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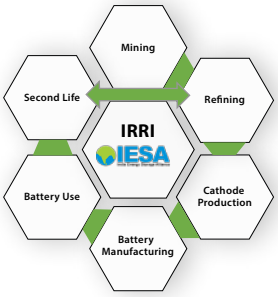
BATTERY RECYCLING



IRRI

'IESA Re-Use & Recycling Initiative' for Battery Recycling under Swachh Bharat Abhiyan

As the volume of battery manufacturing grows, a parallel system of disposal and recycling will be essential to minimize the detrimental impact on the environment.

Potentially, all the metal elements used in a Li-ion battery namely Li, Co, Ni, Mn, Co, and Al could be recovered and re-used for either battery or other applications. However, currently, only Cobalt is partly recovered due to its high cost and concerns regarding its availability. Strict regulations regarding the disposal of batteries need to be enacted in order to give impetus to the Li-ion battery recycling industry.

In terms of recycling, the lead-acid battery industry is very advanced with almost 96% of batteries being recycled worldwide. This is reliant on robust and scalable recycling technology, strict regulations prohibiting improper disposal and a well-established supply chain for collection of used batteries from the customer. In this webinar, we will discuss the extent of materials recovery possible from recycling, the concept of urban mining and technological advances in recycling in recent years.

With this problem statement in mind, IESA launched the IESA RE-use & Recycling Initiative (IRRI) for Battery Recycling.

The focus areas for the initiative will be the following:

Battery collection mechanism

Proper classification and segregation of batteries at centralized locations is key for enabling the recycling industry. Launching an initiative to create a collection network for used batteries.

Encouraging Battery recycling research

As part of IESA R&D activities we will be sponsoring one postdoctoral student for research on recycling processes.

Creating awareness for the need for recycling of batteries Commercial opportunities for 'Urban Mining'

Commercial opportunities for 'Urban Mining'
Regulatory support required for encouraging recycling

We Encourage all our Members to participate in our IRRI Initiative and be instrumental to make the storage Industry truly sustainable in the long run.

Contents

1. Introduction

In today's society batteries are considered as the most important component for a wide range of applications from cars to mobiles, laptops, watches, remote controls, toys, medical devices, etc. With increasing presence of a variety of electronic gadgets, electric vehicles and stationary storage the battery market is expected to become a $90 billion market by 2025 from $60 billion in 2015.[1]

As demand for batteries increases in upcoming days, it is anticipated that waste generated from batteries also will increase. But, handling the waste is a complicated task due to presence of different types of chemicals in the battery, and each of them have a different environmental impact. In addition, batteries come in different sizes and different packaging material, hence segregating them is a challenging task. For example, sorting of dry-cell batteries is an expensive and complex process as these batteries comes in a range of shapes, sizes and chemistries. Some of the dry cell battery chemicals are extremely toxic and can cause harm to humans and the environment. In a landfill, corrosion takes place in the metallic container of Ni-Cd battery, resulting in cadmium dissolutions which go into soil and water. This further contaminates the complete ecosystem.

In absence of proper recycling or disposal mechanism, dead batteries not only pollute the environment, but there is loss of economic value associated with it. Batteries come with various metal compositions, rare elements and alloys, which can be recycled after their life and reused as primary source for the same battery or for other applications. Lithium-ion, Ni-Cd and NiMH batteries are having key elements like Li, Ni, Co, Cu, and their reserve in India is very less, thus strategic value is associated with these elements. With growing presence of Li-ion battery in the market, recovery of primary elements from end-life battery could be economical in coming years.

There are several benefits associated with recycling of battery like,

- **Recovery of key material:** as India develops, the demand for primary material for infrastructure like iron, aluminium, copper and zinc will increase with global demand. Other key elements that are used in batteries like Li, Ni, and various rare material have strategic value in India due to their scarcity here. Hence it becomes extremely important that we focus on resource recycling of these metals.

- **Reduction in waste generation and pollution:** battery recycling will reduce the load of landfills and decrease the amount of hazardous waste and also the mining requirement.

- **Reduction in resource consumption for mining and extraction:** the mineral beneficial process of some minerals involves high energy consumption. Increased use of recycled metals can reduce the greenhouse gases, which are the by-product of metal refining process.

2. Recycling technology

There are different methods used in the battery recycling process. Among them, the most common methods are (a) mechanical treatment(b) pyrometallurgy and (c) hydrometallurgy.

(a) **Mechanical treatment:** this method is primarily suitable for the industrial batteries. The treatment process is considered as first phase of the recycling process, in which initial treatment of the scrap is followed by the recycling process. The process uses only physical mechanism and hence it is cheaper than any other treatment.

(b) **Hydrometallurgy:** in this recycling process, scraps are leached with acid or base, turning the metal into a solution. In the following step metal is recovered from the solution by the precipitation method. Different strategies are followed to recover the selective element from the solutions, like different pH is maintained, or sometimes it is done with addition of reaction agent or by electrolysis.

(c) **Pyrometallurgy:** this is a high temperature process to recover the different elements from waste. With the pyrometallurgy process, mercury is eliminated from Zn-MnO dry batteries followed by Zn recovery by distillation process.

2.1 Battery recycling process

2.1.1 Lead acid battery

Recycling of Lead acid batteries and primary lead production are very similar processes. The recycling starts with removal of plastic case with help of hammers or saws. Subsequent steps are acid removal, metallic lead and paste separation, reduction, refining and casting. Figure1 shows lead acid battery recycling process in a flowchart.[2]

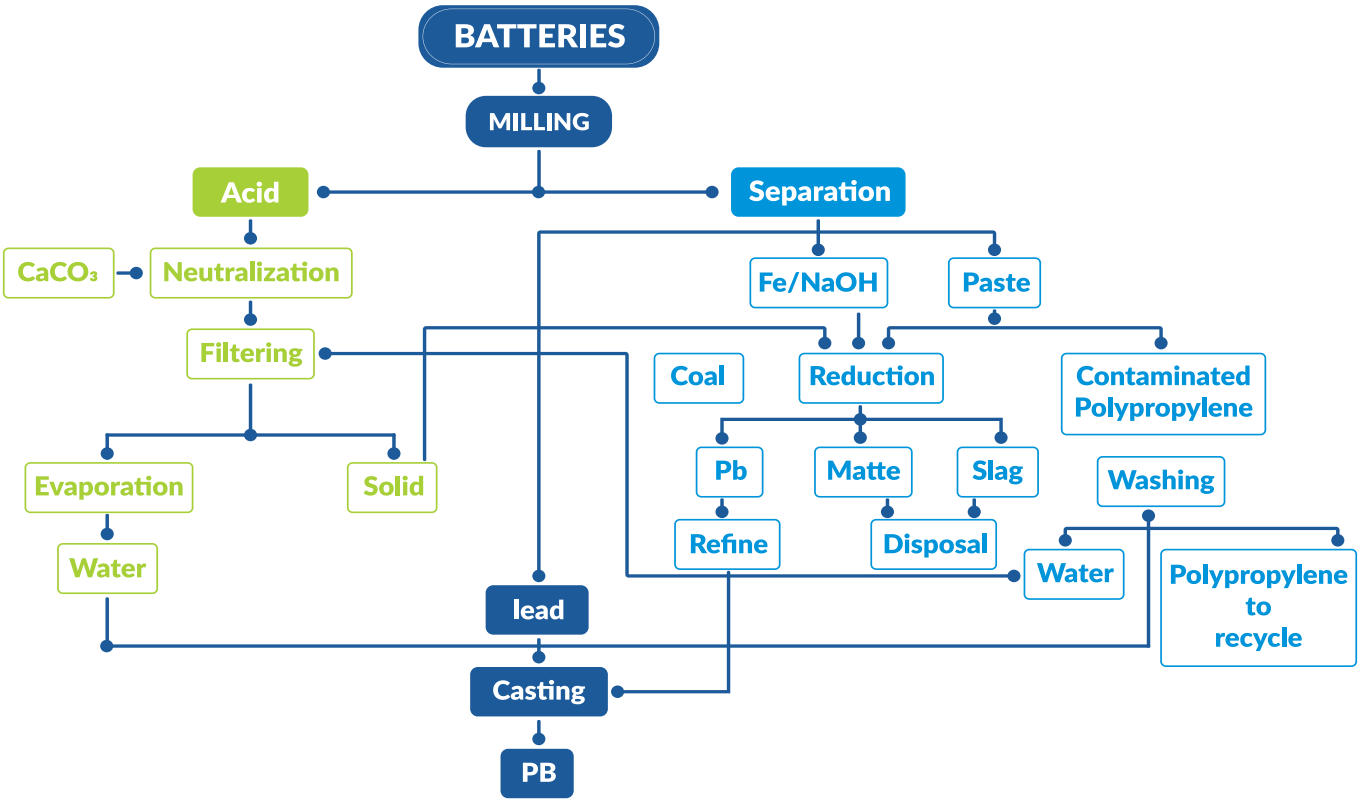


Figure 1: Lead acid battery recycling process

2.1.2 Zn-MnO_2 based battery

In 1980s, Sumitomo process was one of first treatment methods for the household Zn-MnO2 batteries. The process is in industrial use in Wimmis, Switzerland. In the beginning, mercury evaporation takes place at 750^{o}C, followed by reduction in electric furnace at around 1500^{o}C. Another process is Recytec process which is similar to Sumitomo process for treating household batteries.[2]

J&T Recycling Corporation is one of the leading recyclers for Zn-MnO2 battery in Japan. They collect used dry cell batteries and detoxify it from hazardous materials and then recycle resources in a consistent cycle. Figure 2 shows dry cell battery recycling process in J&T.[3]

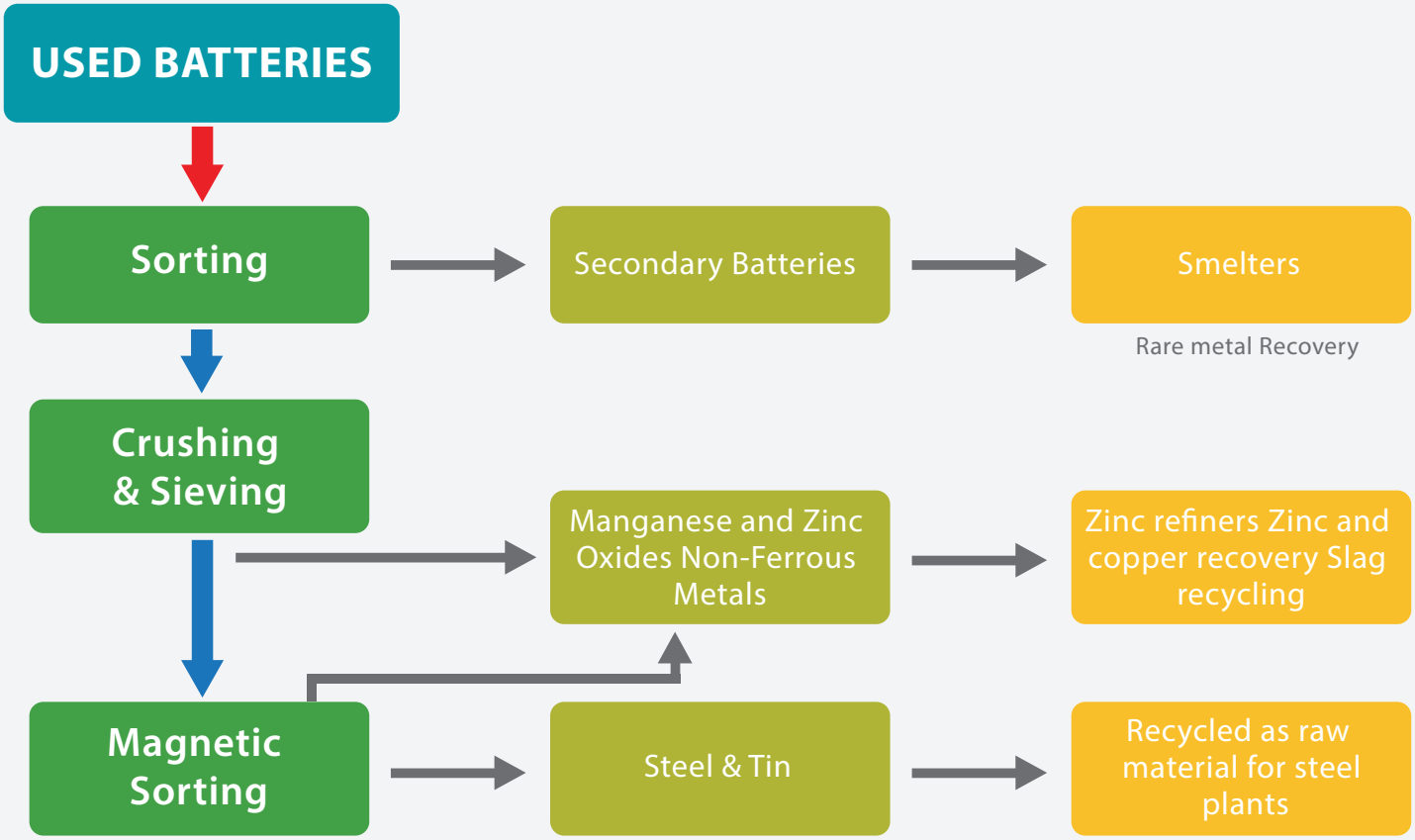


Figure 2: Dry cell battery recycling flow

2.1.3 NiCd battery

NiCd batteries are recovered by pyrometallurgical process separately due to the presence of Cd. In France and Sweden, the Snam-Savam and Sab Nife processes are used respectively, to recycle this battery. Both processes use fully closed furnace, and at a temperature between 850 and 900^{o}C Cd distillation takes place. In the next stage, Nickel is recovered in electric furnaces by reduction and smelting.[2] Production of cadmium oxide in open furnaces involves unhealthy working conditions, thus recycling of NiCd battery has been stopped in many places in the world. In the United States, only the company Inmetco is authorized to perform high temperature recycling.

2.1.4 NiMH and Lithium-ion battery

Consumption of NiMH and Li-ion batteries has increased mainly due to its superior electrochemical properties and also due to the restrictions on the use of NiCd batteries. Recycling of NiMH and Li-ion batteries involves more complex procedures than that of zinc and NiCd batteries. NiMH and Li-ion batteries are not included in the recycling programme of most countries. As a result, there is no obligation on establishing a proper collection system and on developing recycling processes.

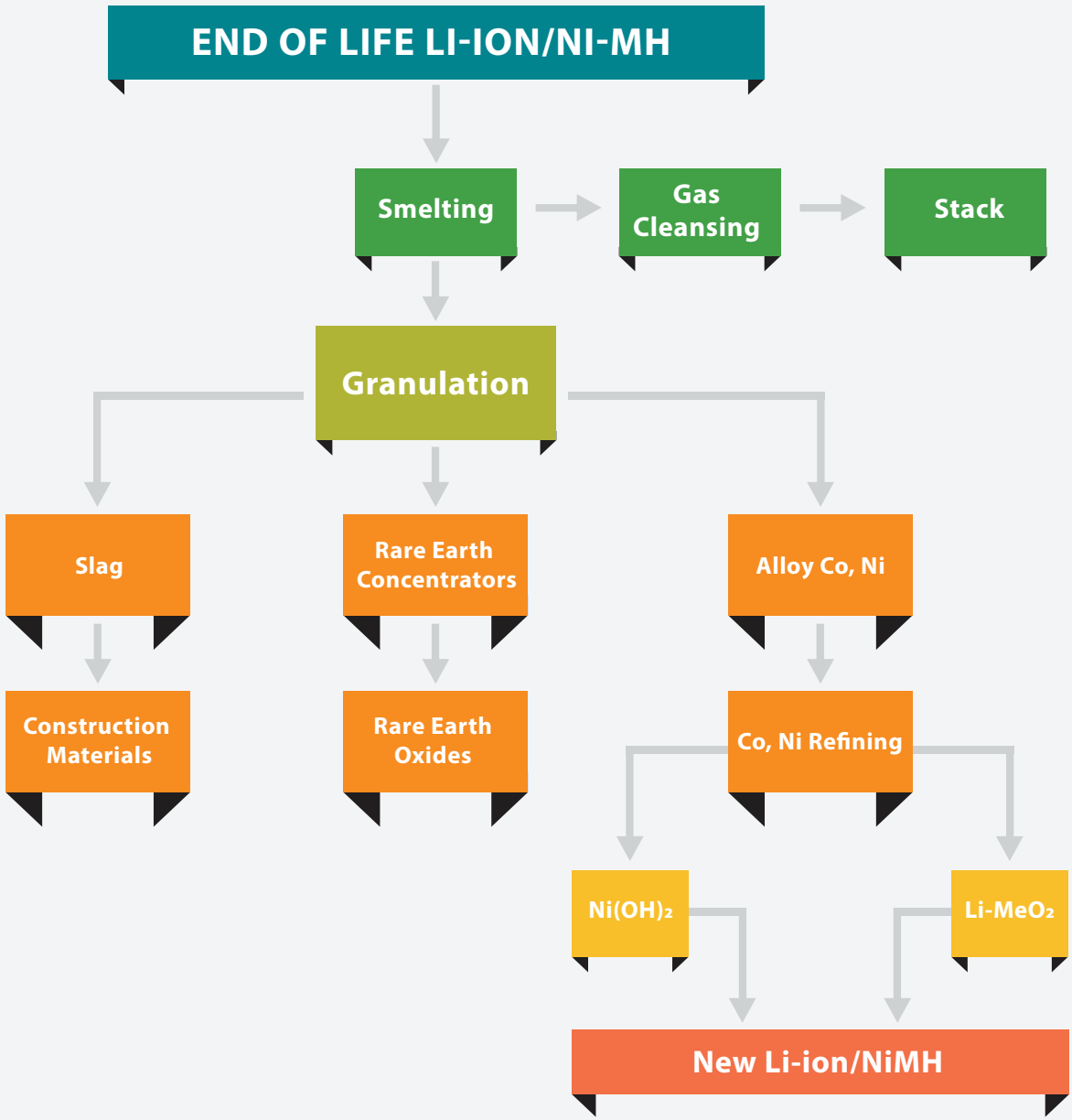
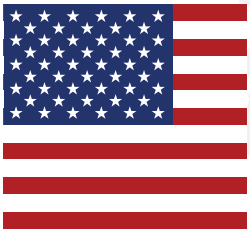


Figure 3: Li-ion and NiMH battery recycling process in Umicore

One of the leading lithium-ion cathode material manufacturers, Umicore, has developed a recycling process that can be used for Li-ion as well as NiMH battery together. The Umicore battery recycling process is a combination of pyrometallurgical and hydrometallurgical processes. Umicore process is considered one of the most advanced processes for recycling of batteries without any mechanical pre-treatment of the battery cells. This process is structured to recover Nickel, Cobalt and Copper as alloy. Lithium and REEs can be recovered from slag fraction. The first pilot plant of this recycling process was run in Hofors (Sweden) for few years. Figure 3 shows battery recycling process of Umicore.[4]

3. Battery recycling initiatives globally

Globally, most of the battery recycling is carried out by private enterprises. For efficient resource recovery, sophisticated machinery with state-of-art chemical processes are used. In addition to that, a proper collection of battery is in place to execute the whole process. Following are the some of the best practices across the world used for battery recycling:[5]



USA - As per the federal universal waste regulation of United States Environmental Protection Agency (USEPA), battery is considered under one of the universal waste categories. Based on different types of battery, safe disposal is framed in 90s (see Table 1). The Battery Act (Mercury-Containing and Rechargeable Battery Management Act) came in 1996, which helps in increased collection and recycling of NiCd and certain small sealed lead acid (SSLA)batteries.

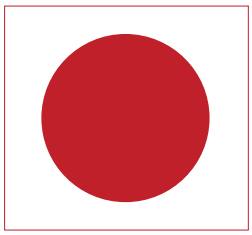
Table 1. Safe disposal rules for household batteries in USA

BATTERY TYPE	DISPOSAL METHOD
Alkaline (Mn)	**Place in the trash (normal municipal waste). Exceptions in California where disposal of such batteries is in accordance with the California Universal Waste Rules.**
Lithium / Lithium Ion	**Complete discharge is required before its handover for recycling.**
Nickel-Cd (Rechargeable)	**Bring it to a household hazardous waste collection site**
NiMH (rechargeable)	**These batteries are safe for disposal in the normal municipal waste stream, although these batteries are acceptable for recycling by Rechargeable Battery Recycling Corporation (RBRC)**
Reusable Alkaline Manganese (Rechargeable)	**Possible to dispose with household trash**

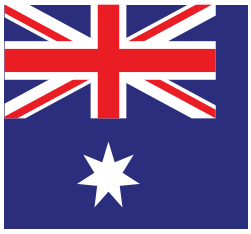
Household recycling programme, **'Call2Recycle',** was developed by the Rechargeable Battery Recycling Corporation (RBRC) –a non-profit based in the USA. Under this programme, Ni-Cd, NiMH, nickel zinc, lithium ion, small sealed lead acid and single use batteries including alkaline and lithium primary are recycled.

CANADA - There is no producer responsibility legislation in Canada. Although, British Columbia, Quebec, Manitoba and Ontario have own regulations to recycle of all types of primary and secondary batteries and it is mandatory. In Canada, consumers (like in USA) can drop off their used batteries at any Call2Recycle collection sites free of charge.

EUROPE - In 2006, the European Commission has legislated a Battery Directive which has rules for collection, recycling, treatment and disposal of batteries and also restricts mercury and cadmium content in batteries. It directs phase wise collection targets: 25% by 2012 and 45% by 2016, whereas recycling efficiency targets 65% for lead acid batteries, 75% for nickel cadmium batteries and 50% for all other types. It also has minimum rules for producer responsibility and labelling provisions. By the end of 2016, many European countries like Slovakia, Luxembourg, Belgium, Sweden and Germany among many others, had achieved successfully the target of 45 % collection rate as mandated by the EU directive.



JAPAN - Extended Producer Responsibility (EPR) rules in Japan apply only for rechargeable batteries. The law of Promotion of Effective Utilization of Resources (2000) promotes 3R (reduce, reuse and recycle) which applies to the manufacturers, importers, and the product lines of rechargeable batteries. The 'take-back' EPR legislation sets recycling targets for recovery rates of rechargeable batteries, which are 60% for NiCd, 55% for NiMH, 30% for Li-ion and 50% for SSLA batteries. In 2004, the country established the Japan Battery Recycling Centre (JBRC), to fulfil the producers' recycling obligations.



AUSTRALIA - Battery recycling is currently voluntary in Australia. The Australian Battery Recycling Initiative (ABRI) comprises battery manufacturers, recyclers, retailers, government bodies and environment groups. Its primary responsibility is to promote collection, recycling, and safe disposal of all type of batteries. ABRI has an area-wise battery drop-off location for free recycling of different type of batteries. Battery World stores, a retail franchise network in Australia, also offer free battery recycling services for their customers.

Different battery recycling initiatives around the world are summarized in Table 2 as a form of rules, regulations by different govt and private agencies.

Table 2: Best practices across the globe used for battery recycling

REGION	RECYCLING INITIATIVES
USA	**Waste regulation of United States Environmental Protection Agency (USEPA) 1990s, The Battery Act 1996, Call2Recycle programme**
Europe	**Battery Directive in 2006**
Canada	**Regulations in certain parts of Canada, Call2Recycle programme**
Japan	**Extended Producer Responsibility (EPR) rules, Promotion of Effective Utilization of Resources (2000)**
Australia	**Australian Battery Recycling Initiative (ABRI)**

3.1. Lithium-ion battery recycling companies around the world

There are different companies working in lithium-ion battery recycling globally (Table 3). Among Asian countries South Korea, Japan and China are leading in lithium-ion battery recycling activities. SungEel HiTech is South Korea's largest battery recycler and urban mining company. SungEel's patented Hydrometallurgy based lithium ion battery recycling technology is deployed at plants in S. Korea. The company has expansion plans for recycling lithium ion batteries globally and has started developing plants in India and USA. Anhua Taisen is a China based Li-ion battery recycler since 2014 and it has formed an alliance with Recytech of S.Korea. The company uses Hydrometallurgy to extract critical battery elements, and ses additional processes for producing new battery material. Another China-based company, Shenzhen Green Eco-Manufacture (GEM) is one of the largest lithium ion battery recycling companies in China. Using Hydrometallurgy, the company extracts all critical battery materials. Nippon Recycling Centre Corp is based in Osaka, Japan with over 40 years of recycling operations. NRCC uses pyrometallurgical recycling technology for extraction of Nickel and Cobalt. NRCC has facilities based in Tsukuda and Nakajima, Japan for Li-ion and Nickel type battery. 4R Energy Corporation, a joint venture between Nissan and Sumitomo, is Japan's first plant specializing in the reuse and recycling of the Li-ion batteries from electric vehicles.

Accurec is based in Germany and it uses mechanical pre-treatment, pyro and hydrometallurgy to recover battery cathode materials, with over 60% efficiency. Their core focus is on NiMH and Li-ion battery recycling. Another Germany-based company, Litho Rec, is Li-ion battery recycling company mainly working on research, piloting and assessment coordination. Umicore is world-leader in urban mining and lithium-ion battery recycling and material production based in Belgium. Umicore has developed a proprietary combined Pyro-Hydrometallurgy technology for Cobalt and Nickel extraction from Li-ion and NiMH Batteries.

Retriev Technologies (earlier Toxco) is a California-based pioneer in recycling of batteries, including lithium ion batteries. Retriev's Li-ion battery recycling facility is based in British Columbia, Canada. Retriev uses cryogenic hydrometallurgy to extract materials.

Table 3. Lithium-ion battery recycling companies around the world

COMPANY	COUNTRY	BATTERY TECHNOLOGY	TECHNOLOGY
SungEel HiMetal	South Korea	Lithium-ion	Hydrometallurgy
Umicore	Belgium	Li-ion & NiMH	Pyro - Hydrometallurgy
Anhua Taisen Recycling	China	Lithium-ion	Hydrometallurgy
Shenzen Green Eco Manufacture (GEM)	China	Lithium-ion	Hydrometallurgy
Accurec DE	Germany	NiMH and Li-ion	Pyro - Hydrometallurgy
Litho Rec	Germany	Li-ion battery	
Dusenfeld	Germany	Li-ion battery	Pyrometallurgy
Retriev Technologies	California (USA)	Lithium-ion	Cryogenic Hydro-metallurgy
Li-cycle	Canada	Li-ion	Hydrometallurgical
Nippon Recycling Centre Corp	Osaka (Japan)	Li-ion and Nickel type battery	pyrometallurgical
4R Energy Corp	Japan	Li-ion	
Taisen Recycling	Korea	Li-ion	

4. Battery recycling status in India

In India, a huge number of dead or old batteries are dumped into a household waste as low or no monetary value is associated with it. There has been some focus in recycling of lead acid batteries, but there are no proper regulatory mechanisms to deal with 'pencil cells' and 'dry cells' after end life. The current Municipal Waste Rules, 2016, does include batteries as part of domestic hazardous waste, but there are no collection systems, recycling facilities and any proper disposal methods to manage these batteries which are generated in millions annually. Lack of scientifically designed landfills in the country makes it even worse to manage the hazardous & toxic materials leaching out from the spent batteries. Majority of the household batteries end up in normal municipal waste bins.

India's dry cell battery market is mainly dominated by non-rechargeable zinc-carbon battery with a share of more than 95%.[6] The remaining share goes to alkaline and rechargeable battery segments. The major players in India in dry cell/pencil cell are Eveready Industries India Limited (EIIL), Nippo, Panasonic and Duracell.

4.1 Lithium-ion battery recycling industry

In absence of any formal structure of recycling in the country and also due to lack of up-takers, the waste from dry and alkaline batteries end up in landfills. With growing presence of different lithium-ion batteries in India, many companies have set up recycling facilities here. Table 4 shows a list of companies in India who are involved in lithium-ion battery recycling. As per the table, mechanical and hydrometallurgy are two dominating recycling technologies use for lithium-ion battery recycling in India.

Table 4: Companies working on battery recycling in India

RECYCLER	LOCATION	CAPACITY (LIB)	TECHNOLOGY	PARTNERSHIP
Tes-Amm	Chennai/ Singapore	1200 MTA	Mechanical & Hydro-metallurgy	Recupyl (Singapore)
Attero Recycling	Noida	5000 MTA	Electro & Hydro-metallurgy	In-house Patents
SungEEL HiMetal	Anantpur, AP	5000 MTA	Hydro-metallurgy	In-house Patents
E-Parisaraa	Bangalore	2000 MTA	Mechanical	SungEEL India
EcoReco	Mumbai	1200 MTA	Mechanical	Nippon Recycling
Eco Tantra	Pune	350 MTA	Mechanical	Nippon Recycling
Eximo Recycling	Vadodara/Surat	1200 MTA	Mechanical	N/A
Surbine Recycling	Jamnagar	1500 MTA	Electro & Hydro-metallurgy	In-house Patents

5. Recommendations

Following are the recommendations based on current battery recycling and disposal scenario in India:

Dedicated consumer education drives and product stewardship programs

Globally, the lack of an appropriate product stewardship program and consumer awareness regarding recycling options for battery are the main obstacles which need to be addressed to increase a country's battery collection rate. Low collection rate may not attract industry for investment in recycling infrastructure.

A proper product stewardship scheme and government subsidies would help rapid expansion and investment into the waste stream. Simultaneously, consumer awareness campaign with various educational programs would help in recycling processes and technology.

A regulatory framework for battery management

With material development and technological advancements, there is a greater chance to have different battery chemistries in the market, hence handling and segregation according to the battery chemistry is important after its life. So, upstream regulation for battery materials, design and labelling requirements are key for success of effective segregation strategies.

Introduction of Extended Producer Responsibility (EPR)

For the effective recycling process, 'take-back' or EPR legislation for the different battery manufacturers and also retailers will help immensely. Under EPR, manufacturers are financially and organizationally liable for the proper management of their products during various stages of collection, transport, processing, reuse, recovery and disposal.

A proper battery collection mechanism

So far in India, the un-organized sectors have been playing an important role in collection and recycling of different batteries. A proper framework would streamline the process of battery collections and segregations as well as prevent recycling in the unorganized sector where proper safety considerations are often ignored.

Focusing on battery recycling research

It is important that India should focus on development of state-of-art recycling process for recovery of metals and other materials from battery waste. Currently, scientists from Council of Scientific and Industrial Research (CSIR) labs National Metallurgical Laboratory (NML) and Institute of Minerals and Materials Technology (IMMT) are actively working on lithium-ion battery recycling. Research can be carried out on 'circular economy' for the different battery technologies which will give a direction to the industries to set-up a recycling facility.

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About IESA

India Energy Storage Alliance (IESA) is the premier alliance to focus on advancement of advanced energy storage and e-mobility technologies in India. The alliance was founded in 2012 by Customized Energy Solutions (CES). We work to make India a global hub for R&D, manufacturing and adoption of advanced energy storage and e-mobility technologies.

We have been at the forefront to contribute in development of enabling policy frameworks for adoption of Energy Storage and e-mobility technologies in India. We provide a eco-system to our members to network and grow their business in India and around the world through in-depth analysis and active dialogue among the various stakeholders. Our initiative 'IESA Academy' addresses the much-required skill development area through capability building programs and customized trainings with collaboration of Industry and academia.

Our members encompass all the vertices of the Industry covering energy storage manufacturers, research institutes, renewable energy, power electronics, EV manufacturing companies.

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