The Future of Lithium-Ion Battery Recycling: A Review of Cutting-Edge Technologies

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Abstract:- The rapid increase in Electric Vehicles as well as portable electronic device (Mobile and laptop) sales blazed an explicit discussion regarding the availability of critical metals. The impending threat to the environment and public health posed by the end of life of these lithium ion batteries (LIBs), which contain heavy metals and other harmful compounds, calls for a suitable strategy. Generally, spent LIBs are composed of 2-25 wt. % Co, 5-10 wt. % Ni, 3-5 wt. % Li, 10-15 wt. % Mn, along with aluminum, copper, Iron and plastics. These end-of-life LIBs have the option of being recycled, which can ultimately lower the cost of producing new LIBs which benefits the economic, preventing the environmental pollution from harmful components, conserving and preserving natural resources. The four primary methods of recycling lithium ion batteries (LIBs) include mechanical treatment, pyrometallurgy, hydrometallurgy and bio treatment, among which hydrometallurgy dominates all the approaches being optimal, environmental friendly and recover high purity metals with low energy consumption as compare to pyrometallurgy process due to loss of Li, Al and Mn in slag. Hydrometallurgical processes involve various acids like organic and inorganic as leaching agents. However, with organic acids, there has been evidences of selective recovery of metals which can be extracted under reducing environment; however separation turns out to be tedious task. We aim to present the current demand and supply of these critical metals and develop a closed loop recycling technology to extract these metals from end-of-life LIBs and also focuses on their economic and environmental impact, in vogue.

Keywords:- *Critical Metals; End-of-Life LIBs; Hydrometallurgy; Recycling; Solvent Extraction.*

I. INTRODUCTION

The digital revolution and advancements in electronic devices (Mobile & Laptop) and electric vehicles (EVs) have driven rising demand for lithium ion batteries (LIBs) over past 8-10 years. The interest towards LIBs has surged due to the necessity of sturdy energy storage systems (ESS) in order to facilitate the shift to sustainable energy sources. The desire for EVs has grown due to a number of other causes, including more performance, comparatively low maintenance costs, and fluctuating oil prices [1]. The main factors attracting attention to LIB are its long life cycle, high energy density under tolerant working circumstances, and relatively low self-discharge rates. Due to this, the demand for lithium ion batteries growing exponentially and this becomes a prerequisite for many different industries [2]. Markets of EVs are predicted to reach 21 million by 2030, up from approximately 2 million in 2019. By 2040, it is anticipated that this demand would have increased to 60 million EVs. By 2030, it is anticipated that the global market for LIBs recycling would reach $23.72 billion [3, 4].

Since Sony initially introduced LIBs to the market in the early 1990s, researchers have made numerous modifications to the cathode-active materials in an effort to lower costs while improving other performance characteristics including recharge time, lifetime, and charging capacity [5]. Nevertheless, there are notable quantities of rich metal deposits in them, such as Li (2–3%), Ni (3–8%), Co (15–25%), Mn (7–12%), Al (15%), and Cu (10%). [4]. Numerous new Li-ion battery types, including lithium iron phosphate (LFP), lithium nickel manganese cobalt oxide (NMC), lithium nitrate oxide (LNO), lithium manganese oxide (LMO), lithium cobalt oxide (LCO), and lithium nickel cobalt aluminum (NCA), have recently been the subject of intensive research in order to meet the steadily increasing demand for battery-powered devices [6]. With the growing population the demand of products also growing which in turn produces more wastes. Waste is produced at different stages of recycling including manufacturing stage, during its usage and lastly when it reaches to the end of its life.

The impending threat to the environment and public health posed by the end of life of these lithium ion batteries, which contain heavy metals and other harmful compounds, calls for a suitable strategy. Negligent handling of spent batteries can result in a significant volume of environmental trash that is challenging to manage [7]. Thus, in order to protect the environment and optimize its economic worth, LIBs must be managed and recycled carefully. To create next-generation rechargeable LIBs, several researchers are looking into recovering important metals (including Li, Co, Mn, and Ni) from spent LIBs and recycling them. Four distinct processes have been used to recover important cathode-active components from discharged lithium-ion batteries. These are hydrometallurgy; pyrometallurgy; mechanical processing, and direct physical recycling. Hydrometallurgical procedures must be employed either alone or in conjunction with other techniques such as the pyrometallurgical process, in order to recover high-value components. But since Li gets into the slag here, it can't be recycled. Furthermore, a lot of fumes, including CO, HF, and volatile organic compounds which are all harmful to the environment will be released throughout the various recycling steps [8]. On the other side, acid leaching is a crucial method for obtaining valuable metals without these disadvantages. It has also been possible to separate current collectors and active materials using binder dissolving solvents like N-methyl pyrrolidone (NMP), despite the fact that it is expensive and risky. Other solvents, such as dimethyl isosorbide (DMI), have been researched more recently, because they are less dangerous for the environment [3]. With the sporadic support of a reductant (such as H_2O_2), it dissolves metals and changes their oxidation state to one that is more soluble [9]. Solvent extraction, precipitation, or electrochemical methods can more easily separate the metals [10]. With lithium and cobalt recoveries surpassing 99%, various leaching agents, including H_2SO_4, HCl, and HNO_3, have been studied.

These end-of-life LIBs have the option of being recycled, which can ultimately lower the cost of producing new LIBs which benefits the economic, preventing the environmental pollution from harmful components, conserving and preserving natural resources. Materials are recovered, repurposed, or reused locally rather than ending up in a landfill in a circular economy. Hence the recycling of these end-of-life LIBs has garnered a lot of attention from the last few years.

II. REVIEW OF LITRETURE

- *Lithium Ion Batteries (LIBs)*

When a rechargeable LIB is being charged, lithium ions are transferred from the negative electrode to the positive electrode, and vice versa. During discharge, lithium ions (Li^+) move current from the negative electrode to the positive electrode through the non-aqueous electrolyte and separator diaphragm. Lithium batteries use lithium metal or lithium compounds as the anode [11, 12].

- *Uses of LIBs*

Most of the electronic devices, including laptop computers, cell phones, cameras, cordless power tools, hand-held electronics, and communication equipment, use lithium ion batteries. In addition LIBs used in solar batteries and other alternative energy production systems. They are also used in the batteries of electric and hybrid vehicles [1].

- *Structure & Components of LIBs:*

The LIB cell is made up of many facets that are encased in a metallic casing or shell. There are five primary parts to these layers, and each one is reusable and potentially useful again. The following figure 1 [2] illustrates the components of lithium ion batteries (LIBs), which include the cathodic component, anodic component, electrolyte, separator, and two (anodic & cathodic) current collectors.

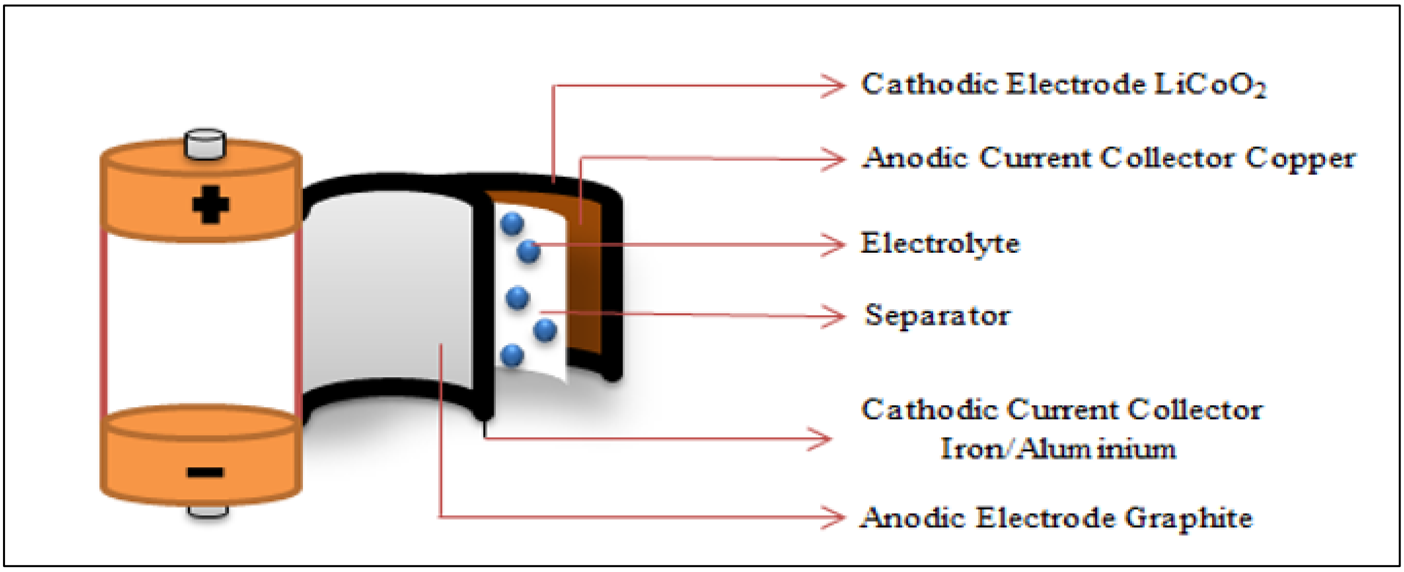


Fig 1 Various Components of Lithium Ion Batteries (LIBs).

The most widely used anodic material is graphite, whereas nickel-cobalt-aluminium (NCA), $LiCoO_2$ (LCO), $LiMn_2O_4$ (LMO), and $LiFePO_4$ (LFP) are possible cathode materials [13]. In the cathode, there is also an organic binder, like poly-vinylidene fluoride (PVDF). In order to create electrolytes that function as conductive channels for Li ions to flow through, lithium salts such as $LiPF_6$, $LiBF_4$, and $LiClO_4$ are combined with organic solvents such as ethylene carbonate (EC), propylene carbonate (PC), and dimethyl carbonate (DMC) [14]. To avoid physical contact, a separator-made of layers of non-woven fabric mats or polymeric membrane is positioned between the cathode and the anode [15]. Additionally, bridging elements called current collectors collect the electricity generated at the electrodes. Commercial current collectors are comprised of copper foil for anodes and aluminum foil for cathodes [16]. As can be seen from figure 2, the casing, cathode, and anode each contribute significantly-by 30.2%, 25.5%, and 14.5%, respectively to the weight of the LIB [2].

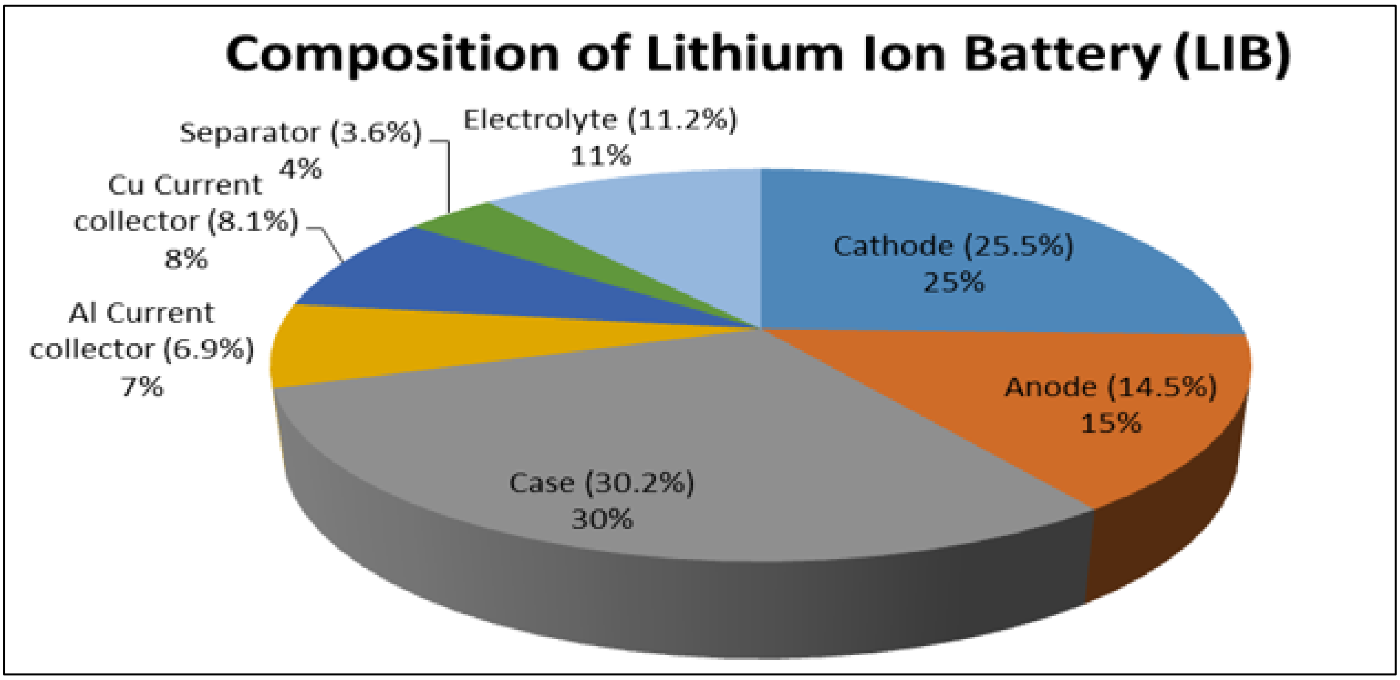
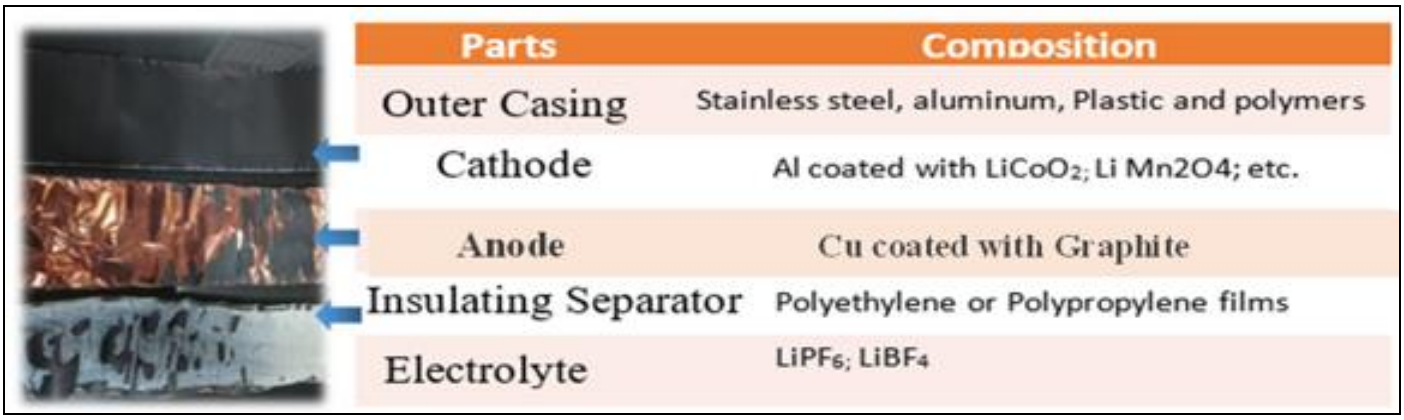


Fig 2 Percentage Composition of Various Components of LIBs.

There are three different constructions of LIBs: pouch cells, prismatic cells, and cylindrical cells [17]. The anode, cathode and separator foil are rolled together and then placed into a stainless steel or aluminium cell housing to create a cylindrical cell. Laptops, electric vehicles like Lucid, Tesla and Mars exploration rover all use cylindrical LIB cells. Prismatic cells, on the other hand, reduce the thickness of the cell by adopting a thick rectangular shell. The components of the cell might be found in rectangular stacks or rolled like cylindrical cells and flattened. Batteries with this kind are frequently found in electronics since they are simple to replace. Last but not least, pouch cells, often referred to as lithium polymer cells; resemble prismatic cells in form but employ flexible polymer/aluminium housing rather than a stiff metal shell. Both smart watches and drones can use it [2, 17].



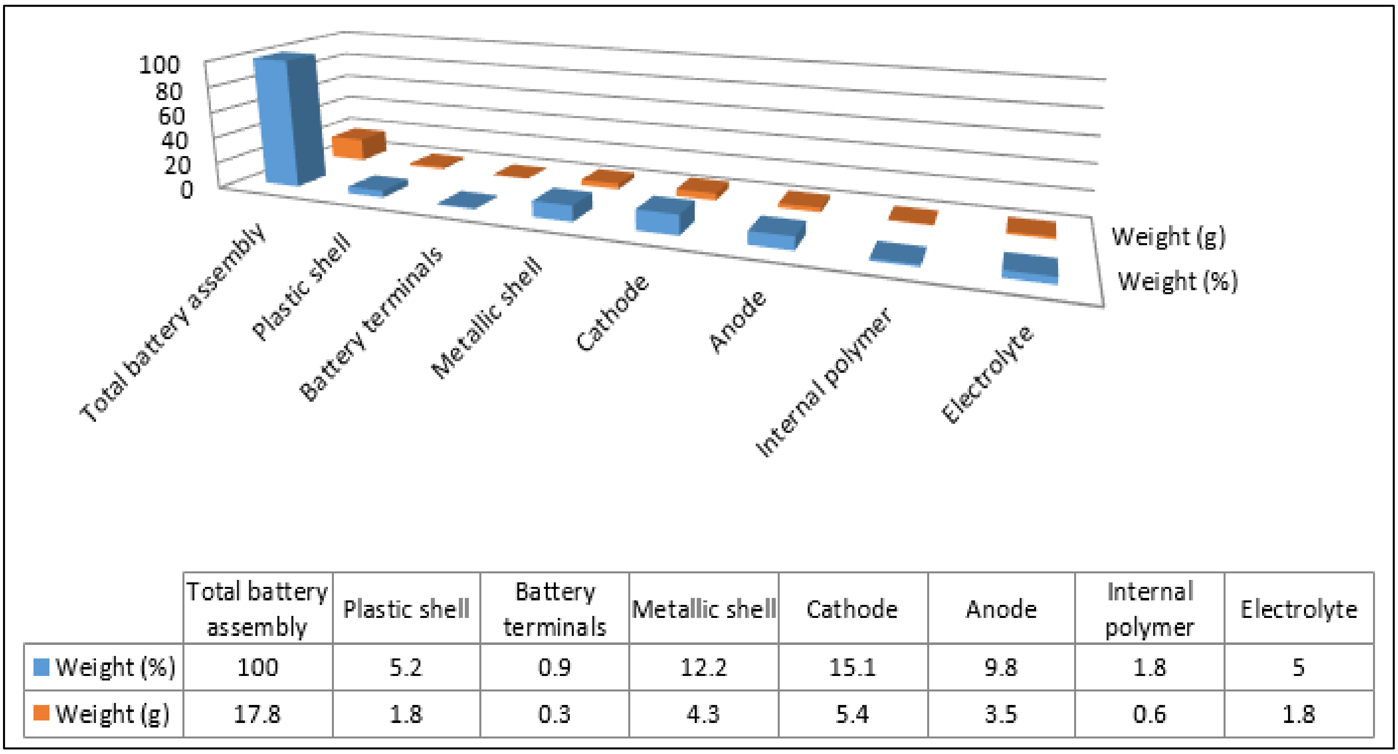
Parts	Composition
Outer Casing	Stainless steel, aluminum, Plastic and polymers
Cathode	Al coated with $LiCoO_2$; Li Mn2O4; etc.
Anode	Cu coated with Graphite
Insulating Separator	Polyethylene or Polypropylene films
Electrolyte	$LiPF_6$; $LiBF_4$

Fig 3 Different Foils Present in Lithium ion Battery

Lithium iron oxide ($Li_xM_yO_z$) coated on aluminum foil (in Figure 3) serves as the cathodic compound for LIBs. Anode: The negative active compound in LIBs is coated on copper foil with active material (tin, graphite, etc.). It was the lithium metal anode that produced dendrite formation and short circuit problems. Among the substances that comprise the first generation anode are graphite and other carbon-based cocaines. After then, scientists have focused on the second generation, which includes alloys made of silicon, tin (Sn), and lithium titanate (LTO) [18]. The separator, on the other hand, is essential to LIBs and is mostly made of a porous membrane material. A crucial component of LIB separators for electrolyte absorption is the porous membrane that sits between the battery's cathode and anode electrodes. The electrically conductive lithium ions (Li+) are moved between the cathode and anode electrodes during the charging and discharging cycles of LIBs with the help of a separator [19]. For creating porous membranes in rechargeable batteries, especially LIBs, the most commonly used polymeric materials are polypropylene (PP), poly(vinylidene fluoride) (PVDF), polyethylene (PE), poly(tetrafluoroethylene) (PTFE), and poly(vinyl chloride) (PVC). Lithium-ion batteries employ four different types of electrolytes: liquid, polymer, ceramic, and composite (polymer-ceramic). Lithium salts that dissolve in organic or ionic liquids are the basis of non-aqueous electrolytes, which are present in liquid electrolytes [19], [20]. The polymer matrix dissolves the lithium salt directly in organic solvents, maintaining the mechanical properties of polymer electrolytes. Among the often used lithium salts are $LiClO_4$, $LiCF_3SO_3$, $LiAsF_6$, $LiN(CF_3SO_2)_2$, $LiPF_6$, and $LiBF_4$. Composite electrolyte systems employ fillers of different kinds, sizes, and concentrations of ceramic fillers [21], [22].

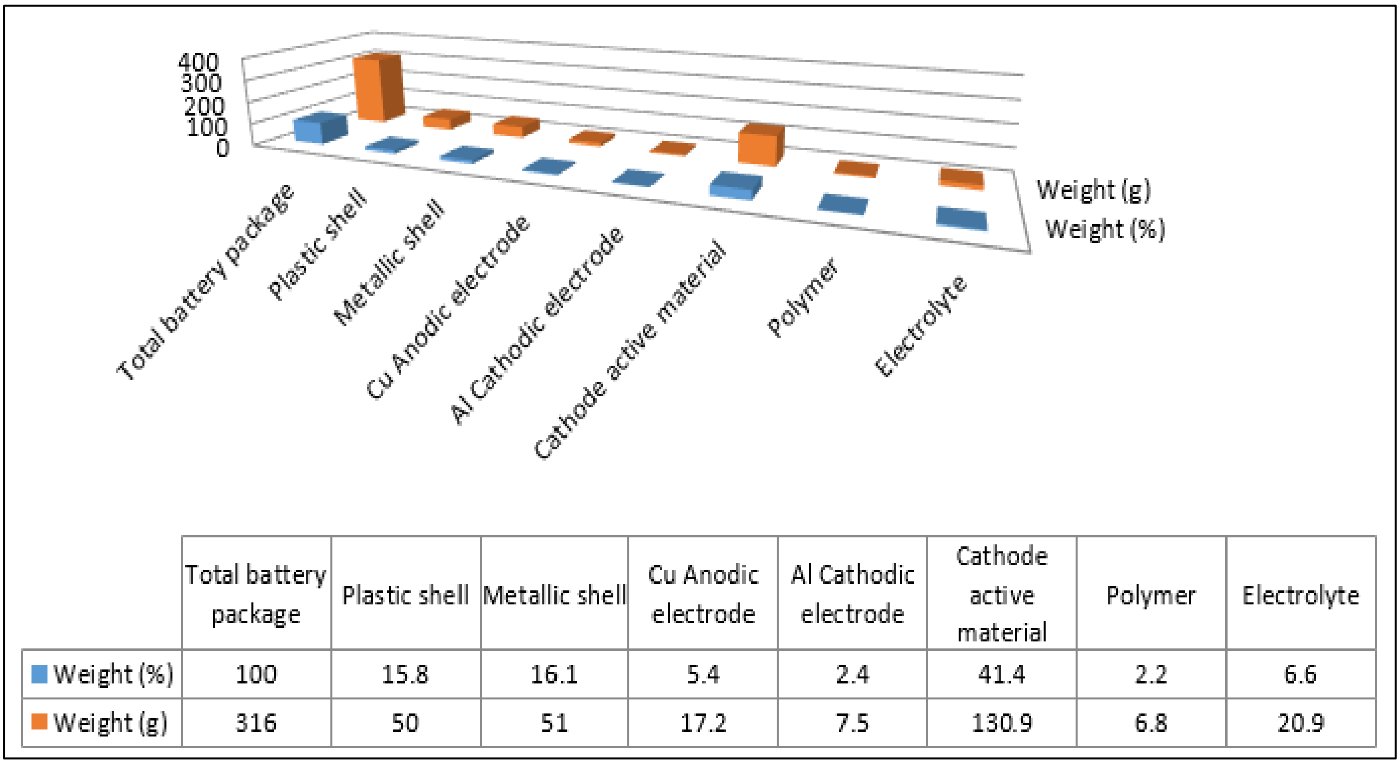
- *Lithium ion Battery Size*

Approximately 15% of LIBs varies between the range of 25 - 75 g while the remaining 85% of batteries used globally have weight between 5 - 25 g. Mobile phones have a single cell that weighs an average of 22-25 g, but laptops often have 4-6 cells, each of which weighs 45 g [23]. The weight of various components of LIBs for mobile and laptops is displayed below in figure 4a and 4b.



	Total battery assembly	Plastic shell	Battery terminals	Metallic shell	Cathode	Anode	Internal polymer	Electrolyte
🟦 Weight (%)	100	5.2	0.9	12.2	15.1	9.8	1.8	5
🟧 Weight (g)	17.8	1.8	0.3	4.3	5.4	3.5	0.6	1.8

Fig 4a Weight of Different Components of LIB for Mobiles.



	Total battery package	Plastic shell	Metallic shell	Cu Anodic electrode	Al Cathodic electrode	Cathode active material	Polymer	Electrolyte
🟦 Weight (%)	100	15.8	16.1	5.4	2.4	41.4	2.2	6.6
🟧 Weight (g)	316	50	51	17.2	7.5	130.9	6.8	20.9

Fig 4b Weight of Various Components of Lithium-Ion Battery for Laptops.

- *The Necessity of Recycling*

The global LIBs market is expected to grow at a compound annual growth rate of 14.2% and reach a valuation of USD 187.1 billion by 2032. From 2021 to 2026, the LIBs market in India is projected to develop at a compound yearly growth rate of 22.2%. Overall Market size of LIB grown from 55 GWh in 2015 to 225 GWh in 2020, which is predicted to inc. 2225 GWh in 2030. For, 30 GWh, 33,000 tons Graphite, 25000 tons Lithium, 19000 tons Nickel & 6000 tons Cobalt is required. With the growing population the demand of products also growing which in turn produces more wastes. Waste is produced at different stages including manufacturing stage, during its usage and eventually after the product's life is running out. The Life of LIBs are 3-4 years hence after 3-4 years these battery become waste and goes to landfill which creats environmental pollution hence recycling of these batteries is must which not only full fill the gap between supply and demand also Conserving and Preserving natural Resources and Preventing the Environmental Pollution from harmful Components.

Nowadays spent Lithium ion batteries are becoming a treasure waste, hence simple, environmental friendly, sustainable, and economically effecient process for recycling of these spent lithium ion batteries is become necessary. A suitable strategy is needed to address the impending harm to the environment and public health posed by the end of life of these lithium ion batteries that contain heavy metals and other dangerous substances. Three main factors make the recycling of lithium-ion batteries desirable and important. First off all, recycling has strong economics despite the higher cost of cobalt and lithium. In addition, there is a geopolitical risk associated with the accessibility of these metals because the majorities are only found in small quantities in particular geographic locations. It is very beneficial to make any effort to recover or recycle these metals from wasted LIBs. Thirdly, addressing environmental health is the most crucial factor. In addition to being poisonous by nature, the electrolytes used in LIBs can ignite quickly if handled carelessly. Improper disposal of end-of-life lithium ion batteries in waste lands leads to danger for environment as well as for animal as it carries flammable materials hence it has a risk of explosion or contamination of surrounding. LIBs carry high risk of heavy metals, inorganic compounds which is significant hazard for environment such as at high temperature it can explode or create pollution. Hence, a simple and efficient and economic process is required for LIBs recycling, that gives a proper recovery path for all the valuable metals present in it.

III. RESEARCH METHODOLOGY & METHOD

Many scientific researchers have developed technologies related to recycling of these spent LIBs to recover the treasure component as well as to decline the environmental risks. All the existing recycling technologies mainly focused to extract metals and cathode active materials from LIBs but apart from recovery of these metals no one mentioned a proper or closed recycling method to reclaim other components of LIBs like anode graphite, Copper, Aluminium, Iron, metallic shell and plastic casing in the available literature.

The conventional recycling processes used for most Lithium ion battery types are described in this section. The preparation and pretreatment process, which removes contaminants, is the first step in recycling. The concentrate is subsequently transferred to the pyrometallurgy. Pyrometallurgy produces refined materials that are then delivered to hydrometallurgy for specific purposes. Hydrometallurgy is being used to replace pyrometallurgy in the industry due to its inefficiencies and environmental issues [26]. The following subsections explain each of the procedures from extracting black mass to recover all the metals as represented below in the flow chart of Figure 5.

- *Discharging:*

It is essential that the cell be discharged prior to processing because the most of the used LIBs that are sent to recycling facilities are at least partially charged. The first step before disassembling is to fully discharge the LIBs to avoid an explosion or self-ignition. Due to the toxicity of the fluorinated gases that could be discharged, one of these LIBs could be opened or grounded in the air prior to discharging, which could result in fatalities or severe injuries [2]. In addition, self-ignition and short circuiting are avoided by draining the batteries prior to processing. For discharging few researchers used variety of salt solutions as a discharge medium, including NaCl, Na_2S, or $MgSO_4$. As seen from table 1 different studies employed different discharging procedures among which discharging procedure using NaCl solution is more effective than Na_2S or $MgSO_4$ [27].

Table 1 Different Discharging Processes of LIBs

Process of discharging	**References**
Spent LIB pack connected to a discharger	[28]
Spent LIBs submerged into 5-10 wt % NaCl solution for 24 h	[29]
Spent LIBs submerged in electrolytic sol. (10 w/v% Na_2SO_4) for 24 h	[30]

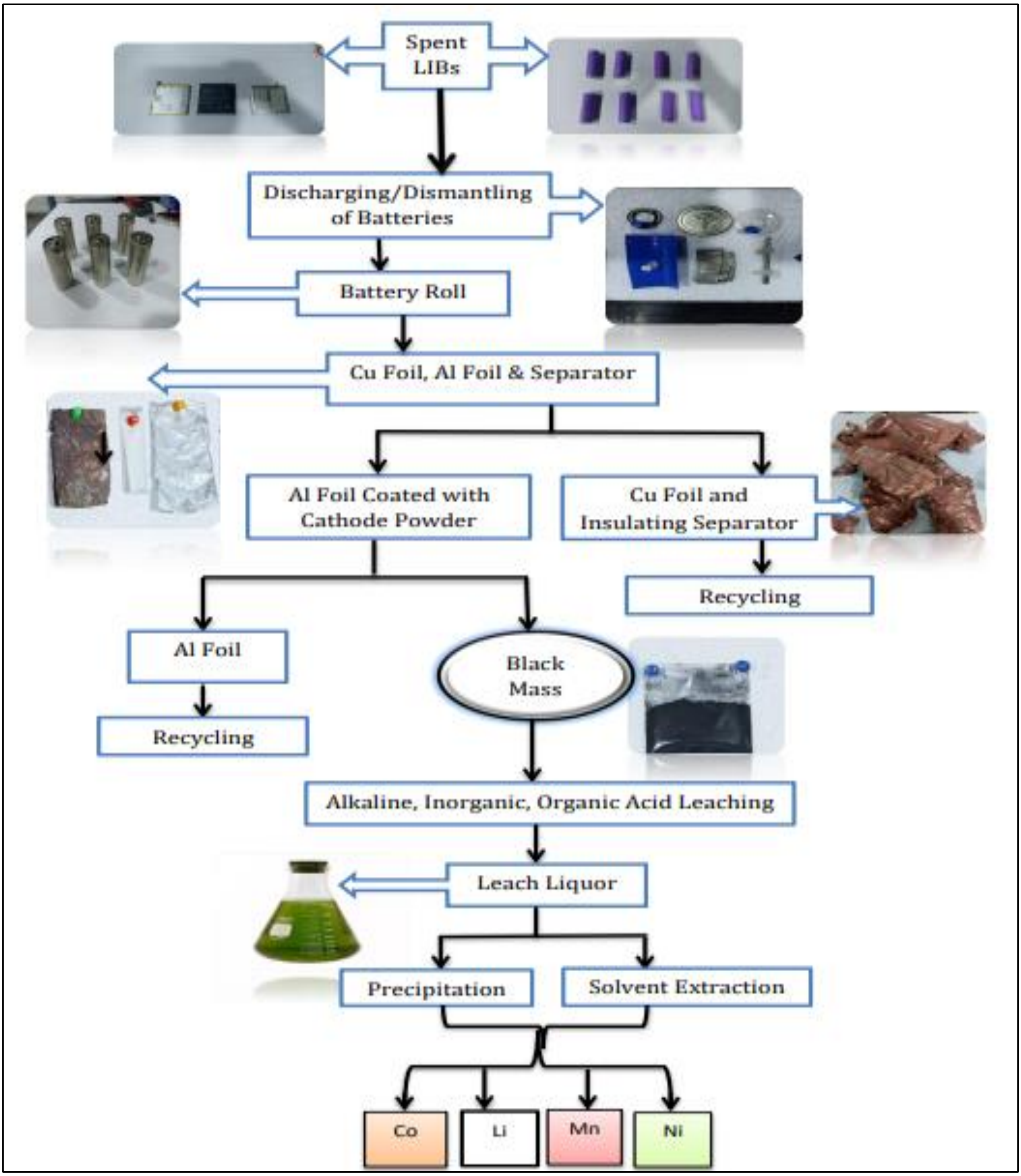


Fig 5 Flow chart represents recovery of critical metals from LIBs.

- *Preparation and Pre-treatment Process:*

Pretreatment is the process of breaking down a big battery pack into smaller cells or modules, detaching the plastic casing, and discharging them. This can be accomplished mechanically, thermally, or in a mix of the two. Pretreatment involves manual sorting, material crushing, pyrolysis, and mechanical processing. This step involves crushing the cells in an environment of CO_2 gas, which causes the volatile organic electrolyte to evaporate and condensate into non-useful substances [26, 31]. Figure 6 illustrates how the target materials (Black mass) are separated from extraneous components.

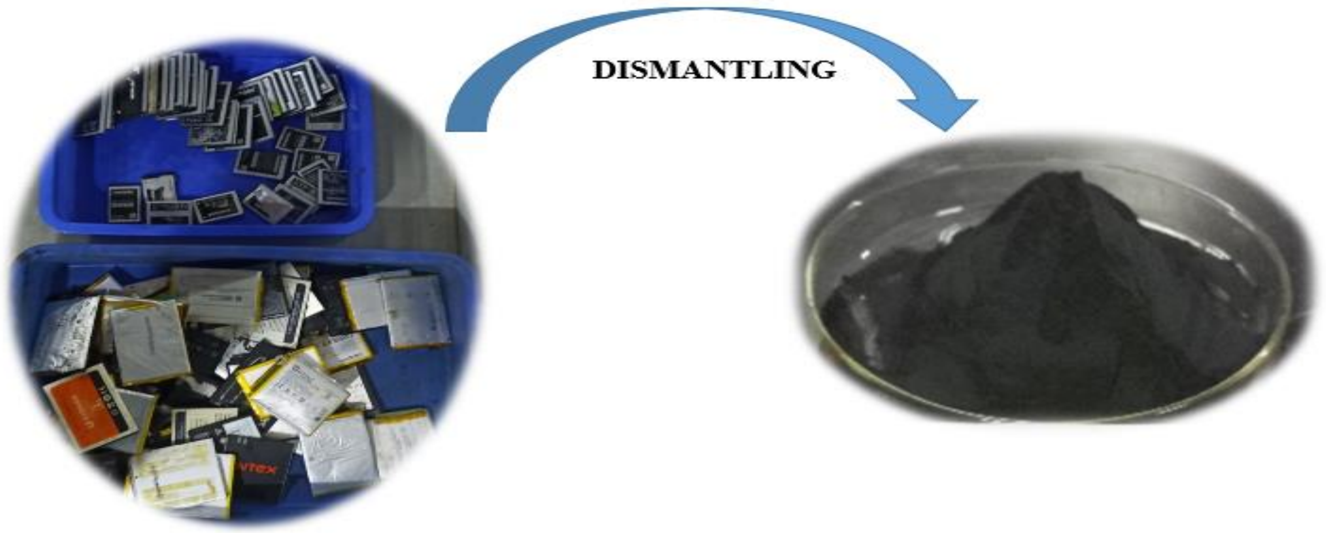


Fig 6 Black Mass Extracted through Pre-treatment Method

- *Recovery of Metal by Hydrometallurgical Methods:*

With hydrometallurgical processing, all valuable metals may be easily and efficiently extracted from waste LIBs. Precious metals are dissolved and extracted from aqueous media using a range of techniques in hydrometallurgical technology. The dissolution of Li, Ni, Co, and Mn in acid leaching is the first essential step. Chemical precipitation, solvent extraction, or electrolysis are the methods used to separate these metals from the solution (leach liquor). Alkaline (NaOH) reagents, organic acids such as oxalic, formic, and malic acids, and inorganic acids such as H_2SO_4, HCI, and HNO_3 are being used in the development of leaching techniques to recover metals from the material produced after physical separation procedures and mechanical pretreatment methods.

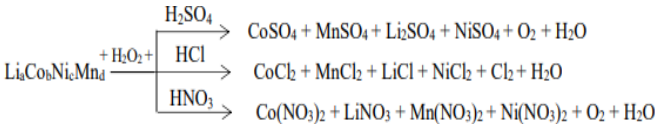
Hydrometallurgical methods including ion exchange, solvent extraction, precipitation, and solution purification can be used after leaching [32]. The relative affordability of inorganic acids makes them more useful than organic acids.

- *Alkaline Leach:*

N-methyl-2-pyrrolidone (NPM) treatment of the electrodes is required in omit the binder and extract black-mass from the Copper and Aluminum foils. After this stage, copper and aluminum are removed, and then leaching of lithium and cobalt occurs. Alkaline (NaOH) leaching is a selective method for recovering aluminum from cathode material [33]. After that, NH_4OH precipitation (pH: 5) is used to recover the dissolved aluminum. Certain experiments that used 4M ammonia solution (NH_4OH) having pulp density 66.6 g/L at 80 °C for 60 minutes produced solids that contained Co and Li but recovered 98% of the Al and 65% of the Cu. To recover Li, Co, and other present metal values the particles are leached again using different acids followed by the selective leaching of Cu and Al [34].

- *Inorganic Acids Leaching:*

Inorganic acids like nitric acid (HNO_3), sulfuric acid (H_2SO_4), phosphoric acid (H_3PO_4), and hydrochloric acid (HCI) have been studied extensively by many researchers for the aim of recovering critical metals from end-of-life lithium-ion batteries. Their relative affordability, effectiveness as leaching agents, comprehension of reaction chemistry, and convenience in accessing subsequent treatments for metal extraction and solution purification processes account for this [35, 36]. Utilizing inorganic acid as lixiviant for spent LIBs, few works are listed below in table 2.



When compared to another inorganic acid, hydrochloric acid has a superior leaching efficiency [37], however Equation illustrates that Cl_2 was generated, which could pose an environmental risk. Because it increases the leaching effectiveness, sulfuric acid is typically employed in conjunction with hydrogen peroxide (H_2O_2) as a reducing agent.

$$2LiCoO_2 + 8HCl = 2CoCl_2 + Cl_2 + 2LiCl + 4H_2O$$

Table 2 Different Inorganic Acids used for Leaching

Battery Type	**Molarity**	**Acid**	**Parameters**			**Efficiency/Recovery%**				**References**
			Time (hr)	**Temp (°C)**	**S/L (g/L)**	**Li**	**Mn**	**Ni**	**Mn**	
LCO	1M	HNO_3	-	75	10-20	95	95	-	-	[38]
LCO	4M	HCl	1	80	20	97	97	97	98	[39]
NMC	5M	HCl	1.16	95	10	98	99	-	-	[40]
NMC	1M	H_2SO_4	4	95	50	93.42	66.2	96.3	50.2	[41]

LCO	1.5 M	H_2SO_4 + 15% H_2O_2	1	60	40	98.1	94.07	-	-	[42]
LMO	2%	H_3PO_4	1	90	8	88	99	-	-	[43]
LCO	15%	HF	2	75	20	80	98	-	-	[44]
NMC	2M	H_2SO_4 +10% H_2O_2	-	70	33.3	99.8	98.5	98.6	98.6	[45]

✓ *Sulfuric Acid Leaching:*

Many papers and patents mostly covered hydrometallurgical process leaching with H_2SO_4. During the leaching process of important metals like nickel, manganese, copper, and cobalt, sulfuric acid (H_2SO_4), which is the cost effective inorganic acid, is frequently preferred [46]. The necessary acid and reducer/oxidizer are processed to achieve the desired leaching outcomes; temperature, leaching period, and mixing rpm are other important factors. To achieve high metal extractions, acids with higher concentrations (2-4 M H_2SO_4) are frequently needed. The resultant pregnant leach solutions contain large amounts of sulfate. Moreover, a significant amount of neutralizing reagent is usually required to neutralize the leach solution before the metals are retrieved downstream due to the high acidity. To attain a high rate and amount of metal extracted from the cathode active material of spent LIBs extractions in H_2SO_4 leaching and reducing reagents like $Na_2S_2O_5$; H_2O_2 and $NaHSO_3$, and are employed as reluctant [47, 48]. The steps involved in dissolving lithium and cobalt through sulfuric acid leaching of $LiCoO_2$ are depicted below in figure 7. The leaching of black material using H_2SO_4/H_2O_2 and the extraction of several metal salts, such as $CoSO_4$, $NiSO_4$, $MnSO_4$ using H_2SO_4, and MnO_2 using $KMnO_4$, from this leach liquor are depicted in flow chart represented below in Figure 7.

$$6H_2SO_4 + 4LiCoO_2 \rightarrow 2Li_2SO_4 + 4CoSO_4 + 6H_2O + O_2$$

$$3H_2SO_4 + H_2O_2 + 2LiCoO_2 + \rightarrow Li_2SO_4 + 2CoSO_4 + 4H_2O + O_2$$

➢ *Solution Purification and Metal Recovery:*

As lithium-ion battery leaching solutions are very acidic and include a wide range of metals, complex techniques may be required for the selective recovery of metals of interest during the solution purification and metal recovery stages [49]. The cathode component has varying quantities of foil-derived Cu, Fe and Al depending on the mechanical pretreatment that was employed. Preventing Cu and Al leaching will enable more effective and focused metal recovery, which will ease downstream processing. Metals like Al, Fe, Mn, and Cu are usually extracted first to further extract Li, Co, and Ni [50, 51]. Then, by employing solvent extraction and metal precipitation techniques, these metals can then be recovered from leached.

- *Solvent Extraction:*

Solvent extraction (SE) is a technique used to remove impurities and recover metals from lithium-ion battery leaching solutions. It involves transferring the metal into the organic phase from the inorganic (aqueous) phase by binding an organic liquid reagent to the metal [52]. There is no shortage of SE reagents due to the widespread use of bis(2,4,4-trimethylpentyl) phosphinic acid (Cyanex 272), hydroxy-oxime derivatives (Acorga M5640), di-(2-ethylhexyl) phosphoric acid (D2EHPA), and 2-ethylhexyl phosphonic acid mono-2-ethylhexyl ester (PC-88A) in SE applications. The main barriers to solvent extraction include high reagent needs for concentrated solutions, challenges with Co/Ni/Mn separation, and costly capital and operating costs [53-55]. While lithium is still in solution, different metals like Cu, Ni, Al, Fe, Mn, and Co can be extracted selectively at pH (6.5) using the appropriate SE method. It appears that PC-88A, Cyanex 272, and Acorga 5640 are prefer to treat pregnant leach solutions [35].

- *Precipitation:*

Pregnant leach solutions are treated with NaOH or $CaCO_3$ to precipitate contaminants such as Cu, Fe, Al, and Mn. Precipitating metals from cathode active material leaching solutions is a rather simple and uncomplicated procedure. pH is one of the main variables affecting the precipitation of metals, and under the correct conditions, it might allow for their selective recovery or elimination. By precipitation, Co and Li salt can be recovered from pregnant leach solutions as seen in Figure 7, utilizing the pH difference that facilitates the formation of their respective hydroxides. From the leach liquor, iron is recovered as jarosite (pH 3-3.5; 95 °C) [56-58].

$$Na_2SO_4 + 3Fe_2(SO_4)_3 + 12H_2O \rightarrow Na_2Fe_6(SO_4)_4(OH)_{12} + 6H_2SO_4.$$

Potassium permanganate (0.5 M $KMnO_4$) was added to the solution to extract manganese as MnO_2 or Mn_2O_3. Similarly, by raising the pH of the pregnant leach solution to 11, nickel can be recovered in the form of nickel hydroxide [59].

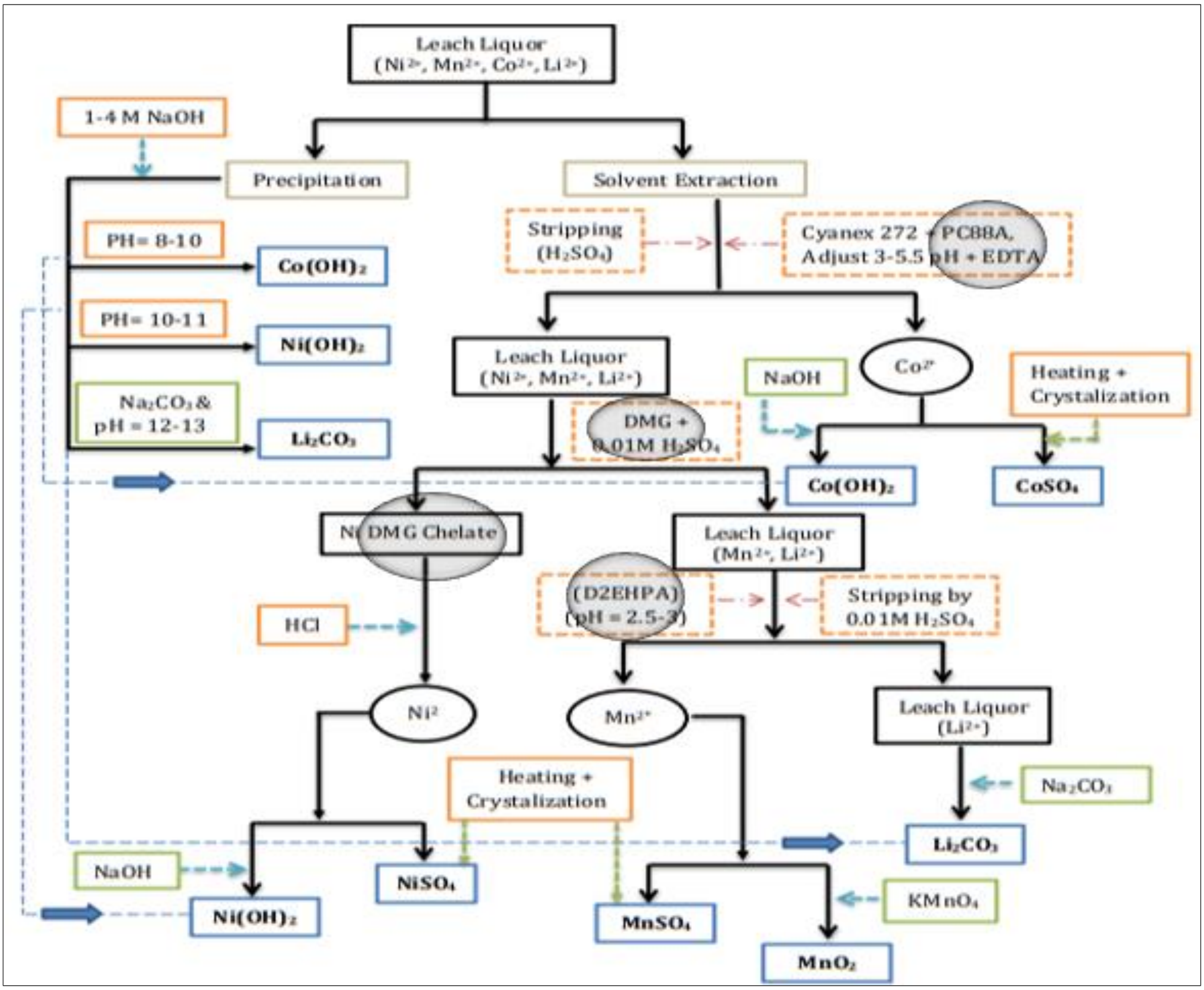


Fig 7 Flow Chart Representing Leaching of Black Mass using H_2SO_4/H_2O_2 and Extraction of Various Metal Salts from Leach Liquor.

IV. CONCLUSION

The importance of lithium-ion batteries (LIBs) has grown as a result of increasing use of electric vehicles (EVs and HEVs) and various portable electronic gadgets (e.g., mobile phones, video cameras, laptops, etc.). Lithium and cobalt prices have recently risen due to increased demand. By 2050, there will be a scarcity of 46,720,818 tons of lithium. Recycling trash LIBs is the only solution to meet demand. Recycling LIBs requires caution because to the presence of electrolytes and heavy metals (Cu, Pb, Cd, and Zn) that pose environmental and health risks. LIBs are recycled using mechanical, hydrometallurgical, and pyrometallurgical processes. The majority of research has concentrated on hydrometallurgical procedures, which include leaching and recovering critical metals from leach liquor. To leach cathode active materials of lithium-ion batteries (LIBs), sulfuric acid is often used with other reducing agents due to its low cost better performance and on further treatment, this leached solution yields various metal salts. Leach solutions are handled with chemical precipitation or solvent extraction to recover metals in various forms. Research is ongoing to develop sustainable methods and procedures for recovering metals from wasted LIBs. The goal is to reduce costs, streamline recycling, and minimize environmental impact.

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