battery cell comprises two electrodes - a positive electrode or a cathode, and a negative electrode or an anode. In between the two electrodes, a separator layer that consists of an electrolyte allows for the movement of electrons or ions. In general, batteries can be classified into two categories:

- Primary batteries, commonly known as single-use batteries and are not rechargeable
- Secondary batteries can be charged and recharged. Lithium-ion batteries belong to this category

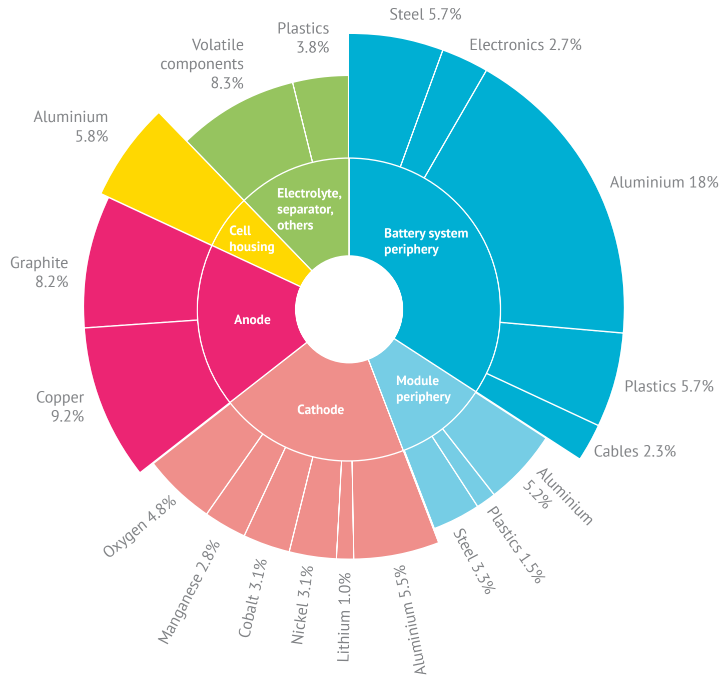
Over the years, the demand for lithium-ion batteries has increased across various sectors, including telecommunications, mobile phones, and electric vehicles (EV). The demand is attributed to the benefits these batteries have over other types:

- High energy density which can be used for powering electronic devices over a longer duration
- Capability to withstand a high number of regeneration cycles and temperatures
- High voltage per cell ratio
- Favorable discharge resistance
- Relatively low environmental impact when compared to lead-acid batteries

Key metals

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

Figure 1.1: Generic composition of lithium-ion battery pack



Source: Jan Diekmann et al. J. Electrochem. Soc. 2017, JMK Research

Table 1.1: Salient features of metals/ materials used in lithium-ion batteries

	Cobalt	Nickel	Lithium	Copper	Graphite
Uses	Used in cathode for all type of lithium-ion batteries except lithium iron phosphate battery	Used in cathode for Lithium Nickel Cobalt Aluminium Oxide (batteries)	Used in the cathode of all kind of lithium-ion batteries	Used in collector foil, electrical tabs, connections and functional items at cell and pack level	All lithium-ion batteries use graphite as anode
Abundance	Rare metal	Rare metal	Abundant	Abundant	Abundant
Reserves	Almost 55- 57% of the world reserves exist in Congo	Australia has the largest reserves (24%), followed by Brazil and Russia	75% of the world reserves exist in Argentina, Chile, and Bolivia	Chile (20.5%) has the largest reserves, followed by Australia and Peru	China accounts for almost 60% of the graphite reserves
Key characteristic	Most expensive metal in lithium-ion batteries	Most important metal by mass in lithium-ion battery cathode	Lithium is an essential part of these batteries, and hence the name lithium-ion batteries	Copper is used outside the battery cell, but it is one of the most important components in the battery pack due to its superconductivity	Quantity of graphite in the lithium-ion battery is 40 times more than lithium
Current prices (2019)	32,000 USD/ tonne	15,700 USD/ tonne	13,000 USD/ tonne	5,700 USD/ tonne	1,800 USD/ tonne

Source: Battery University, London Metal Exchange, JMK Research

Typically, these five key metals constitute 50-60% of the cost of lithium-ion batteries[1]. Therefore, any fluctuation in these metal prices will have a direct impact on the overall cost of batteries as well. This variation in prices of these metals is dependent on various economic parameters which are discussed in detail in the next section.

[1]Report on- A Bottom-Up Approach to lithium-Ion Battery Cost Modelling with a Focus on Cathode Active Materials; https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28

Price trends of key raw materials

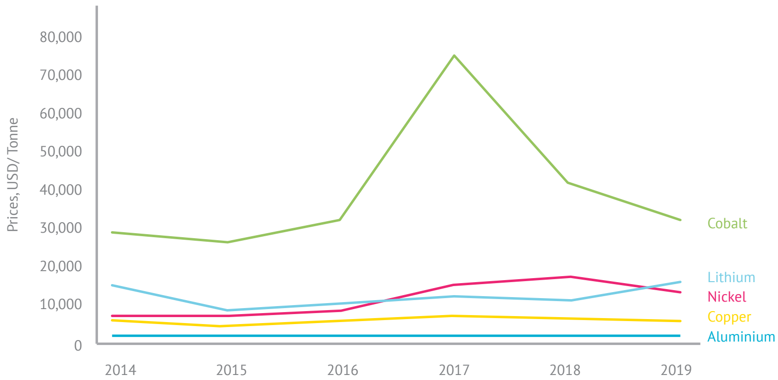
Over the last 4-5 years, the prices of key metals constituting lithium-ion batteries have been fluctuating mainly due to rising demand and the expected boom in the electric vehicle industry. As can be seen from the chart below, the cobalt is the costliest of all metals. Since 2010, the demand for cobalt has risen at a rate of 3% - 4% annually. The expected boom in the electric vehicle industry led the price of cobalt, in the commodity market, to peak at $79,000 per tonne in December 2017. This rise was short-lived, and the prices have since seen a steep fall of over 30% due to excess production and less than expected demand for EVs.

Nickel and lithium too share a similar story of rise and fall of prices. In 2011, nickel peaked at almost $29,000 per tonne but saw a sharp fall later. Although the prices of nickel have been on a gradual rise since 2016, the prices in July 2019 stood at $16,000 per tonne.

The prices of lithium rose significantly from $7,000 per tonne in 2014 to peak value of $17,000 per tonne in 2017. Since then, the prices have softened and are presently hovering around $13,000 per tonne.

Over the last five years, aluminium has shown maximum price stability and has been in the range of $1,800-2,250 per tonne.

Figure 1.2: Price trends of key raw materials used in lithium-ion batteries



Source: London Metal Exchange, JMK Research

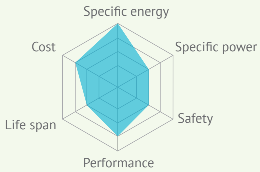
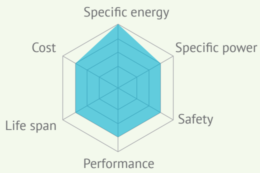
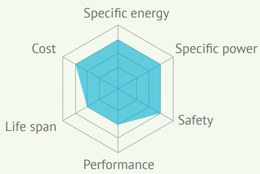
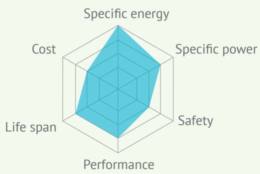
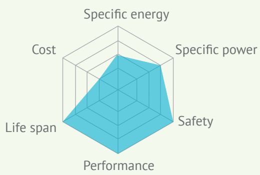
The price variation of different metals leads to the formation of various chemistries of lithium-ion batteries. The objective is to optimize the cost by reducing the share of cobalt and identify the best combination with similar benefits. Further section details various types of batteries basis the different metal combinations and their global adoption share.

Different types of lithium-ion batteries

The lithium-ion battery is a generic name given to the dry batteries made out of lithium, nickel, cobalt, copper, and aluminium. The types of lithium-ion batteries differ on the percentage compositions of these metals. Thereby, The different type of batteries available commercially, offer energy, safety, lifespan, cost, and performance.

The most common types of lithium-ion batteries currently in use are Lithium Cobalt Oxide (LCO) and Lithium Nickel Manganese Cobalt Oxide (NMC). Of these, LCO has the highest market share of 37%, mainly because of its usage in small portable devices such as mobile phones, tablets, laptops, and cameras. Nickel Manganese Cobalt is ranked second highest with a market share of 29% and is mainly used in electric vehicles and medical devices.

Table 1.2: Details of various lithium-ion battery types

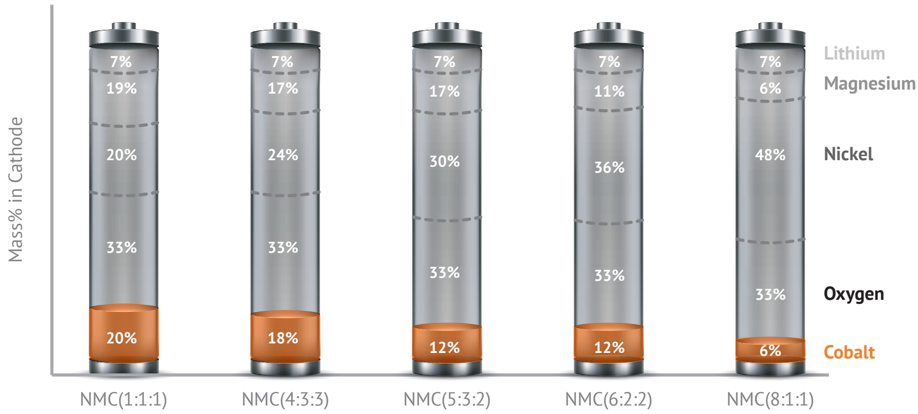
Abbreviation	Chemistry / Technology	Major Metals	Key Parameters	Estimated global market share	Typical usage
LCO (LiCoO2)	Lithium Cobalt Oxide	Cobalt		37%	Cell phones, Laptops
NMC (LiNiMnCoO2)	Lithium Nickel Managanese Cobalt Oxide	Cobalt- 19% Manganese- 17% Nickel- 19% Lithium Carbonate- 3.5% Others- 41.5%		29%	Tesla Power Wall, Power tools, Electric Vehicles, Medical devices
LMO (LiMn2O4)	Lithium Manganese Oxide	Cobalt- 2.5% Manganese- 21% Nickel- 7% Lithium Carbonate- 3.5% Others- 66%		21%	Nissan Leaf Electric Vehicles, other consumer electronics
NCA (LiNiCoAlO2)	Lithium Nickel Aluminium Cobalt Oxide	Cobalt- 6% Nickel- 35% Lithium Carbonate- 3.5% Others- 55.5%		7%	Tesla Model 5 EV, ISRO satellites
LFP (LiFePO4)	Lithium Iron Phosphate	Iron, Phosphate		5%	Starter batteries, light storage and 2W, 3W EV applications

Source: Battery University, Lithium battery recycling in Australia, JMK Research

In India, NMC and LFP batteries are typically used. As per various industry sources, the typical life of NMC batteries is 2-3 years while for LFP batteries, it is 5-7 years in the Indian market. NMC batteries are most commonly used in the last 3-4 years in the Indian market, mainly in EVs, street lights and other small stationary storage battery applications. However, LFP batteries have now started gaining more traction in the Indian market.

At present, researchers are working on an 8:1:1 chemistry ratio of NMC batteries to bring the prices down by reducing cobalt's share in the overall battery mix.

Figure 1.3: Share of key metals used in various lithium-ion batteries



Source: Wood Makenzie, JMK Research

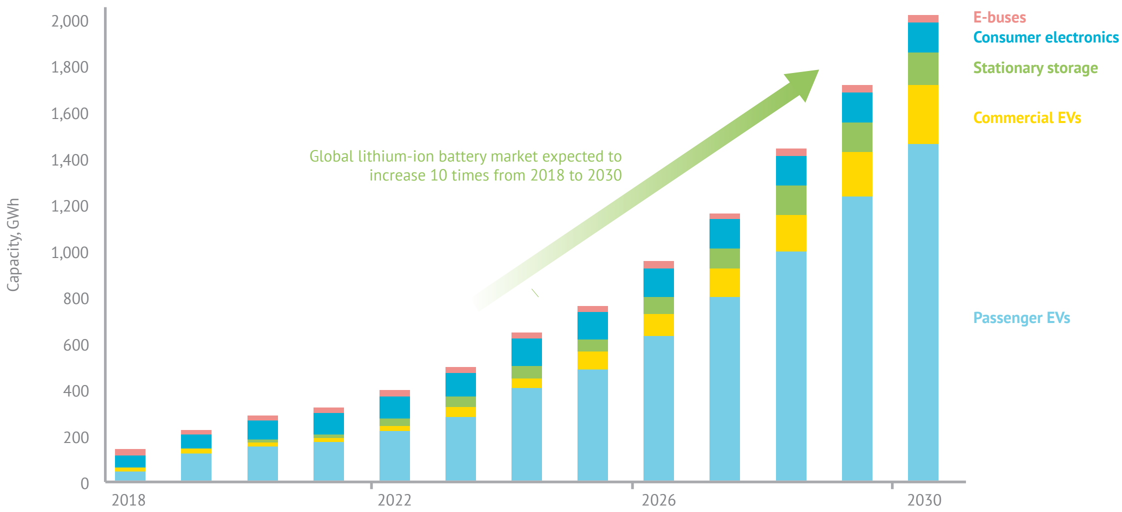
As can be seen from the above chart, recycling could play an important role as the amount of cobalt recovered from recycling of NMC (1:1:1) battery now can be used to energize three NMC (8:1:1) batteries in the next few years.

Lithium-ion battery market size

Global lithium-Ion battery market growth

As per Bloomberg New Energy Finance (BNEF), globally, the lithium-ion battery market is set to grow about 10-fold from ~180 GWh in 2018 to 2,000 GWh in 2030. By 2030, about 85% of the lithium-ion battery market will be held by EVs alone. 50% of the cost of an electric vehicle is cost of battery only. So with growth in EV the battery market will also grow. Key drivers for this are the falling battery costs and the expected boom in the electric vehicles segment in the global market.

Figure 2.1: Global lithium-ion battery market size, GWh



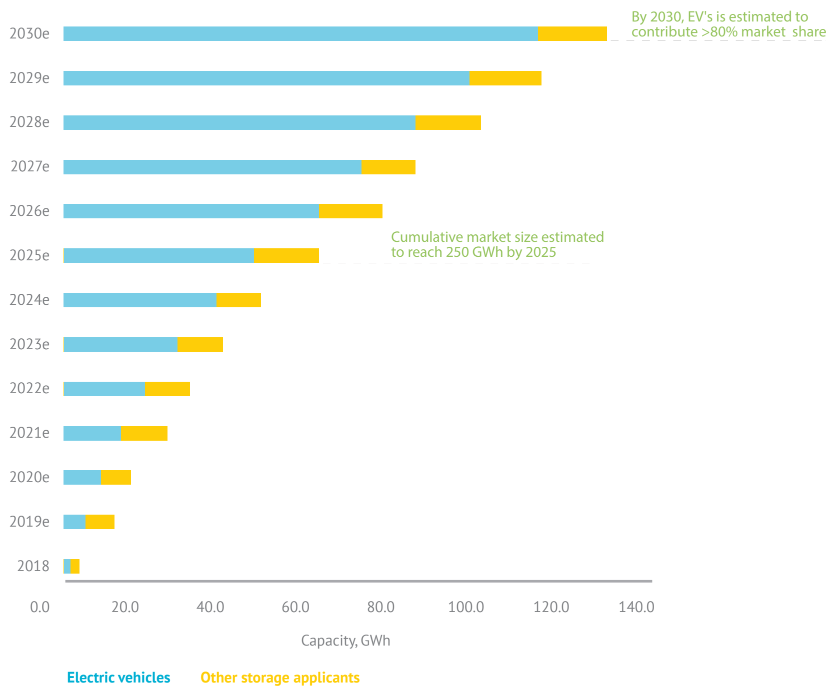
Source: Bloomberg NEF 2019 Electric Vehicle Outlook, JMK Research

The electric vehicle boom in the global market would also have a similar impact on the lithium-ion batteries growth in the Indian market in the next ten years.

Lithium-ion battery market growth in India

JMK Research estimates the annual lithium-ion battery market in India to increase at a CAGR of 37.5% to reach 132 GWh in 2030. Cumulative lithium-ion battery market size is estimated to increase from 2.9 GWh in 2018 to reach to about 800 GWh by 2030. At present, about 65% of lithium-ion batteries are used in the telecom sector, data centers, street lights, and other small consumer applications, while the remaining 35% market is held by the electric vehicles segment. However, by 2030, the share of electric vehicles is expected to be about 80% on the pretext of government push towards electric mobility.

Figure 3.1: Lithium-ion battery market size in India, GWh



Source: JMK Research

Assumptions to calculate market size:

1. Other storage applications include- Consumer electronics, telecom sites, data centres, stationary storage applications for power plants, among others.
2. For EV's, battery size of two-wheeler – 2 kWh, three-wheeler – 5 kWh, four-wheeler – 15 kWh, Electric buses – 250 kWh.
3. Sales of electric vehicles estimated to increase from 0.2 million in 2018 to 128.5 million by 2030 (CAGR of 71%)

"Initial volumes for recycling are expected from rejected batteries or from Batteries with defects and warranties issue."

-Kapil Kumar, GM, Fortum

Some of the important initiatives by the Government of India that are expected to accelerate the growth of lithium-ion batteries market in India are:

- Electric Mobility Mission Plan 2020, with a projection of getting 6-7 million electric vehicles on Indian roads by 2020
- Installation of 175 GW of renewable energy by 2022 and 500 GW by 2030

In addition to the above initiatives, in March 2019[2], India's union cabinet approved the setting up of a National Mission on Transformative Mobility and Battery Storage, to drive clean, connected, shared, sustainable and holistic mobility initiatives. As per this mission, a five-year Phased Manufacturing Program (PMP) till 2024 is planned to support setting up a few large-scale integrated batteries and cell-manufacturing plants in India and to localize production across the entire EV value chain. The Government is in the process of opening tenders to set up a 50 GW battery manufacturing base at around $50 billion investment[3].

This is being done to enhance manufacturing of lithium-ion batteries in India as, at present, almost all electric vehicles in India run on imported batteries, mostly from China[4].

[2]https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1567807
[3]https://www.power-technology.com/comment/electric-vehicles-in-india-2019/
[4]https://www.livemint.com/companies/news/panasonic-may-set-up-lithium-ion-battery-module-assembly-unit-in-india-1565895588828.html

To ensure that India has strategic access to lithium and cobalt, in July 2018, Government has directed three state-owned mineral companies- National Aluminium Company (NALCO), Hindustan Copper (HCL) and Mineral Exploration Corp. Ltd (MECL) to explore and acquire these strategic mineral assets abroad. This proposal is currently with the Niti Aayog, which would conduct due diligence before it can be formalised.

Raasi Solar is the first company that has started the domestic production of lithium batteries in India in 2019 in Tamil Nadu

As India is getting ready to build its roadmap for transition to electric mobility, leading global manufacturers of lithium-ion batteries have also started exploring opportunities to first build assembly units, and then eventually transition to large-scale lithium-ion cell manufacturing in the country. Raasi Solar is the first company that has started the domestic production of lithium batteries in India in 2019 in Tamil Nadu. Many other Indian companies including, Exicom, Amaron, Greenfuel Energy Solutions, Trontek, Coslight India, Napino Auto & Electronics, Trinity Energy Systems, Versatile Auto Components, have also announced their plans to make lithium-ion batteries locally. Other key announcements include:

- Panasonic Corporation is exploring opportunities to set up a facility for assembling lithium-ion (li-ion) battery modules in India.
- Suzuki Motor Corporation has tied up with Toshiba and Denso to set up the country's first lithium-ion battery manufacturing facility in Gujarat at an investment of INR 11.5 billion.
- Exide Industries Ltd and Amara Raja Batteries Ltd have also formed joint ventures with foreign companies to start assembling batteries.
- South Korea's LG Chem Ltd and Japan's Toshiba have also formed collaborations for assembling battery packs with Mahindra and Mahindra (M&M) Ltd. Indian Oil Corporation Ltd. announced its plans to partner with a foreign start-up to set up a 1 GW battery manufacturing plant in India.

Looking at the scale of investments planned to set up battery manufacturing in India, it is assured that batteries would become more affordable and so would be the products running on these batteries. This scale of manufacturing and usage would also bring in a concern about recycling and safe disposal of spent batteries. Next section focusses on these concerns and proposes a plan of action to safeguards us from piles of spent batteries.

Need for recycling

Depending on the chemistry, size, configuration, and purpose, a lithium-ion battery can perform between 500 to over 10,000 cycles of charging and discharging.

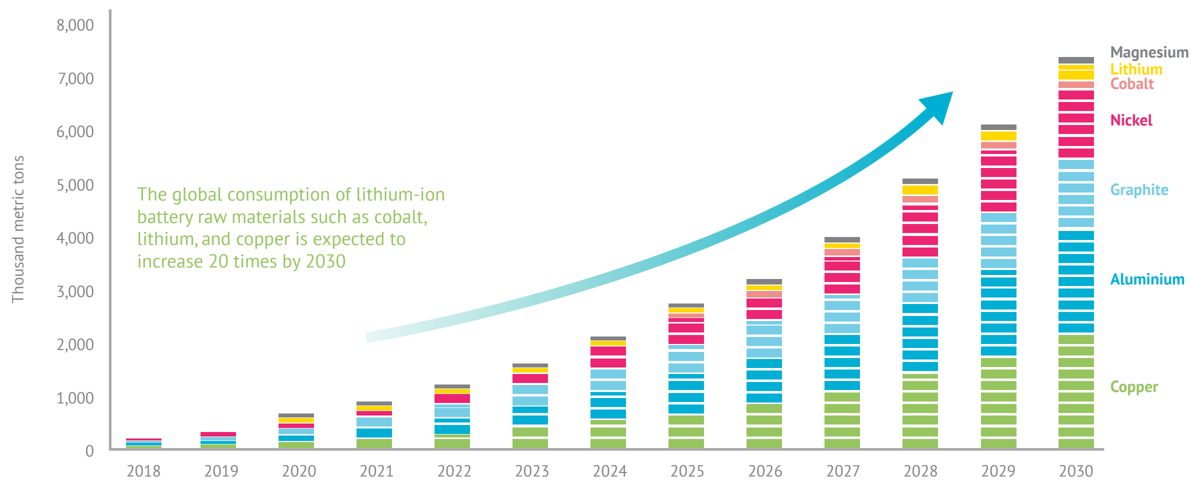
The battery manufacturers are meticulously making strategies about setting up huge plants, producing affordable batteries so that they can be sold and fitted in large numbers. It is however, important to consider the limited life of these batteries and where would they end up once they are spent. Depending on the chemistry, size, configuration, and purpose, a lithium-ion battery can perform between 500 to over 10,000 cycles of charging and discharging. Therefore, the pace in which batteries will reach end-of-life depends highly on its application. So far, the largest amounts of batteries that have reached end-of-life are portable batteries used in consumer electronics and power tools[5]. Apart from these, there is a huge scrap stock of lithium-ion batteries piling up at the telecom sites.

Further, with the entire world shifting its focus towards EVs and other lithium-ion battery products, the production size of these batteries is expected to be very high. The limited life of these batteries would eventually give rise to dead batteries which would require an effective process to recycle them. Key drivers to recycle lithium-ion batteries are:

Scarcity of metals and materials used in lithium-ion batteries

As per Bloomberg New Energy Finance, the global consumption of lithium-ion battery raw materials such as cobalt, lithium, and copper is expected to increase 20 times by 2030. Reserves and supplies of these raw materials are concentrated in select regions of the world and are mostly located outside India. Therefore, recycling of these precious metals from spent batteries is essential, especially for countries like India which are entirely reliant on imports for these metals.

Figure 4.1: Metals and materials demand from lithium-ion battery in passenger EVs



Source: "Electric Vehicle Outlook 2018 | Bloomberg New Energy Finance" BNEF, 2018

[5]Report on "The lithium-ion battery end-of-life market – A baseline study"

To reduce dependence on future imports of key metals and avoid environmental and health hazards recycling of lithium ion batteries is essential.

Further, the changing international and political relations with countries owning natural reserves of these key metals and raw materials and fluctuating prices of raw material in global markets could also impact the battery prices in India. Since lithium-ion batteries currently make up almost 40-50% of the EV cost, an increase in the price of batteries could increase the already high cost of electric vehicles and be a hindrance to the sale of EVs.

Environmental Hazards

The high percentage of heavy metals like copper, nickel, and organic chemicals may contaminate soil and water if disposed of along with municipal waste ending up in landfills. Additionally, incinerating lithium-ion batteries releases toxic gases resulting in air pollution.

Health Hazards

Lithium requires proper handling as it poses health risks to humans and animals. It can get absorbed and accumulated in edible plants and can enter the food chain, causing various genetic, reproductive, and gastrointestinal problems.

Reduction of GHG emission

The raw materials used in the batteries are mined from select places on earth. Transportation of these materials to different parts of the world for the production of lithium-ion batteries results in increasing its carbon footprint, the cause of greenhouse gas emissions. Usage of recycled materials can reduce the CO_2 emissions from the production cycle by up to 90%[6].

Therefore, to reduce India's dependence on imports of key metals of lithium-ion batteries, recycling of spent batteries to extract the precious metals makes complete business sense. Also, a proper disposal of batteries should be made mandatory by the government to safeguard against potential environmental and health hazards associated with lithium-ion batteries waste.

[6]https://www.fortum.com/products-and-services/recycling-waste/recycling-services-and-products/lithium-ion-battery-recycling-solution

Managing lithium-ion battery waste

The two most rational solutions that help to re-use and recycle used lithium-ion batteries are:

1. **Second Life use:** Once the drop-in capacity of the EV battery is below 70-80%; they could still be used in other applications such as in households or energy backups
2. **Recycle in a closed-loop process:** Recycling of lithium-ion batteries help to recover the metals - cobalt, lithium, nickel, and others

Short term solution: Second Life Use

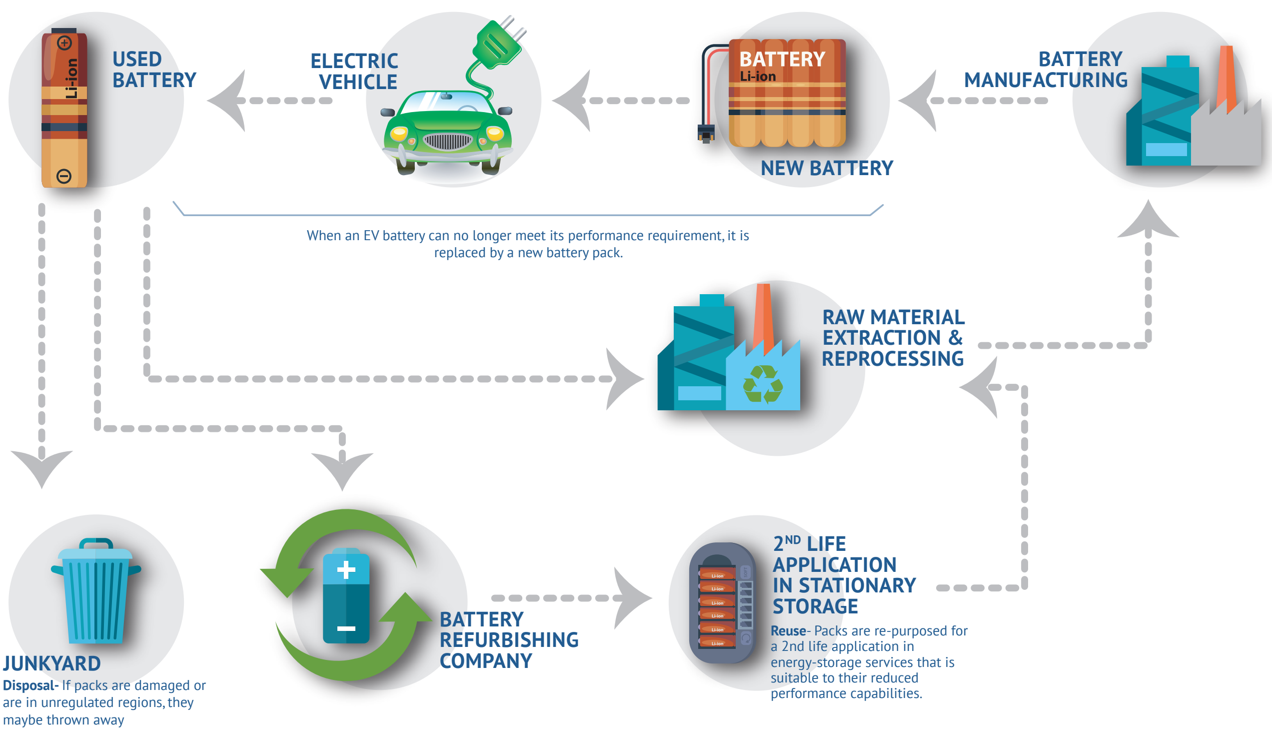
Batteries can be used for other secondary applications as these 'spent' batteries still retain 70%–80% of their initial capacity and can function for several years.

Lithium-ion batteries used in electric vehicles have a shelf life of less than ten years. After a 5 to 8 year usage period, the power generated by the batteries is not enough for an EV to achieve the desired range. Therefore, these batteries can be used for other secondary applications as these 'spent' batteries still retain 70%–80% of their initial capacity and can function for several years.

Some of the potential second-life uses for lithium-ion batteries are:

- Electric power management for residential and commercial spaces
- Power grid stabilization (firming up the peak power)
- Renewable energy system firming by providing storage

Figure 5.1: Electric Vehicle battery life cycle



Source: JMK Research

A second life use system would be economically and environmentally advantageous in the short-term before there is a sufficient number of lithium-ion batteries ready to be recycled. These benefits include longer lifetime of batteries (up to 5-10 years more) after serving their primitive use, reducing waste and decreasing the amount of energy required to create new batteries.

Europe can be a good example, wherein several vehicle manufacturers, have installed used batteries primarily in different kinds of energy storage systems, ranging from small residential systems to large grid-scale solutions.

Table 5.1: Second life initiatives by automobile companies

Car manufacturers	Second life initiatives				
	C&I Energy storage	Grid scale energy storage	Residential Energy Storage	EV charging	Remanufacturing
BMW		✓		✓	
DAIMLER	✓	✓			
GM					✓
HYUNDAI	✓	✓			
NISSAN	✓			✓	✓
MITSUBISHI	✓				
RENAULT		✓	✓	✓	
TESLA					✓
TOYOTA	✓	✓			
VOLVO			✓		
VW	✓				

Source: JMK Research

As per a report from E&Y[7], a potential cumulative capacity availability of "re-purpose" batteries, at worldwide level, is expected to be around 1,000 GWh by 2030, at a re-purpose (using it in other applications) rate of 80%.

[7]Report on "Electrifying India: building blocks for a sustainable EV ecosystem", May 2018

Challenges in utilizing battery for the second life

Recycling of lithium-ion batteries is not expected to take off for a while due to following challenges and issues:

- Lack of policies and protocols for re-use of batteries for energy storage- At present, consumers cannot be assured that second-life batteries would provide a standard and reliable life span, or are supplied from a certified and reliable manufacturer or distributor.
- Absence of any methodology to assure EV manufacturer whether the batteries reaching end-of-life are re-purposed with a reliable re-use opportunity and that the waste products from second life are adequately handled and disposed.

Irrespective of the above concerns, the increasing recognition of the opportunity to re-use batteries by car manufacturers are expected to continue to support this opportunity. As in the future, with an increase in the number of EVs on the road, their subsequent end-of-life batteries would also increase.

Long-Term Solution: Closed Loop Recycling

The present recycling processes are able to recover only 50% of the economic value

Second life battery cannot be called a means of sound disposal since after using the battery it still contains heavy metals. It then needs to go through the closed-loop recycling to extract the useful elements of the battery. Closed Loop Recycling can be done through various process:

1. **Direct Recycling (Mechanical process)** - includes crushing and physical separation of components and recovery of the black mass.
2. **Pyro-Metallurgical (with heat and flame)** - requires the processing of spent lithium-ion cells at high temperature without any mechanical pre-treatment and loading batteries directly into the furnace.
3. **Hydro – Metallurgical (With liquids and chemicals)-** does mechanical pre-treatment and metal recovery from the black mass by means of leaching, precipitation, solvent extraction, ion-exchange resins, and bioleaching.

Table 5.2: Percentage of various elements recovered in different industrial processes

Material	Pyrometallurgical & hydrometallurgical	Hydrometallurgical	Hydrometallurgical
Type of Batteries	*NMC and LFP*	*NMC*	*LFP*
Lithium	57	94	81
Nickel	95	97	NA
Manganese	0	~ 100	NA
Cobalt	94	~ 100	NA

Source: Report on 'Lithium-ion battery value chain and related opportunities for Europe, 2016.'

"The Cost of Li Battery recycling depends on lot of factor like Battery chemistry, Volume, Scale of Operation, Raw material prices etc. The Recycling can be done in profitable way for most of battery chemistry with sufficient volumes."
-Kapil Kumar, GM, Fortum

A recent study[8] discovered that the seven principal components (cobalt, lithium, copper, graphite, nickel, aluminium, and manganese) constitute more than 90% of the total economic value of a spent lithium-ion battery. The present recycling processes are able to recover only 50% of this economic value. However, companies like Fortum claim to have achieved a high recycling rate of 80% with a low-CO_2 hydrometallurgical recycling process. In their process, the lithium-ion batteries are first made safe by separating out plastics, aluminium, and copper before subjecting the batteries to recycling process[9].

Recycling challenges

There are lot of challenges and risks in closed loop recycling of lithium ion batteries. Some of them are:

- Battery recycling is a highly complex procedure. The technology behind lithium-ion batteries is still emerging. Constant research and design updates by manufacturers to make the batteries more efficient have created batteries of varying designs and compositions. These design differences make the adoption of a uniform recycling process very difficult and reduces process efficiency. The current recycling efficiency of about 50% of the economic value, along with high recycling cost makes the process a costly affair. At the current scale, recycling may not be very economical.
- High cost of recycling- As per industry sources, the cost of recycling a lithium-ion battery in India is about INR 90-100/ kg.A Lithium-ion battery facility requires high investments in technology for collection, transportation and management of resources while the profile margins are low. It takes at least 5 years to recover costs and start booking profits.
- In India, lack of awareness is another critical challenge among the battery producers as well as end consumers. While the recyclers continue to struggle even in B2B segment, B2C would remain a distant reality at least for next few years.
- The idea of tapping the B2C segment by recyclers is also logistically inconceivable. Only battery manufacturers can tap the market through Extended Producer Requirement (EPR) norms, if imposed strictly.
- Safety issues- The safety risks related to collection, transport and storage can be an issue with waste lithium batteries. If the disposed battery is punctured or short circuited, the remaining energy can be released rapidly and potentially cause a fire.
- Collection and transportation of waste lithium ion batteries is a difficult task. At present, less than 5% of the lithium-ion batteries that are spent are being collected today

"The main challenge is to ensure safety throughout the whole battery recycling value chain, from collection to logistics and Safety during recycling treatment keeping all emission under control."
- Kapil Kumar, GM, Fortum

However, with the growth of the lithium-ion battery market and standardization of its compositions, these challenges would eventually subside.

[8]Article on "Lithium battery re-using and recycling: A circular economy insight", June 2019
[9]https://www.fortum.com/products-and-services/recycling-waste/recycling-services-and-products/lithium-ion-battery-recycling-solution

Key battery recycling players

Industrial recycling of lithium-ion batteries is done mainly in the European Union and China. The map below shows the companies involved in the recycling of lithium-ion batteries around the world.

Figure 5.2: Lithium-ion battery recycling companies across the globe

Source: JMK Research

Market opportunity: Battery recycling in India

"We are pretty optimistic about lithium-ion battery recycling potential in India. Unlike those in Lead-acid battery segment, the organized players in lithium-ion market won't have to compete with the informal sector."
- Raman Sharma, Director, Exigo Recycling

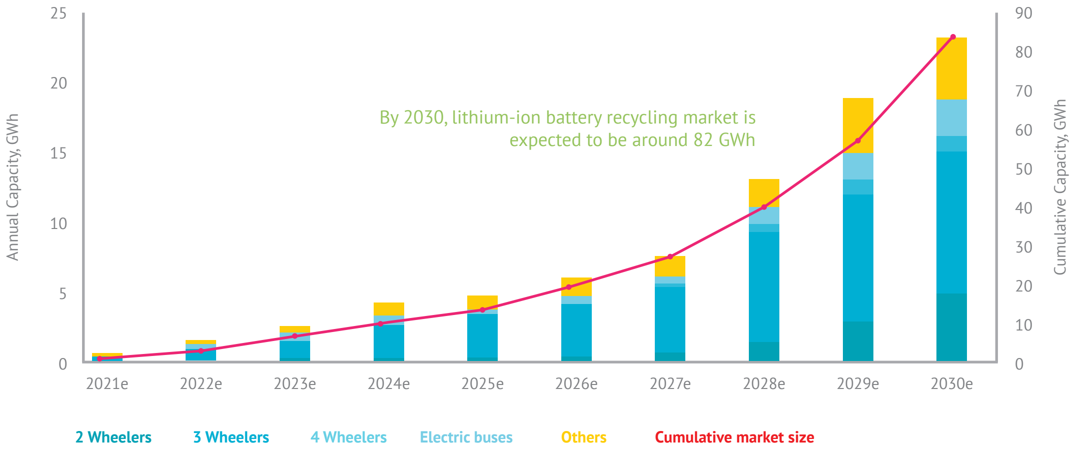
Only about 50% [10] of the batteries that reach end-of-life find their way to recyclers around the world. There could be several reasons for the same:

- Battery hoarding or storing
- Battery disposal in waste
- Second life usage in other applications

As per JMK Research estimates, the recycling market in India is expected to pick up from the year 2022 onwards when lithium-ion batteries which are presently in use would reach their end of life. In the year 2030, the annual recycling market is expected to be around 22 - 23 GWh, which is a $1,000 million opportunity.

Between year 2022 and 2030, the batteries from electric vehicles would contribute to majority of the recycling market with public transport leading at almost 75% of the total recycling market (as these batteries are subjected to extreme operating temperatures, hundreds of partial cycles a year, and changing discharge rates, which results in high degradation of lithium-ion batteries in their early life)[11].

Figure 6.1: Lithium-ion battery recycling market in India



Source: JMK Research, *Others include batteries from stationary storage applications, mobiles, telecom sites, laptops etc.
Assumptions:

- This data includes batteries available for second life use as well as recycling
- Most of the EV's batteries will be used for second life while Other applications will be available for closed loop recycling
- Every year certain percentage is assumed from EV's and Others which will be available for closed loop recycling/ second life use., which will gradually increase till 2030. For EV's this is assumed to be 40% from 2021, for 'Others" this factor is assumed to be only 1% from 2021
- Life of battery: 3 wheeler – 3 years, Buses- 4 years, two-wheelers – 5 years and four-wheelers – 8 years, Storage- 8 years and others– 10 years

Going by the battery manufacturing targets set by NITI Aayog under its Energy Storage Mission, by 2030, the cumulative lithium-ion battery recycling market is estimated to be about 160 GWh. As per various industry sources, these targets are highly ambitious and extremely difficult to achieve.

[10] Report on "The lithium-ion battery end-of-life market – A baseline study"
[11] Second-life EV batteries: The newest value pool in energy storage – Mckinsey & Company

"Recycling of lithium-ion batteries is a time consuming and costly affair and only long-term focussed players will be able to sustain. With rising volumes profits will also rise for them"

- Tapan Dash, TES-AMM

In near future if cell manufacturing units are setup in India another 8-10% of the production waste from these units can be further used for recycling.
Many Indian companies have already started looking at this lucrative opportunity and have either already established or announced plans to set up recycling operations. Some of them include:

- Attero Recycling is a key player having commercial lithium-ion battery recycling plant operational in India for more than 15 months.
- In August 2019, Tata Chemicals launched its lithium-ion battery recycling operations in Mumbai. The operations, launched at the pilot-scale, could recycle the spent batteries successfully. They now plan to scale their operations up; to recycle 500 tons of spent lithium-ion batteries.
- Raasi Solar has announced plans to set up a 300 MW plant focussing on lithium battery recycling along with battery assembling and cell manufacturing.
- Mahindra Electric also has expressed its plans to enable EV battery recycling, in a method similar to the recycling of cell phone batteries, with the help of a supply partner.

Apart from these major players, other players who manage e-waste and have plans to do lithium-ion battery recycling in India are listed below:

Table 6.1: Other players who are working on recycling of lithium ion batteries in India

Recycler	Location	Technology	Partnership
TES-AMM	Chennai/ Singapore	Mechanical and Hydro Metallurgy	RECUPYL (Singapore)
Exigo	Haryana	Mechanical	In house patents
Sungeel Hi-metal	Andhra Pradesh	Hydro Metallurgy	Sungeel, India
E-Parisaraa	Bangalore	Mechanical	In house patents
ECORECO	Mumbai	Mechanical	NIPPON Recycling
ECOTantra	Pune	Mechanical	NIPPON Recycling
EXIMO Recycling	Gujarat	Mechanical	N/A
Surbine Recycling	Gujarat	Electro & Hydro Metallurgy	In house patents

Source: IESA, JMK Research

"Li Battery recycling requires high investment, so companies would invest when they see clear business growth."

- Kapil Kumar, GM, Fortum

International Regulations: Recycling and Disposal

Globally, spent lithium-ion batteries and lithium-ion waste are classified as 'Dangerous Goods.'

Although there is awareness around the recyclability and reusability of batteries, this market would pick momentum only when the Indian Government brings in a well-defined regulatory and policy framework.

Globally, spent lithium-ion batteries and lithium-ion waste are classified as 'Dangerous Goods.' With the growth of the EV market, the number of spent lithium-ion batteries would also increase. In the absence of regulations around the disposal and recycling of batteries, it would be difficult to understand and contain the hazards associated with improper handling of spent lithium-ion batteries.

Currently, the regulations governing the disposal of spent lithium-ion batteries vary significantly across countries. Stipulated regulations related to the disposal of batteries[19] in some of the key countries are as listed:

European Union

In 2006, the European Union set up a Battery Directive, which was part of the EU Sustainable Development Goals (SDGs). The Battery Directive was intended for the EU members to contribute to the protection, preservation, and improvement of quality of the environment by minimizing the negative impact of waste batteries, including lithium-ion batteries. European Union had set a timeline for battery manufacturers and importers for recycling of spent lithium-ion batteries. The "Batteries directive" of the EU had the following mandates:

- Collection rates for the used batteries should be 25% by 2012 and 45% by 2016
- Recycling of battery and accumulator content, to produce similar products or for other purposes, had to be 65% (by weight) for Lead Acid batteries, 75% of Nickel-Cadmium batteries and accumulators (including as much lead recycling as feasible from these), and 50 % of all other battery and accumulator types
- Prohibition of disposal of industrial/automotive batteries/accumulators to landfill or incineration
- Allowing the recycling and treatment treatment of battery waste outside the EU, provided EU legislation for transport/transfer of hazardous waste was followed

Reports[12] indicated that the targets for 2012 were met by most EU members, but the targets for 2016 were too ambitious. As of year, 2014, while seven member states had already achieved the 2016 target of 45%, four-member countries were yet to reach the 2012 target of 25%.

United States of America

In the USA, lithium-ion batteries are considered hazardous and are regulated under the Standards for Universal Waste Management (Electronic Code of Federal

[12]Report on the implementation of EU waste legislation, including the early warning report for the Member States at risk of missing the 2020 preparation for re-use/recycling target on municipal waste

Regulations, Title 40, Part 273, US EPA). This regulation mandates that waste batteries be collected as hazardous wastes and sent for further treatment and/or recycling. The order strictly prohibits the disposal of batteries to landfills. However, the Federal Government standards do not include any directive about resource recovery from lithium-ion batteries waste. Some states in the USA are developing their own regulations that enforce producers to offer or fund battery recycling. These schemes are active in California, Minnesota, Iowa New York, Florida, Vermont, New Jersey, and Maryland.

China

In China, the car manufacturers responsible for the recovery of new energy vehicle batteries and require them to set up recycling channels and service outlets

China's industry ministry issued draft rules in 2017 that hold car manufacturers responsible for the recovery of new energy vehicle batteries and require them to set up recycling channels and service outlets where old batteries can be collected, stored and transferred to specialist recyclers.

- The car manufacturers must set up a maintenance service network that allows members of the public to repair or exchange their old batteries conveniently.
- Car manufacturers must also set up a traceability system enabling the identification of owners of discarded batteries.
- To help automate the recycling process, the battery makers are encouraged to adopt standardized and easily dismantled product designs.
- Battery makers must provide technical training to car manufacturers to store and dismantle old batteries.

Japan

In Japan, the Law for the Promotion of the Effective Utilisation of Resources (2000) mandates that rechargeable batteries be classified for recycling, at the manufacturing stage, using a standardised three arrow recycling mark indicating battery type and primary metal components. On reaching end-of-life, these marked batteries are collected and recycled appropriately(Battery Association of Japan 2010a). The Law also sets lithium-ion batteries recycling target of greater than 30% and stipulates that all manufacturers and importers of batteries must have a recovery system for waste products. The Japan Portable Rechargeable Battery Recycling Centre (JBRC) was formed in 2010, as part of the Battery Association of Japan, to provide free collection and recycling of portable rechargeable batteries.

India

At present, India does not have any policy framework or mechanism for lithium-ion battery recycling and second use market. However, in October 2019, the Indian Government has announced that it is in process of framing a recycling policy for lithium-ion batteries under which offer tax sops are offered to recyclers. This policy also imposes liability on battery producers to collect used batteries under the Extended Producer responsibility (EPR) norms. Proposed policy is also expected to have incentives for companies setting up recycling facilities and make it incumbent on producers to collect used batteries[13].

[13]Source: https://economictimes.indiatimes.com/industry/auto/auto-news/electric-vehicles-lithium-battery-policy-to-incentivise-recycling-entities/articleshow/71497181.cms

The E-waste management and handling rules that were notified in the year 2011 made batteries (except the lead-acid batteries) a part of e-waste. But these rules don't specifically mention about safe disposal and recycling of batteries. Certain states and UT's have come out with separate e-waste guidelines wherein list of Collection Centres authorized by the state agencies are mentioned for collection of e-waste. However, on ground implementation of these guidelines is still a challenge.

For lead-acid batteries, in the year 2001, the Indian Government had notified The Batteries Management and Handling Rules, with the primary objective of channelizing the used lead-acid batteries for environmentally sound recycling[14]. This was done considering the hazardous nature of lead-acid batteries. However, to date, the implementation of these rules has been a challenge.

As per data collected from various sources, presently more than 85% of the lead-acid batteries are recycled in India. While 40% of the batteries are recycled by the formal sector, the rest is done by the informal sector, as it is economically remunerative.

Table 7.1: Overview of International regulations on lithium-ion batteries

Country	Lithium-ion battery specific regulations	Other regulations	Collection targets	Collection models
European countries	Battery directive, 2006		With collection targets of 45% by 2016	State funded, environmental agreement, competing organisations, without organisations
USA	No specific regulation	Regulated under the standards for Universal waste management as hazardous waste	With collection targets of 45% by 2016	State funded, environmental agreement, competing organisations, without organisations
China	No specific regulation	Catalog of waste electrical and electronic products recycling, 2015 mentions lithium-ion battery	No collection model	Present but nor for lithium-ion batteries
Japan		Japanese law for the promotion of effective utilisation of resources, 2000 addresses lithium-ion battery	No collection model	Present but nor for lithium-ion batteries

Source: Report on "LITHIUM-ION BATTERY RECYCLING IN INDIA- Opportunities and challenges" by Agnes Richard, July 2019

[14]Status Review Report on Implementation of Batteries (Management and Handling) Rules, 2001 (as amended thereof) - Report published by CENTRAL POLLUTION CONTROL BOARD in 2016

Conclusion

The recycle and re-use of lithium-ion batteries is no longer an option but the need of the hour. Recycling batteries would help India deal with both the end-to-end manufacturing issues of batteries (ensuring less waste, avoiding environmental pollution, and reducing costs), while also dealing with the shortage of certain minerals in India by re-using them as much as possible to displace imports.

The manufacturing, re-use, and recycling of batteries would lead to a circular economy where the manufacturers would either double up as recyclers or new entrants with the sole focus on recycling of batteries would enter the market.

New business models providing better solutions are likely to emerge with time. One such model could be battery leasing wherein the battery is returned at the end of the lease period and the onus to re-purpose and recycle lies with the manufacturer. Battery suppliers in India have already started selling with a buy-back option.

"The government needs to provide a robust and transparent policy framework to incentivize efficient technology players in this market"
- Raman Sharma, Director, Exigo Recycling

Although there is awareness around recyclability and reusability of batteries, this market would pick momentum only when the Government brings in well defined regulatory and policy guidelines. Clear guidelines have to be laid out for collection, storage, transportation and recycle of waste batteries. Detailed instructions for both consumers and battery suppliers also have to be laid out and implemented. Key recommendations for the Indian Government are:

- Throwing of batteries in landfills should be made illegal. Effective mechanism should be developed for proper disposal of batteries through recyclers.
- A guideline or standard should be made to label lithium-ion batteries which would be helpful in segregating them from other battery types.
- The Government should consider establishing a research program for more efficient direct recycling processes that are environmentally friendly. Established research centers should be well funded to make it attractive for researchers and academicians.
- Policies have to be framed to develop a detailed incentive framework such as subsidy for setting up tax holiday and income tax deduction for setting up recycling plants for lithium-ion batteries in India.
- Legislation required to incentivise spent battery collection and proper disposal.
- Finally, the Government should establish Extended Producer Responsibility (EPR) to ensure that battery suppliers are responsible for the recycling of batteries they have sold into the market. This includes that all electric vehicle suppliers should take back used lithium-ion batteries and enable second-use of these batteries before giving them to a suitably certified recycling organization for disposal. To make EPR commercially viable, a small battery fee can be charged to consumers.
- The government should aim toward closed-loop recycling, where materials from spent batteries are directly recycled, minimizing energy use and waste by eliminating mining and processing steps.

All these measures if taken now would help India streamline and formalize the processes to ensure proper disposal and recycling of lithium ion batteries in a sustainable and cost effective manner.

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