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The Potential of Lithium Ion Battery Recycling in India

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Abstract: India, in its effort to becoming self-reliant, has set its sights on 100% Electric Vehicle Penetration and is focused on the Electric Vehicle and Renewable Energy sectors, supplemented with at least 225 GW of renewable energy capacity installation by 2030. Recognising that Lithium Ion Batteries (LIBs) are the drive train for both of these industries, the Government of India (GoI) is encouraging indigenous manufacturing of lithium ion batteries. Consequently, global giants in the lithium ion battery manufacturing space, such as BYD and Panasonic, are planning to install facilities in India for cell and pack manufacturing. However, the local absence of an established upstream supply chain, including lack of raw material availability, could prove to be an impediment to the growth of this industry. Given that at least 40% of the cost of LIBs is attributed to the mining and refinement of the raw material feed [1, 2] and that India barely contains deposits of the required metals, battery manufacturers will have to import the relevant raw materials, increasing foreign dependence and cost. To address this deep reliance on imports, the government has recognised urban mining, also referred to as lithium ion battery recycling, as a potential solution to create a local supply and alleviate import costs. Hence, the question is, how plausible is urban mining in India? To what extent will lithium ion battery recycling reduce the import dependence of raw material resources? What factors affect the implementation of lithium ion battery recycling? This article attempts to address these questions and provide relevant insights into the viability of lithium ion battery recycling in India.

Keywords: Lithium ion battery recycling, raw material availability, economic viability.

1. MARKET OVERVIEW

The lithium ion battery recycling market can be explained by highlighting the demand and supply sides of the market independently.

1.1 The demand side

There are three factors that verify the demand for LIB Recycling.

1. The lack of currently unavailable metals in India:

Lithium Ion Batteries (LIB) have been recognised as the most viable solution in the foreseeable future for electric vehicle battery systems and renewable energy storage. With the E-mobility and Renewable Energy policy set by the Government of India stating 100% Electric Vehicle penetration by 2030 and at least 225 GW of renewable energy capacity, there is a strong demand for lithium ion batteries. According to JMK research, the cumulative lithium-ion battery market size in India is estimated to increase from 2.9 GWh in 2018 to 800 GWh by 2030 [2]. To meet this demand for batteries, the government is pursuing an initial 50 GWh of LIB cells to be manufactured in India by 2025, a small number compared to the estimated demand [3]. For this 50 GWh facility (s), there is a requirement of at least 13 kilotonnes of Lithium Carbonate Equivalent (LCE), 38 kilotonnes of Cobalt, 15 kilotonnes of Nickel, 61 kilotonnes of Copper, and 40 kilotonnes of Aluminium. Currently, only copper and aluminum are available in India. Cobalt, Nickel, Lithium, and other metals are import dependent. Therefore, if there is another way to provide these metals, the local demand will exist.

2. The predicted demand for these metals worldwide:

The predicted global demand for Electric Vehicles at least 50 million EVs by 2030, according to a majority of predictions. Therefore, the demand for Lithium, as predicted by Mckinsey & Co., will increase from 214 kilotonnes LCE to 669 kilotonnes LCE (889 kilotonnes LCE in an aggressive demand scenario) by 2025, and the demand for cobalt will increase from 136 kilotonnes to 222 kilotonnes by 2025 (272 kilotonnes in an aggressive demand scenario) [4]. This suggests that the requirement for lithium, cobalt, and the other metals required in the manufacturing of lithium ion batteries, is bound to increase tremendously, straining the source supply for these metals. This unbalanced demand also indicates a heavy increase in the price for the metals by 2025.

3. Current domination of the upstream LIB supply chain by China:

   China currently dominates the complete value chain for Lithium Ion Batteries. Since its adoption of electric vehicles in the early 2000s, China has managed to shift control of not only the production—and consumption—of electric vehicles but also the upstream and downstream supply chain of lithium ion battery manufacturing. According to BloombergNEF, around three-quarters of global battery cell manufacturing capacity is in China, and Chinese companies have unparalleled control of required domestic and foreign battery raw materials and processing facilities [5]. China's control on the supply chain has led to the growth of research, expertise, and patented technology. The significance of China's dominance is that most countries will be largely dependent on Chinese production.

   A further concern is the refining of the raw metals for use in lithium battery manufacturing. Lithium ion batteries require high purity metals, with almost no impurities. Since the mined metals are not sufficiently pure to be directly used in lithium ion batteries, further chemical refining is required. This process produces various polluting effluents and requires high volumes of water. Since Chinese companies entered the market for mining and refining at an early stage, they have conquered the metal refining industry. Furthermore, to prevent international competitors from competing at similar prices, China relaxed environmental laws and allowed internal mass production. For example, between 50-60% of the global refining capacity of Cobalt is concentrated in China. Hence, penetrating the cobalt refining market may be particularly difficult [4].

   Considering the lack of an established upstream supply chain and the lack of abundant raw metal resources, manufacturers of lithium ion batteries in India will be resigned to importing these refined raw metals, raising the base cost of raw materials through transport and taxes. Furthermore, since the ratios and costs of the materials vary on use and availability of the lithium ion battery technology, the effect of the cost of raw material can contribute up to 66% of the cost of manufacturing Lithium ion batteries [3]. Therefore, recycling is an effective step in the direction of indigenous metal sourcing and of reducing incumbent import costs.

1.2 The Supply Side

While the demand for lithium ion battery recycling is well-known, the supply of these recyclable materials is less straightforward. Highlighted below are a few different sources from which recyclable batteries and recyclable battery material can be attained. These sources are: the formal market for spent batteries, the informal market for spent batteries, and the LIB cell manufacturing segment of the LIB industry for battery production waste.

1.2.1 The Spent Battery Markets. The spent battery market refers to the consumers who discard their end-of-life batteries. The consumer and the form of disposal affects the type of market the batteries end up in. At the commercial level, the batteries are either sold to recyclers, stored, or disposed in landfills. This flow is generally a part of the formal market. At the individual level, the batteries are mostly disposed in the trash, normally leading to the informal market. Further information on these markets is presented below.

1. The formal market

At the commercial level, consumers such as electronic distributors, OEMs, and bulk consumers, require multiple battery packs for their products, machinery, tools, vehicles, and energy storage applications. When the batteries reach end-of-life, the consumers will try and salvage value by selling the battery packs to approved and regulated recyclers, or by finding a secondary use for the battery packs (for example, batteries that are used in electric vehicles are considered 'spent' when the battery depth of discharge has fallen below 80%, but the battery may yet be used in other energy storage applications such as household energy storage). The battery consumers in the formal market also have a legal responsibility to safely discard their batteries. As stated by the Extended Producer Responsibility (EPR) mandate and the E-waste rules of 2016, manufacturers and importers, who procure batteries for use in their work, have a legal obligation to the collect (through a take back system), ensure proper handling, and recycle the batteries that reach their end-of-life. If the batteries are not recycled internally, the companies have to assure that the batteries are sold only to registered (formal) recyclers. This is the first mechanism through which a supply of spent lithium ion batteries can be confirmed.

An example of recycling through the formal market is the collaboration between MG motors and Umicore. MG Motor India Pvt Ltd - one of the new entrants in the Indian automobile market - announced its partnership with Umicore, a lithium battery recycling solutions provider, for effective life cycle management of the lithium-ion batteries to be used in MG Motors' e-ZS electric vehicle [6].

2 The informal market

At the household level, batteries are consumed at a small scale per household. Since a single cell of lithium ion battery is not valued significantly (and since people are unaware of the toxicity of spent batteries), individuals tend to discard the spent batteries in regular household trash. These batteries eventually end up in the informal battery waste stream. Diagram 1 below shows the waste stream that the battery waste follows.

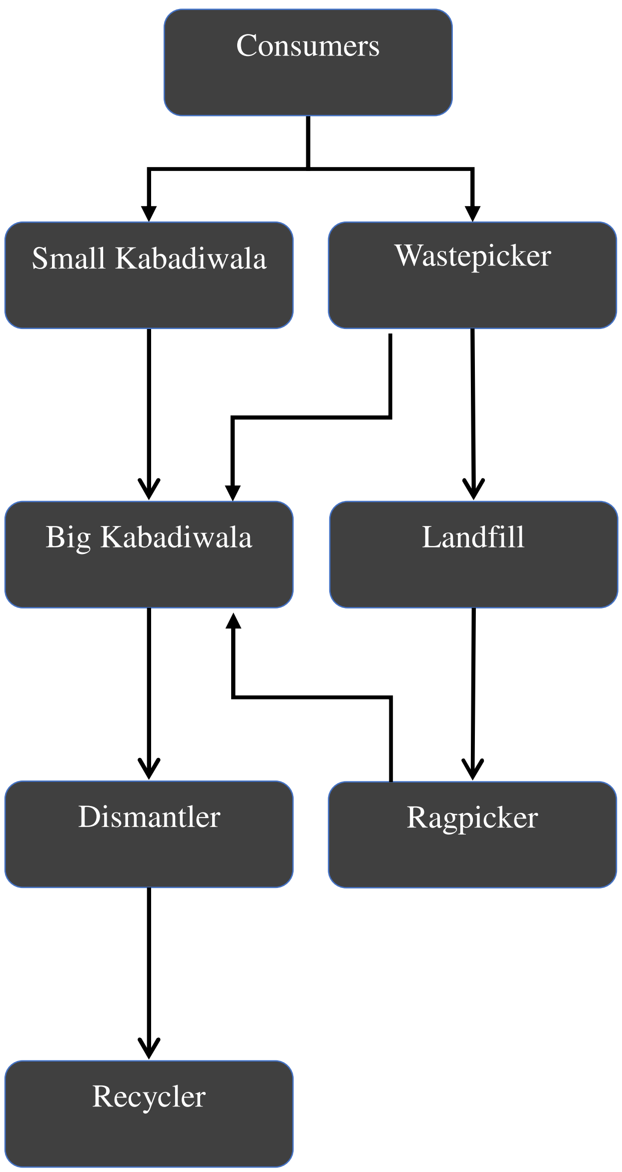

Fig. 1. Waste flow for Battery Waste in Delhi. Source: Toxicslink

As displayed in figure 1, when a household removes trash, wastepickers go through the trash and segregate the items according to economic value. In the case of batteries, a wastepicker will either collect the batteries and sell them to Kabadiwalas (scrap dealers) or discard the batteries in a landfill. The scrap dealer will then sell a bulk of batteries to an informal dismantler, who will dismantle the batteries mechanically using unsafe protocols, and sell the individual components to various recyclers. These recyclers will smelt the components, without protection, and resell the recycled product to appropriate users who will further refine the products for their utility. This is the basic operational flow of the informal market for battery products. If these kabadiwalas or dismantlers can be contacted, a second mechanism through which a supply of spent lithium ion batteries can be developed.

1.2.2 The LIB cell manufacturing segment. In the manufacturing world, there is an expected loss in the manufacturing productivity at any facility. Amongst other factors, This loss in yield occurs from losses in equipment setup and failure, reduced performance, and process defects. In the case of LIB cell manufacturing, a yield loss through production is expected to be at least 10% of the total input. This production waste can be repurposed through recycling [2]. Using the numbers suggested by CSTEP [3], the production waste from a 50 GWh plant at 10% loss would equate to 1.3 kilotonnes of Lithium Carbonate Equivalent (LCE), 3.8 kilotonnes of Cobalt, 1.5 kilotonnes of Nickel, 6.1 kilotonnes of Copper, and 4 kilotonnes of Aluminium. This production waste can be regarded as the third mechanism through which a supply of spent lithium ion batteries can be ascertained.

An example of this battery production waste being utilised would be Tesla’s Gigafactory and its inefficiency currently and during the scale up of operations. During its scale up, Tesla’s (Panasonic) Gigafactory scrapped around half a million cells per day—a large loss in material for its operational capacity of 23 GWh. They tied up with third party recyclers for the recycling of the scrapped cells. Those recyclers were recycling at least 60% of the rejected cells.

1.2.3 Limiting factors for the supply of spent batteries and battery waste. Each mechanism for battery and battery waste collection has several limitations in the form of accessibility and availability.

Formal market supply limitations:

The key concern in the formal market is that of availability. The current state of recycling material available through the formal market is abysmal. Most corporate entities who use the batteries for products that will further be sold to an individual consumer do not spend resources on creating collection mechanisms for the batteries, hence reducing the number of batteries in the formal market. While these companies have been approved by the Central Pollution Control Board as members of the EPR mandate, very few companies actually follow the rules and regulations. For example, of fifty multinational companies compared in a study, many of who are appreciated for their recycling practices internationally, twenty six reported to have collection centers in Delhi, but less than ten had operational collection centers [7].

Informal market supply limitations:

Informal markets have their own set of problems in terms of accessibility. Firstly, because of the nature of informal markets, access to the scrap dealers is limited. The dealers avoid paying taxes and do not want to attract the attention of the regulatory system. Furthermore, they do not want their businesses to be disrupted by known or unknown entities. Secondly, consistent supply of spent battery waste is questionable since the supply is based on unpredictable trash disposal. Thirdly, members of the informal market constantly change occupation, and hence can abruptly disappear. And finally, there is a complete lack of transparency in the process, due to improper handling practices, leading to unpredictable costs and safety hazards.

Another problem for the informal market supply is the transportation of batteries. Ideally, spent batteries must be carefully discharged and handled at the source of collection to avoid risks such as electrolyte leaks and fires. If each source has only a few batteries, a lot of resources may have to be spent in the collection process, making this mechanism uneconomic.

LIB Cell manufacturing production waste supply limitations:

While this mechanism for supply would likely be the most consistent and reliable source of battery waste for recycling, there is uncertainty surrounding the collection and setup of manufacturing facilities in India. As of 2020, a lot of announcements have been made for setting up lithium ion battery manufacturing facilities, but no investments have been confirmed. Furthermore, even if the manufacturing facilities are confirmed to be built, the timeline of their production and scale up is unknown, implying that the recycling aspect will be considered much later.

2. LIB RECYCLING TECHNOLOGY

The most important factor to assess the economic viability of lithium ion battery recycling is the available technologies in LIB recycling.

For the safe recycling of lithium ion batteries, a process chain combining several independent unit operations is needed for the recovery of valuable materials and for circumventing safety issues from electrical dangers, chemical hazards, burning risks, water sensitivity of lithium hexafluorophosphate (possible electrolyte), and other potential reactions. Recycling processes include the discharging of battery packs, disassembly of the batteries, mechanically processing, hydrometallurgical processing and pyro metallurgical processing [8].

The process flow diagram below highlights the current recycling methods and how they add the recycled materials back into the process flow.

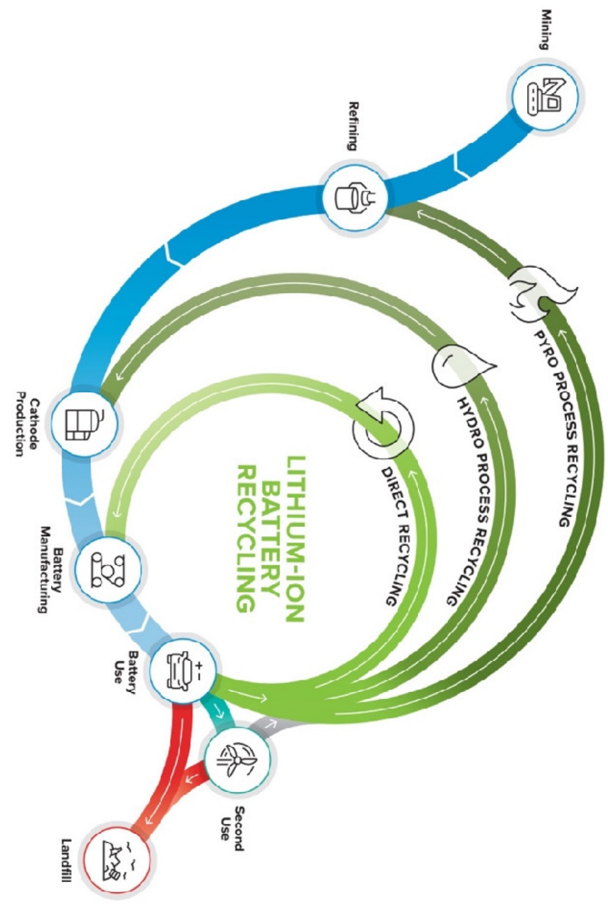

Fig. 2. Recycling potentials. Source: Argonne National Laboratories

Figure 2 shows the process flow of metals in the lithium ion battery value chain and how different recycling methods can help form a closed loop system. The blue arrows indicate the traditional method of manufacturing. This blue section of the process flow is explained below:

1. Mining: Metals such as lithium, cobalt, manganese, aluminium, etc. are mined for use in LIBs. This mechanical process extracts metals in their natural state. These metals contain many impurities and hence require further refining.

2. Refining: In the LIB industry, the metals must be at a purity greater than 99%. The metals have to be refined using chemical processes to remove these impurities. This process can be highly polluting, and is the primary

reason as to why LIBs are not considered a 'clean' technology.

3. Cathode production: The refined metal compounds must be combined to form powders suitable for use in LIBs. Since the performance requirements are dependent on the end application, different metal compounds are required. These compounds are usually applied on the cathode component of the battery cell.

4. Battery manufacturing and battery use: The cathode, which contains many of the mined metals, is combined with other components to make battery cells. These cells are installed in packs and are further used in various applications.

5. Second use and landfill: When the battery is no longer useful in a particular application, it is either used in another application where it could be useful or discarded (the red arrow) in a landfill. The landfill option is potentially dangerous to humans and the environment. If lithium batteries are crushed and exposed in landfills, while still in a charged state, they could ignite a fire. Landfill fires can continue for years under the surface.

The best option to avoid these risks and to recover the metals would be to introduce recycling in the process flow. This would allow the reuse of the battery metals, closing the process loop (indicated by the blue lines).

The green lines in Figure 2 show the different recycling methods that can be applied in the lithium ion battery process flow.

A. Pyro process recycling:

Pyro processing refers to the exposure of waste to thermal activity in order to recover some of the metal content. This process is used for the effective extraction of metals such as cobalt, nickel, copper, and iron from spent batteries. The recovered metals can have major impurities, which will have to be removed in order to use the metals in the LIB value chain. Furthermore, the pyro process does not require any pre-treatment for the batteries.

The disadvantages of pure pyro recycling are:

- The loss of graphite, electrolyte, aluminium, and lithium. The high temperature in the pyro process burns the organic solvents in the electrolyte and carbon (graphite) compounds in the anode. The process also creates an unrecyclable slag that contains the ignoble metals lithium and aluminium [9].
- The creation of toxic fumes such as hydrogen fluoride and the release of carbon dioxide in the environment.
- The high capital required for the equipment manufacturing and the high operating cost required to maintain the high temperature in the furnace.

B. Hydro process recycling:

Hydro process recycling refers to the usage of aqueous processes in order to recover metals. This process tends to recover most of the metals at high purity. Metals such as nickel, manganese, cobalt, iron, lithium, aluminium, and copper can be extracted using this method. The metals, when recovered, will have low impurities and may not require further refining for use in LIBs. Therefore, some (or all) of the metals can potentially be inserted in to the cathode manufacturing phase.

The disadvantages of hydro process recycling are:

- The process for recycling is rather complicated. Firstly, the metals have to be discharged, and dismantled to the bare components. Many of the components, such as the electrolyte and the separator must be recycled separately. This process can be dangerous if not done correctly. Thereafter, the components require further leaching, separation, and purification.
- The leaching process requires high volumes of strong acids and reducing agents. This can be uneconomic in certain cases.
- The hydro processing, from a industrial standpoint, may have further restrictions on incoming material in shape and composition. An incorrect mixture of different battery chemistries can heavily impact the recovery rates.
- The leachate usually contains many ionic impurities, which increases the burden of subsequent separation and purification [10].

C. Direct Recycling:

Direct recycling refers to the physical separation of components, with some components that can be directly used in new battery production (for example, the current collectors on the electrodes) and the other components separated for further treatment and recovery. In the separation, A black mass containing the cathode and anode powders (containing lithium, cobalt, nickel, manganese, carbon (graphite) is collected for further treatment. Physical processes like gravity separation and magnetic separation are applied in this process.

The disadvantages of direct recycling are:

- The mechanical methods cannot completely separate the components of spent LIBs from each other. This means that only the separated components can be directly reused in the manufacturing of new batteries. Furthermore, the improper separation of the other components could complicate the further treatment process.

- The decomposition of the electrolyte and separator (LiPF6, DEC, and PC) during mechanical processes poses a threat to the environment [10].
- The mechanical separation can be used to improve other processing mechanisms such as hydro or pyro processing, but may not be economically feasible as a stand-alone technology.

As described, each mechanism poses a unique set of advantages and disadvantages. To increase the efficiency of metal recovery and better recycling, research companies and researchers combine the aforementioned methods or try to improve individual mechanisms.

2.1 The Competitive Landscape

Until a few years ago, pyrometallurgy was the dominant technology for lithium ion battery recycling because of the lack of technological advancements in the recycling space coupled with the lack of awareness of the economic value of lithium batteries and relatively low requirements for safe recycling. Furthermore, the economics of recycling were costly since pyrometallurgical methods led to impure metals, which had less value realisation. Hence, there were only a limited number of recycling entities. Since then, the surging demand for LIBs has led to the attention of material availability and the recovery of materials through the spent lithium ion battery space. Realising this potential, companies have started to develop profitable technologies that combine both mechanical treatment—for the separation of plastics and electrolyte for reuse—and chemical treatment—for the recovery of valuable metals—in order to maximise returns on the metals and minimise costs.

For example, Umicore is one of the largest recyclers of spent batteries and it uses a combination of pyrometallurgy and hydrometallurgy. In its process, spent LIBs are smelted without pretreatment in a furnace. The plastics, organic solvents, and graphite in the batteries are burned to provide heat during combustion, while the metal components are converted to alloys [11]. The alloys are then leached to obtain cobalt oxides and nickel hydroxide. Ignoble metals such as aluminium and lithium are slagged and are thence sold to other industries. Any toxic fumes that are released are scrubbed for safe release into the air. While Umicore's process leads to the loss of reusable lithium and aluminium in the lithium battery space, it profits from the high quality cobalt and nickel recovered. Additionally, Umicore is also a manufacturer of cathode powders, and thus reinjects the recovered material into its cathode manufacturing business, reducing the reliance on its external upstream supply chain.

Duesenfeld in Germany uses mechanical, pyrometallurgical, and hydrometallurgical mechanisms. Duesenfeld discharges the batteries, crushes them in an inert atmosphere, evaporates and re-condenses the organic solvents of the electrolyte and separates the electrode coating material from the rest. The metals are then leached from the former active materials. The graphite is filtered and regained, after which lithium-carbonate, nickel-sulfate, cobalt-sulfate and manganese-sulfate are produced [12].

The Indian competitive landscape for lithium battery recycling has also grown in the last few years. Giant OEMs (Original Equipment Manufacturers) such as Raasi Solar and Mahindra Electric have announced their active interest in this space, while other companies such as Tata Chemicals have already set up recycling facilities. Umicore has also partnered with MG motors for effective life cycle management of the lithium-ion batteries to be used in the e-ZS electric vehicle [6]. Smaller companies, such as Lohum and Fortum, are also operating in the Indian market for the recycling of lithium ion batteries. However, the mechanism, efficiency, and purity of the recycled materials from most of these companies are unknown.

2.2 The Role of Government Legislation in Recycling

Since formal recycling is an industry that is not considered progressive, there is a lack of attention towards recycling in India. Hence, the government plays an important role in both legislation and enforcement.

Used Batteries in India are identified as hazardous waste and legislation for batteries is considered in both E-Waste Management Rules and Solid Waste Management Rules. Until 2020, there was barely any progress in legislation that supports the formal collection and recycling of batteries. Below is an outline of what the current legislation entails, and the current status of battery recycling.

E-waste Rules, 2011: In 2011, the Ministry of Environment, Forest and Climate Change introduced E-waste rules focused on the collection, processing, and ensuring of proper recycling of E-waste in India. The driving mechanism of these rules was Extended Producer Responsibility (EPR), which held the producers of electronic products responsible for the management of their products at the 'end-of-life'. This included installing take-back/buy back systems, spreading awareness, collecting 'used' products, and ensuring proper recycling of the E-waste. The agencies responsible for the implementation of the program were State Pollution Control Boards (SPCB).

According to a report from Toxics Link [7], the evaluation of producers that were to implement the rules was appalling. Most producers barely took any action in the direction of collecting or recycling their products. Furthermore, the SPCBs were unprepared and lethargic in monitoring the producers. From 2011 to 2016, the state of EPR compliance continued to remain poor. The reasons for poor compliance were ambiguity in the terms of EPR, the lack of incentive from producers to collect, the lack of monitoring by the SPCBs, and lack of repercussions for producers who failed to comply. Further, the ambiguity in the terms allowed producers to bend the rules by claiming their compliance through paperwork but not complying in reality.

E-Waste Management Rules, 2016: The identification of E-waste Rules 2011 as incomplete and vague led to an updated version in 2016. This version was written to amend the previous rules by ways of stringency and explicit compliance terms. These Rules required that all producers must have authorisation by the Central Pollution Control Board (CPCB) in order to import electric and electronic components for their production/manufacturing. Furthermore, all handlers of electronics—including collection centres, dealers, refurbishers, bulk consumers, dismantlers, and recyclers—must be authorised and each handler must comply with the responsibilities to safely manage and recycle E-waste. The Rules also introduced Producer Responsibility Organisations (PRO), who could be hired by producers and manufacturers to handle all EPR-related obligations.

Lastly, the 2016 Rules also specified recycling targets for producers. In the first two years, producers must collect (and assure recycling) 20 percent of the waste generated by their sales. For the five following years, the collection must be increased by 10% year on year. Hence, by year 7, 70% of the waste generated must be collected and recycled.

Toxics Link reported that, of the 54 largest producers considered in its report, 5 had a ‘poor’ rating, 29 had a ‘below average’ rating, 13 had an ‘average’ rating, and only 7 had a ‘good’ rating. The findings suggested that the Producers might be doing the absolute bare-minimum so that they are not in violation with the Rules. Additionally, a large majority of companies have take-back systems on paper but their collection centers are either not functional or have no clear information available. As a result, less than 20 producers had takeback mechanisms in all States of India. The E-waste collection centres also appear to be terribly managed, with most centres non-functional. The report showed only 7 of 26 collection centers in Delhi were found operational and were accepting waste. Lastly, the 178 registered recyclers authorised by SPCBs to process E-waste are not recycling the waste. While some are storing it in hazardous conditions, others don’t even have the capacity to handle such waste, as per by the report of Union Environment ministry [13].

Solid Waste Management Rules (SWM), 2016: Small batteries are not regulated separately in India but are mentioned in the Solid Waste Management Rules (SWM), 2016. The Rules define ‘used batteries’ as ‘domestic hazardous waste’, along with paint and pesticide containers, CFL lights, expired medicines, broken mercury thermometers and used bio-medical waste generated at the household level. In the mandate, all domestic hazardous waste must be segregated at the source. But the SWM Rules does not specify separate segregation or collection for batteries. All ‘hazardous waste’ is directed for aggregation. EPR is also introduced in the SWM Rules, but EPR is defined as the responsibility for producers of packaging products such as plastic, tin, glass and corrugated boxes, and sanitary napkins. The responsibilities do not include batteries. There is no mandate in the EPR conditions for small battery producers or for the recycling of battery materials through formal networks.

Battery Waste Management Rules (BWM), 2020: In late 2019, the government recognised the need for battery waste management as a separate entity in waste management. It also recognized the need for EPR to specifically address batteries. In March 2020, the government released the Draft Rules for Battery Waste Management. As per the draft rules, manufacturers and producers will have to record and collect used batteries and register new imported batteries that are sold to consumers. The used batteries would also have to be similar to the type and specification of new batteries that are sold. The other responsibilities for manufacturers, producers, distributors, importers, bulk consumers, waste battery collectors, and recyclers are similar to the responsibilities for the entities in the E-Waste Management Rules of 2016. The mandate also requires the batteries to be labelled with a “crossed out wheeled bin symbol” and have Lead, Cadmium, and Mercury symbols printed if the battery contains those three metals. This labeling will help in segregation at source and segregation at collection centres.

Hence, if these Rules are confirmed, batteries will rightfully be acknowledged as their own waste sector and the various stakeholders will have to pay specific attention to batteries. However, the potential problems in the implementation of these Rules are the same as the other aforementioned rulings:

1. The incentive to follow the rules are not explicitly mentioned. To the same extent, the penalty for breaking the rules are also not explicitly stated.

2. The lack of proper monitoring by CPCB and SPCBs will result in minimal physical compliance.

3. Monitoring standards must be quantified and examined in deep detail to accurately represent the level of obligation by the relevant stakeholder.

4. The lack of labeling of lithium ion batteries would lead to problematic segregation from batteries that do not contain lead, cadmium, and mercury.

5. Collection mechanisms remains a major challenge regardless of responsibility delegation. For example, LIBs are present in all electronics, small and large, including mobile phones, laptops, headphones, stationary storage, etc. This means that the batteries are bought and spread all over the country. For batteries to be accessed and collected from rural areas will likely be extremely difficult.

6. Finally, corrupt practices in monitoring and lack of transparency in the compliance can play a strong role in the authorisation, assessment, and enforcement of the Battery Rules.

With no existing infrastructure for the disposal of batteries, and a currently weak legal framework for battery recycling, India has an extremely limited number of mechanisms for the collection and safe recycling of batteries. Other factors such as market size estimation, informal market involvement, technology infusion, and regulatory framework strengthening must also be considered.

3. CONCLUSIONS AND RECOMMENDATIONS

India is becoming a large consumer and potentially a large producer of LIBs. Therefore, the existence of the recycling sector in the LIB value chain is inevitable. The success of recycling will depend on the access to recyclable batteries as well as access to recycling technology. The involvement of government in the enforcement of battery collection mechanisms and in the integration of the informal recycling sector will play an essential role in addressing the access to material. The efficacies of the recycling technologies employed in India will determine the use of the recycled products and the value obtained by recycling. The timeline for recycling in India to be economically feasible across the industry is approximately 6-7 years away (2026-2027), as the recent ‘first’ lot of EV batteries reach their end of life and cell manufacturing facilities start to function and generate recyclable battery waste. The expected competition in this industry is likely to be dominated by local and foreign industry giants such as Tata, Mahindra, and Umicore (through MG motors) who will have access to spent batteries from their own EVs and manufacturing facilities.

Currently, there are a few challenges for industry entrants to address:

1. High cost of recycling: As per industry sources, the cost of recycling a lithium- ion battery in India is only INR 90-100/kg. However, a recycling facility requires high investments in technology for collection, transportation and management of resources, making the profit margins low. Furthermore, it takes at least 5 years to recover costs and break even [2].

2. Future value of recovered metals: Since recycling of LIBs tends to be financially capital intensive, the future economics for the recovered metals must be considered. Currently, the expensive raw metals are cobalt, lithium, and nickel. Hence, the economic feasibility of recycling will also be based on the selling price of these metals in the next 10 years. While EV batteries today consist of a considerable amount of cobalt, many companies are pushing to reduce the use of cobalt in their battery chemistries. The success of their effort in removing this metal can cause a drop in the profitability of recycling.

3. Lack of government incentives: Currently, no incentives have been announced for recycling in India. Companies looking to enter this industry may struggle without support.

4. The large gap between the formal and informal market: The informal market has deeper access to spent batteries from electronics than the formal market has. The lack of connection between the formal and informal markets coupled with the instability of consistent supply from the informal market can deter potential entrants.

5. Lack of awareness: This is another critical challenge among the battery producers as well as end consumers. While the recyclers continue to struggle even in B2B segment, B2C remains a distant reality at least for next few years [2].

6. Safety concerns: 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 [2].

Below are a few recommendations that will help stimulate the growth of this nascent industry.

1. Spreading awareness on Lithium Battery disposal through events and online forums: Although batteries are considered a hazardous waste as per the waste management rules of 2016, they are disposed in regular trash. Furthermore, the awareness level varies drastically depending on the economic status of the household. Efforts must be made to spread awareness of the toxicity of batteries at both the individual and commercial level. This can be done through advertisements, OEM and distributor’s awareness campaign, and government-led initiatives. Each of these initiatives should have a focused approach to inform individuals of the different aspects of e-waste and batteries. The focal points of awareness could be based on potential hazards, the available collection options, the recycling process, etc. Some examples are Ministry of Electronics and

Information Technology's (MEitY) E-waste awareness program for the education of disposal in the unorganised sector,

2. Explicit and transparent governmental governance for overlooking battery management: In the upcoming battery management rules, the Central Pollution Control Board (CPB) must explicitly state the responsibilities of corporates and the repercussions of the inability of these corporates to achieve stated responsibilities. Furthermore, the assessment of the state of recycling (as stated by EPR) of these entities must be quantitatively measured for objective results.

3. Effective government intervention in compliance failure: The repercussions for companies failing to comply with the terms of EPR must be severe enough to incentivise companies to actively follow the official mandate.

4. Incentivising companies in the recycling space: Incentives such as subsidies or tax holidays will encourage the set-up of battery recycling facilities. Categorical inclusion of LIB recycling in the Make in India movement, Faster Adoption and Manufacturing of Electric Vehicles (FAME II), and National Electric Mobility Mission Plan (NEMMP) would assure the recyclers of the accessibility of these incentives. Inclusion would also reduce the need for additional incentive frameworks.

   Further, establishment of start-ups connected with e-waste recycling and disposal could be encouraged by providing special concessions [14].

5. Encouragement of Research and Development (R&D) in recycling technology: Since most recycling technologies that focus on high throughput and high purity recycling are still at the development stage globally, the central government, private sector, universities, and national laboratories can make a collaborative—or individual—effort towards developing and implementing recycling technologies in India. Since the market is likely to experience fast growth in the mid 2020s, the efforts applied in the near future can be realised at an appropriate time. An example of such work is the ReCell center in America. Supported by the U.S. Department of Energy, the ReCell center has a primary goal of expediting the pursuit of profitable lithium ion battery recycling. The key factors being considered are safety of recycling, cost-effective techniques for recycling of cathode and other components, modeling and analysis tools for effective development, and creation of a national supply of recyclable battery materials. The ReCell Center has also been provided a research grant of USD 15 million over three years and its work will include development of test beds and a process scaleup facility at Argonne National Laboratories [15] , located in the state of Illinois.

6. Labeling of lithium ion batteries: According to the draft Battery Waste Management Rules of 2020, batteries containing lead, cadmium, and mercury must have labels with the appropriate symbols printed on the battery. However, the labeling of lithium ion batteries would drastically aid the segregation of LIBs from other battery types.

REFERENCES

[1] NITI Aayog, "*Zero Emissions Vehicles (ZEV): Toward a Policy Framework*" 2018.

[2] CSTEP, "*Indigenisation of Lithium Ion Battery Manufacturing: A Techno-Economic Feasibility Study*," 2018.

[3] JMK Research, "*Lithium battery recycling presents a $1000 million dollar opportunity*," 2019.

[4] Mckinset and Company, "*Lithium and Cobalt—a tale of two commodities*," 2018.

[5] The Print, "*Lithium shortage – the big hurdle on India's road to becoming global electric vehicles hub*," 2020.

[6] Live Mint, "*MG Motor collaborates with Umicore for recycling of used lithium-ion batteries*," 2019.

[7] Toxics Link, "*Time to Reboot III; E-waste Rules: Assessing EPR Compliance*," 2019.

[8] Toxics Link, "*Dead and Buried*," 2019.

[9] Fortum, "*Lithium battery recycling webinar IESA*," 2019.

[10] X. Zheng, Z. Zhu, X. Lin, Y. Zhang, H. Cao, Z. Sun and Y. He, "*A Mini-Review on Metal Recycling from Spent Lithium Ion Batteries*," 2018.

[11] B. Pandey, P. Meshram and T. Mankhand, "*Extraction of lithium from primary and secondary sources by pre-treatment, leaching and separation: a comprehensive review*," 2014.

[12] Battery University, "*BU-705, How to recycle batteries*," [Online]. Available: https://batteryuniversity.com/learn/article/recycling_batteries. [Accessed 30 May 2020].

[13] Down to Earth, "*Recycling of E-waste in India and its potential*," April 2019.

[14] Teri The Energy and Resource Institute, "*E-Waste Management in India: Challenges and Opportunities*," November 2019.

[15] Argonne National Laboratories "*DOE launches its first lithium-ion battery recycling R&D center: ReCell*," 2019. [Online]. Available: https://www.anl.gov/article/doe-launches-its-first-lithiumion-battery-recycling-rd-center-recell.