SCORELCA

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PRODUCTION OF LCIS FOR BATTERY RECYCLING PROCESSES ON THE 3 MAIN CHANNELS:

HIGH TEMPERATURE TREATMENT (PYROMETALLURGY), MECHANICAL TREATMENT (GRINDING), CHEMICAL TREATMENT (HYDROMETALLURGY)

SUMMARY

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SCORE LCA is an association that has been created to financially support collaborative research on LCA and related topics. It aims to promote and organize cooperation between companies, institutional and scientists in order to support the evolution of LCA methods and its practical implementation at European and international level.

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✓ The views and recommendations expressed in this publication are those of the authors and do not necessarily reflect, unless otherwise stated, the views of all members of SCORE LCA.

✓ The information and conclusions presented in this document were established on the basis of scientific and technical data and regulatory and normative framework in force at the date of the publication of documents.

Abstract

The importance of lithium batteries has been increasing recently due to the electrification of transportation and renewable energy storage. Therefore, the recycling of the production waste of Gigafactories is a significant challenge in the short term. In addition, a substantial number of lithium batteries will reach their end-of-life progressively. Hence, It is important to develop sustainable recycling processes for lithium batteries. The most common available or under development recycling technologies are pyrometallurgical, hydrometallurgical, mixed, and direct recycling.

Recycling processes of batteries recover secondary sources (such as cobalt, nickel, lithium, etc.); however, they generate several environmental impacts. So here comes the relevance of assessing the impacts associated with the different battery recycling technologies using Life Cycle Assessment.

Currently, very limited Life Cycle Inventories (LCI) for the different battery recycling processes are available as follows:

- Lithium battery recycling processes are considered emerging technologies,
- Battery technologies are still underdeveloped,
- Scarcity of data and reliable Life Cycle Inventories LCIs for battery recycling processes.

Previous LCA studies have used assumptions, mainly old and unreliable data and life cycle inventories based on old processes and literature reviews. Moreover, primary data for battery recycling processes are subjected to confidentiality agreements, which makes collecting LCA data from battery recyclers challenging. These factors make LCI no longer representative of current battery recycling processes, chemistries, and technologies.

By analyzing the recycling methods and available expertise, inventories can be developed and used for today's and tomorrow's recycling technologies. WeLOOP, in collaboration with TND (metallurgy experts), has worked on collecting recent LCA data from several European battery recyclers and secondary data from current technologies. The collected data resulted in building reliable and robust LCI of the various existing recycling processes (preparation of black mass, pyrometallurgy, hydrometallurgy, mixed methods) for the different lithium batteries. These LCIs were shared with members of the SCORELCA collective and the public.

Establishing reliable Life Cycle Inventories allows us to measure the associated environmental impacts and helps the decision-making process concerning battery recycling legislation. LCA results show the main environmental challenges of the recycling processes are electricity consumption (furnace for pyrometallurgical recycling and evaporation of the effluents for hydrometallurgical recycling) and the different chemical substances their end-of-life treatment in the chemical treatments of all recycling processes. Also, CO2 emissions are released, particularly in the case of pyrometallurgical recycling.

Synthesis

As part of the transport sector's electrification, lithium batteries' development continues to increase due to their use in electric and hybrid vehicles and in energy storage systems for renewable energies. The production of lithium batteries requires critical raw materials, such as cobalt, lithium and natural graphite. Critical materials are, therefore, of great economic importance and represent a potential supply risk. The supply of critical and non-critical raw materials for batteries comes mainly from outside the European Union. Recycling is a way to reduce the criticality of raw materials. Recycling encompasses short-term battery production waste, and the batteries gradually reach the end of their life in the coming years. It is, therefore, essential to develop sustainable recycling processes for lithium batteries. Although LIB recycling processes raise economic and environmental issues, recycling presents a secondary source of raw materials such as cobalt, nickel, lithium, etc.

Recycling processes and mapping of market players and maturity

There are different recycling processes on the market for the treatment of end-of-life lithium batteries; pyrometallurgical, hydrometallurgical and mixed processes. In addition, LIB recycling processes often combine pyrometallurgical and hydrometallurgical techniques with pre-treatment or post-treatment processes. Each process makes it possible to recover different materials and has advantages and disadvantages on the technical, economic, and environmental aspects.

Pyrometallurgical processes are the most mature technologies; they process batteries directly and require higher energy consumption due to the ovens' heating to a temperature of almost 1600°C. Pyrometallurgical processes are often combined with a hydrometallurgical process to recover metals of high economic value. Indeed, pyrometallurgical processes recover only cobalt and nickel using solvent extraction and copper by electrolysis, while lithium, manganese, graphite and aluminium are mainly lost in slag. Recovery rates for cobalt, nickel, copper and aluminium from these processes are good. Nevertheless, the environmental impacts of pyrometallurgical processes are considerable due to the use of harmful chemicals for the chemical treatment of cobalt and nickel recovery and the significant CO2 emissions due to furnaces.

Pyrometallurgical processes may be preceded by pre-treatment, such as hydrometallurgical processes. Pre-treatment optimises the recovery of valuable materials, facilitates the safe handling and disposal of hazardous components, and reduces the amount entering the recycling process. Pre-treatment can be mechanical, chemical or thermal. Most of the time, the pre-treatment steps are as follows: dismantling of battery packs, sorting, discharging, grinding and shredding, separation, electrolyte recovery, separation of binders, heat treatment and washing. Pre-treatments can give different active ingredients, but the most common is Black Mass (BM), which is rich in metals with high economic value: cobalt, nickel, manganese, aluminium and copper.

To treat the BM, hydrometallurgical processes are characterised by the succession of the following steps: leaching of the target metals using an aqueous solution, separation, and recovery of the target metals by precipitation or solvent extraction. The recovery rates of these processes are very high, and the quality of the recovered metals is good. Unlike pyrometallurgical processes, energy consumption and CO2 emissions are very low. However, hydrometallurgy is a complex and expensive process which uses toxic solvents and generates a large amount of effluent whose end-of-life treatment can cause a high energy consumption depending on the type of treatment.

Direct recycling is interesting because it allows the direct recovery of active materials from battery cells, not elements. It consists of separating the active anode and cathode materials, regenerating them using a re-lithiation process and then reusing them directly as active materials in a new cell.

However, direct recycling requires a homogeneous input stream, which means that batteries must be sorted upstream of recycling. Furthermore, direct recycling is still at the R&D stage, as the industrial-scale feasibility of separating active materials from current collectors has not yet been proven.

Currently, most of the recycling of lithium batteries takes place in Asia (China, South Korea and Japan) and uses hydrometallurgical processes. However, Europe is developing industrial facilities to meet the growing need for end-of-life treatments and improve recycling efficiency. In 2020, the European Commission publishes a proposal on the efficiency of recycling. As a result, By2030, the overall recycling efficiency should be at least 70 %, with a recycling efficiency rate of more than 95 % for cobalt, nickel and copper and above 90 % for lithium. The developed processes must therefore be able to comply with these regulations.

The main countries involved in recycling in Europe are Germany, France, Belgium and Finland. Germany's industrial facilities use mechanical, thermal, and pyro/hydrometallurgical processes. In France, the leaders are SNAM, which also uses mechanical, thermal, and pyro/hydro-metallurgical processes, and Eurodieuze, which uses mechanical and hydrometallurgical processes. However, France is developing many pilot projects across the country, including Sanou Koura with an innovative recycling process (mixed process) by TND and Mecaware, which is also developing a new technology based on CO2 recovered from industrial emissions and amines using the BM produced by MTB. In addition, several future LIBs recycling facilities in Europe are also under construction, such as Northvolt and STENA recycling in Sweden.

<u>LCI of LIB recycling processes and Life Cycle Impact Results</u>

There are few Life Cycle Inventories (LCIs) for the various LIB recycling processes, as LIB technologies are still under development. Existing LCA studies on this topic are based on different assumptions, mainly using old unreliable data and LCIs. Indeed, most of the available LCIs are based on literature and not industrial data. The processes studied no longer represent the battery recycling technologies and processes on the market today. The lack of data communication on the part of manufacturers leads to a lack of good quality and reliable inventories. Therefore, WeLOOP conducted a Data Quality Assessment (DQA) for databases and LCIs available for LIB battery recycling processes. The DQA revealed that the databases (Ecoinvent, GaBi, EIME, PEF/OEF) and available inventories are at best of "good quality", with most current data sources being of "medium quality". However, databases and LCIs should score "excellent" or "very good" to be used when conducting a reliable LCA study according to PEF (European commission Product Environmental Footprinting) requirements.

TND has carried out semi-specific LCIs of BM preparation processes, recycling by pyrometallurgy (which treats the battery directly), hydrometallurgy (which treats BM) by precipitation and solvent extraction, and by mixed process (Sanou Koura process); based on a bibliographic study and available data from industrial processes. Life Cycle Inventories were developed by considering a given BM composition, resulting from a mixture of electrical and electronic waste and electric car batteries (LiCo and NMC). The validity of these processes and the LCIs is maintained for a small variation in the order of magnitude of the composition of the BM. It can therefore be assumed that for a small amount of LFP batteries in the composition of the BM, the processes will still be consistent and will only increase the iron recovery share. However, if the proportion of LFP becomes too high, the processes and calculations must be adjusted.

The results of the Life Cycle Impact Assessments show that the environmental impacts of the BM process are mainly derived from the heating stage due to the amount of activated carbon used and its end-of-life treatment. The impacts of the process of hydrometallurgy by precipitation are mainly related to the recovery of cobalt which requires significant consumption of sodium sulfate, which is very present in the effluents and requires very energy-intensive evaporation for its crystallisation at the end of its life. This last hot spot is also found in other processes. The pyrometallurgical process, which includes a chemical step to treat slag, concentrates these impacts on global warming, most specifically at the stage of melting batteries at 1600 ° C and in the steps of calcium recovery. Finally, the mixed process, which includes the steps of hydrometallurgical and pyrometallurgical processes, is the most impactful during the recovery of copper, cobalt and nickel by solvent. Therefore, energy consumption and consumables and their end-of-life treatment stand out as the major environmental issues of LIB's recycling processes.