Special Report

Charging the world through lithium battery recycling

aranca

Contents

Abbreviations

Elements

Abbreviation	Description
Al	Alumina
Co	Cobalt
Cu	Copper
Fe	Iron
Mn	Manganese
Ni	Nickel
Li	Lithium

Compounds

Abbreviation	Description
LCO	Lithium Cobalt Oxide
LFP	Lithium Iron Phosphate
LMO	Lithium Manganese Oxide
NCA	Lithium Nickel Cobalt Aluminum Oxide
NMC	Lithium Nickel Cobalt Manganese Oxide

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Background

- Lithium-ion (Li-ion) batteries provide added advantages over conventional batteries, making them more suitable in a world of portable electronic devices and electric vehicles.
- Li-ion batteries can sustain temperature variations and be rapidly charged, have compact structure, and are made of lightweight material, such as graphite and lithium, which make them a popular choice. With traditional batteries fast losing their space, Li-ion batteries have captured about 70% market share. This market is estimated to grow to $26.45 million by 2025.
- Currently, spent batteries are sent to China for recycling or discarded in landfills, thus adding to environmental degradation. Recycling of these batteries would be cost-effective and also be a green step.
- As production of these batteries is currently increasing, measures should simultaneously be implemented that prevent long-lasting, detrimental impacts on the environment.

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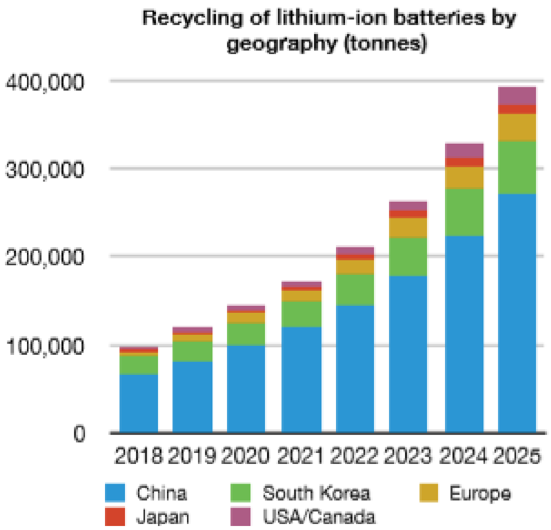
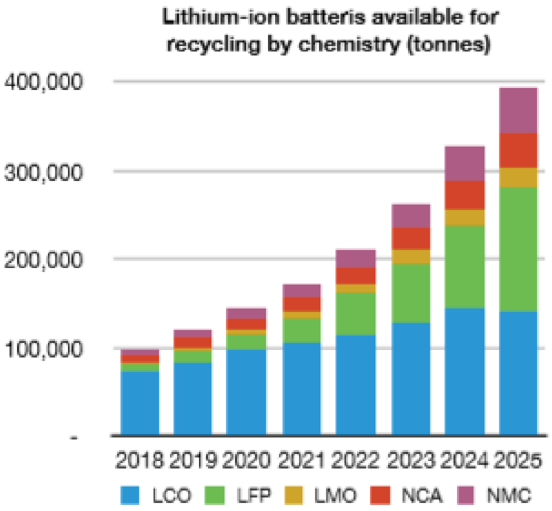
Lithium-ion battery recycling | Current scenario

- Supply and price of lithium are highly influenced by factors such as impact of mining on environment, government policies, and industrial demand. Li-ion battery recycling enables a fair balance between supply and demand of lithium; the process will therefore be given significant importance in the near future.
- With increasing demand for Li-ion batteries, the volumes of spent batteries would also rise. Around 97000 tons of batteries are expected to get recycled worldwide over 2018−25 and reach approximately 300,000 tons by 2030.
- China alone is expected to be responsible for about 2 MMT of spent Li-ion batteries by the end of 2030. The graph below indicates that China and South Korea would be leading in the recycling market in the near future.


Recycling of lithium-ion batteries by geography (tonnes)


Lithium-ion batteris available for recycling by chemistry (tonnes)

Source: Circular energy storage (World Economic Forum)

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Recycling Technology | Overview

- Researchers and industries are now opting for the recycling process to overcome their reliance on lithium. The Li-ion battery cell has a very complex structure, which makes the recycling process complex.
- During the recycling process, the batteries are evaluated on two factors: “state of charge” to ensure safety; and “state of health” to gauge their suitability in recycling. Following these assessments, they are disassembled and then treated primarily through pyrometallurgical or hydrometallurgical processes.
- Compared to other processes, the pyrometallurgical and hydrometallurgical processes are more mature owing to their better material recovery feature and ease of operation.
- During the disassembly process, all the components (metal and plastic) of the battery are separated and sent for recycling. Currently, there is no standard procedure for battery pack manufacturing or cell designing in both automotive and portable electronic device sectors. Hence, most of the dismantling is done manually, which makes the process lengthy and causes uncertainties.
- However, many companies are now developing standards for assembly based on size, shape, QR codes, labels, and so on.

Recycling Technology | Current Technologies

Technology	TRL	Brief Description
Pyrometallurgy	8–9	▪ Components of metals such as cobalt, nickel, copper, and iron are broken down into their alloy form. ▪ Process includes high temperature operations such as smelting to produce alloys, gases having traces of binders and electrolytes, and slag having manganese, aluminum, and lithium. ▪ These particles get separated based on size, magnetism, and hydrophobicity. Processes such as sieving, filtration, and magnetism are employed. ▪ High value metals, such as nickel and cobalt, can be extracted using this method; further processing is required to extract other metals and their alloy forms.
Hydrometallurgy	7–9	▪ Aqueous solutions are used to treat the desired metals via leaching. ▪ Sulfuric acid (H2SO4), hydrogen peroxide (H2O2), hydrochloric acid (HCl), nitric acid (HNO3) and few organic acids are employed as solvents. ▪ Hydrogen peroxide is always preferred over any other solvent during leaching process due to it’s strong oxidizing nature. ▪ Once leaching is done, lithium is usually extracted through precipitation reaction with pH controlling.
Direct recycling	5–7	▪ Spent batteries are dismantled and dipped into an N-Methyl-2-Pyrrolidone (NMP) solution. Then, by adding lithium carbonate, powders are obtained through solid state reactions. ▪ Powders can also be obtained through hydrothermal treatment with lithium hydroxide or lithium sulphate solutions. ▪ This technology enables high recovery from electrodes having lesser value of lithium by eliminating further purification processes. ▪ Further improvements are required in the technology to enable better material selectivity. Low state of charge and state of health could affect overall material recovery.
Mechanochemical separation	7–9	▪ Different methods developed by various researchers and industries are available. ▪ One such method involves dismantling of spent batteries and heat treatment to separate materials other than active materials. Then, the electrode material is ball milled and leaching is performed to get the final metal compounds.
Bioleaching	5–6	▪ Bacteria are used to recover valuable metals such as cobalt and nickel. ▪ In this process, the bacteria digest the metals and reduce them to metal nanoparticles. ▪ This process can be complimentary to the traditional recycling processes.

Recycling Technology | Pyrometallurgical Process

Overview:

- In the pyrometallurgical process, once the smelting/high temperature operation is done, further purification via leaching and precipitation is carried out for the extraction of purified form of metals.
- However, there is no standardized method for recycling batteries. All companies have their own unique method to carry out this process.

Key Players

umicore

eramet

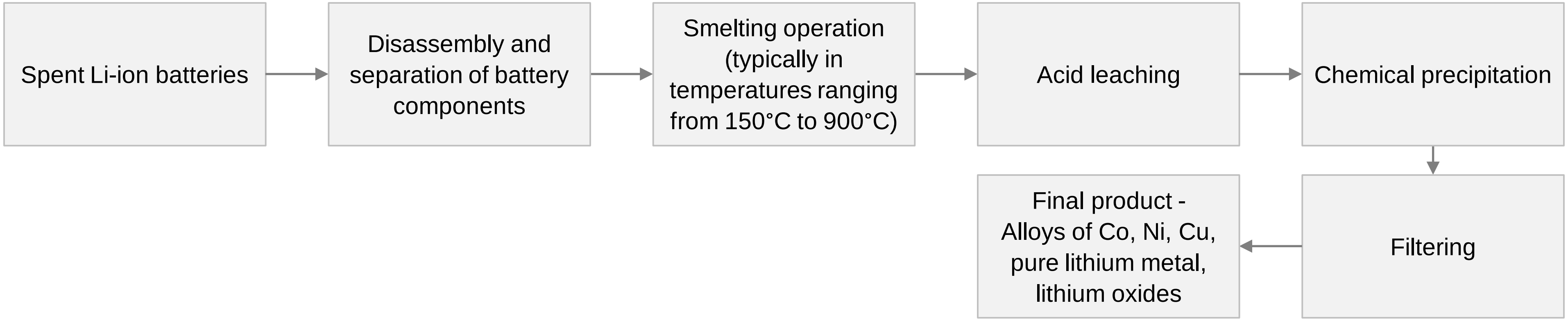
INMETCO

BATREC
Swiss quality recycling solutions

GLENCORE

ACCUREC

Process flow:



Spent Li-ion batteries

Disassembly and separation of battery components

Smelting operation (typically in temperatures ranging from 150°C to 900°C)

Acid leaching

Chemical precipitation

Filtering

Final product - Alloys of Co, Ni, Cu, pure lithium metal, lithium oxides

Recycling Technology | Hydrometallurgical Process

Overview:

- In the hydrometallurgical process, aqueous process route is followed to recover metals and metal alloys.
- Sulfuric acid ($\mathrm{H2SO4}$), hydrogen peroxide ($\mathrm{H2O2}$), hydrochloric acid (HCl), and nitric acid ($\mathrm{HNO3}$) are among the most frequently employed solvents.
- Once leaching is done, lithium is extracted through precipitation reaction with pH controlling.
- A sample reaction wherein reagents are used to extract cobalt is as follows:

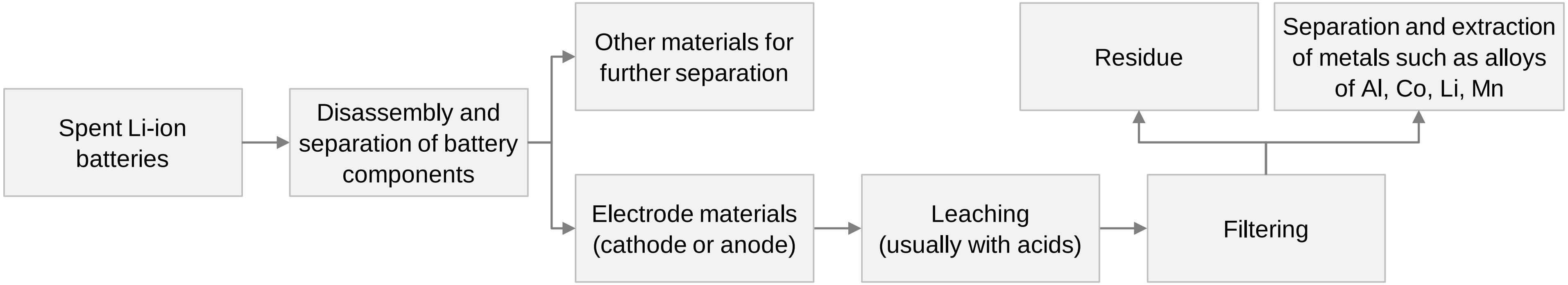
$$\mathrm{2LiCoO2 + 8HCl} \longrightarrow \mathrm{2LiCl + 2CoCl2 + 4H2O + Cl2}$$

Key Players

Li-Cycle™ Lithion GEM

Duesenfeld JX金属 fortum

Process flow:



Spent Li-ion batteries

Disassembly and separation of battery components

Other materials for further separation

Electrode materials (cathode or anode)

Leaching (usually with acids)

Filtering

Residue

Separation and extraction of metals such as alloys of Al, Co, Li, Mn

Recycling Technology | Process Comparison

Process	Hydrometallurgy	Pyrometallurgy
Pros	▪ Chemical process, applicable to any kind of battery ▪ High purity of metals and metal alloys is achieved without any further treatments ▪ Energy-efficient process ▪ Setup cost is lesser	▪ Thermal process, applicable to any kind of battery ▪ No pre-treatments required ▪ Large quantities of feed can be handled
Cons	▪ High volumes of effluents need to be treated or disposed carefully ▪ Pre-treatments can cause adverse effect on further processes like leaching and solvent extraction	▪ Harmful gas fractions generated as byproducts; gas clean-up required to avoid toxic emissions into the atmosphere ▪ Further processing required to extract pure metals and metal alloys ▪ Requires high energy input ▪ Capital-intensive setup required

Recycling Technology | Other Processes

Overview:

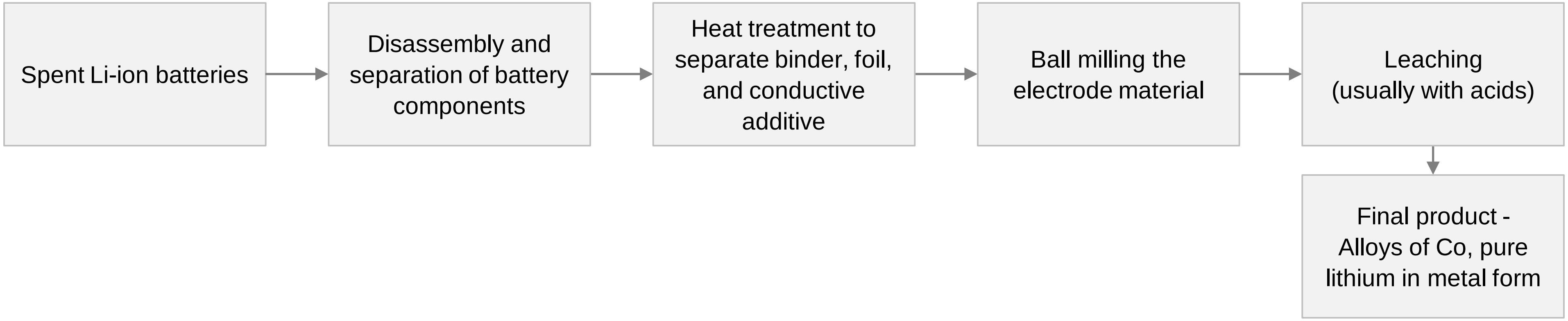
- Alternative recycling processes involve mechanochemical treatment of materials. In one such method, materials are crushed and a chlorine compound and complexing agent are mixed together to produce water-soluble salts of cobalt, which can be separated from insoluble fractions through liquid washing.
- Direct recycling and bioleaching with low carbon footprint are also being researched for recovery of metals and metal alloys of high purity.

Key Players

RETRIEV TECHNOLOGIES

RECYCLE RBRC Li-ion 1.800.822.8837

Process flow: Mechanochemical Treatment



Spent Li-ion batteries → Disassembly and separation of battery components → Heat treatment to separate binder, foil, and conductive additive → Ball milling the electrode material → Leaching (usually with acids) → Final product - Alloys of Co, pure lithium in metal form

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Lithium ion battery recycling | Value chain

Battery dismantling companies

- AKKUSER
- RETRIEV TECHNOLOGIES
- suez
- sortbat

Recycling Process

Hydrometallurgy

SONY & Sumitomo
- 📅 1992
- ♻ 150 tons/year
- 🌐 Ehime, Japan

JX金属
- 📅 1992
- ♻ 150 tons/year
- 🌐 Ehime, Japan

GEM
- 📅 1992
- ♻ 150 tons/year
- 🌐 Ehime, Japan

fortum
- 📅 2013
- ♻ n/a
- 🌐 Finland

Pyrometallurgy

eramet
- 📅 2006
- ♻ 20000 tons/year
- 🌐 Allier, France

BATREC Swiss quality recycling solutions
- 📅 2006
- ♻ 20000 tons/year
- 🌐 Niesenstrasse, Switzerland

motivate our planet DOWA ECO-SYSTEM
- 📅 2006*
- ♻ 1000 tons/year
- 🌐 Tokyo, Japan

Mechanochemical

RETRIEV TECHNOLOGIES
- 📅 2000*
- ♻ 4500 tons/year
- 🌐 Ohio, US

Pyro & Hydrometallurgy

umicore
- 📅 2006
- ♻ 7000 tons/year
- 🌐 Hoboken, Belgium

SNAM FLORIDIENNE
- 📅 n/a
- ♻ 300 tons/year
- 🌐 Saint Quentin Fallavier, France

Technology not disclosed

TESLA
- 📅 2015
- ♻ n/a
- 🌐 Nevada, US

AMERICAN MANGANESE INC.
- 📅 2017
- ♻ n/a
- 🌐 Surrey, Canada

northvolt
- 📅 n/a
- ♻ n/a
- 🌐 Sweden

📅 Plant establishment year ♻ Recycling capacity 🌐 Location

* Approximate year

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Future opportunities in recycling of spent lithium-ion batteries

- The Li-ion battery recycling market is poised for growth. It will also present numerous opportunities at different levels of the battery recycling value chain. At each level, continuous development in technologies would be vital for enhancing process efficiency and reducing cost.
- For example, easy dismantling can help in reducing the cycle time and cost; however, currently, this stage is not considered while manufacturing battery packs, and therefore, the process is not fully supported.
- Technological advances in core recycling would likely drive the market. Novel technologies such as bioleaching can substantially reduce the energy intake of the recycling process as well as overall cost.
- The overall process should reduce the waste generated during recycling. This would further help in cutting down the peripheral costs across the value chain.
- Development and use of sustainable technologies that lower greenhouse gas emissions would be a boon for the environment in future.

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