Economic analysis of Li-ion battery recycling using hydrometallurgical processes

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Abstract: *In recent years, much attention has been paid to the recycling of Li-ion batteries (LIBs) [1, 2]. However, there are only few economic assessments on the recycling of LIBs even if, by 2030, it is possible to reach 2 million tons of spent LIBs/year worldwide [3, 4].*
In this context, the present work aims to present a viable business model that is feasible and economically efficient and can be framed in a circular economic recycling technology of spent LIBs. The proposed business model uses literature data on the hydrometallurgical processing (HP) of spent LIBs. The business plan contains estimates of costs and revenues, and, also, estimates or projections concerning the state of the relevant markets and industries for the products resulting from spent LIBs.
Our work proposes a feasible and sustainable circular economy solution able to deliver critical materials such as cobalt, lithium, nickel, and copper for the supply chain of the LIBs manufacturing. From our estimate, valorising all recovered materials, the annual profit can reach around 600,000 $ for a commercial recycling plant that processes 125 tons/year of spent LIBs.
Keywords*: LIBS, RECYCLING, HYDROMETALLURGY, CIRCULAR ECONOMY, BUSINESS MODEL*

1. Introduction

In the coming decades, the global production of LIBs will increase significantly due to the growing demand for electric vehicles (EV) and portable electronics (PE) [4]. The International Energy Agency (IEA) estimates that between 2017-2030, the number of EV in operation will increase from 3 million to 125 million [5]. At the same time, there is a growing concern about the supply of raw materials, especially rare metals such as lithium and cobalt [6]. Under these conditions the recycling of spent LIBs becomes crucial.

Spent LIBs are recycled mainly in Europe, Asia and North America. Due to the fact that until recently the production of LIBs has been carried out almost exclusively in China, South Korea and Japan, Asian companies are profitable due to the large quantities of spent LIBs [7, 8].

The recovered materials from spent LIBs could be used to make new batteries, reducing manufacturing costs. The lithium, cobalt and nickel prices represent the most expensive components, with substantial fluctuations in recent years [9, 10]. According to the recent studies, recycled material and second life batteries can generate a market worth more than $6 billion, based on current metal prices [11].

The recycling technologies of spent LIBs include mechanical, pyrometallurgical and hydrometallurgical processes [12]. Compared to pyrometallurgical processes, hydrometallurgical processes are known to be flexible, with a high degree of selectivity, low energy consumption, low–level of hazardous gas emissions, and economical, which indicates a great potential in their industrial implementation [13].

The proposed economic analysis of the recycling of spent LIBs, includes a brief presentation of the recycling stages and an assessment of the ratio between turnover, expenses and profit in order to create a sustainable circular economy in the supply of critical materials (lithium, cobalt, nickel and copper).

2. Economic analysis

For the recovery of materials from spent LIBs, we propose a cost assessment of processing through a combined mechanical – hydrometallurgical (CMHP) recycling process.

The proposed technology for recycling spent LIBs consists of the following steps:

- Mechanical separation;
- Hydrometallurgical recovery;
- Valorification of recovered materials.

CMHP is considered an economically sustainable alternative [14]. The most valuable components of spent LIBs are the following metals: cobalt, nickel, manganese and copper [4]. The recovery of lithium, aluminum, graphite and plastics is also targeted [5, 15].

The cost assessment will be based on an average composition of spent LIBs [16] (see Table 1). It is also considered a material recovery rate of 95%. High purity of recovered metals is considered to be provided by hydrometallurgical processing. The recovery process installation based on CMHP will process 125 tons of spent LIBs annually.

Table 1: *Average composition of spent LIBs.*

Component	% (w/w)
Metal housing	7
Plastic	8
Graphite	19
Copper	11
Cobalt	9
Manganese	6
Nickel	6
Lithium	2
Oxygen	11
Aluminum	5
Electrolyte	16

2.1. Mechanical separation (MS)

MS consists of the complete discharge of spent LIBs (to eliminate the danger of explosion by an uncontrolled discharge). After discharge, the components are disassembled manually or mechanically: metal housing, plastic components, cables, battery management unit (BMU) which can be recycled directly and treated separately [17, 18]. The electrode materials (cathodes and anodes), the polymer separators are also separated, and subjected to drying at temperatures between 100 – 140 °C [19], for evaporation and collection of the electrolyte [17]. Electrode materials composed mainly of $LiCoO_2$, LiNixCoyMnzO$_2$, $LiMn_2O_4$, $LiNiO_2$ and $LiFePO_4$ are crushed to obtain the so-called black powder (BP), for further chemical treatment.

2.2. Hydrometallurgical recovery

The solubilization of the BP components is done using 2.0 M H_2SO_4 and 4.0% H_2O_2 at a temperature of 70 °C. The resulting aqueous solution containing ions of aluminum, lithium, cobalt, copper, nickel, iron and manganese is further treated to recover them in the form of salts or pure metal.

To separate the metal ions from the leaching solutions of spent LIBs, a combination of extraction agents such as D2EHPA and TBP will be used to improve the purity of the product [7]. The metals will be precipitated using Na_2CO_3 [20, 21].

2.3. Valorification of recovered materials

The efficiency of the recycling process of spent LIBs is influenced by the processing costs, the purity of the products obtained and their market value. Aspects related to global policies, the demand / supply ratio caused large price fluctuations of metals used in the manufacture of LIBs, as can be seen in Fig. 1. Under these conditions, the prices of the materials resulting from the recycling of spent LIBS presented in Table 2 will be taken into account.

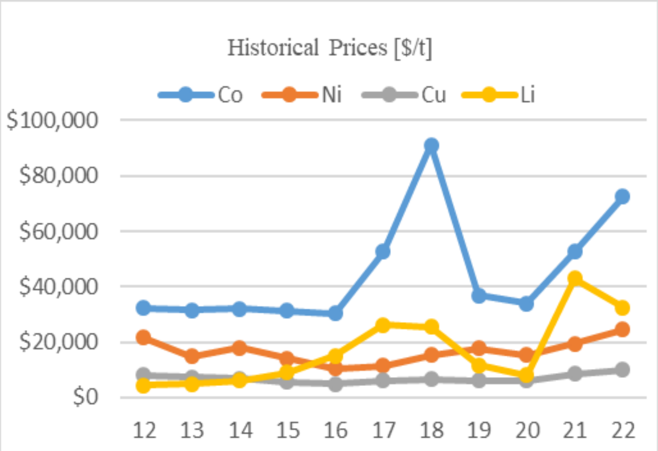


***Fig. 1**. Historical prices from the last 10 years (2012-2022) [9]*

***Table 2:** Estimated data for a financial year*

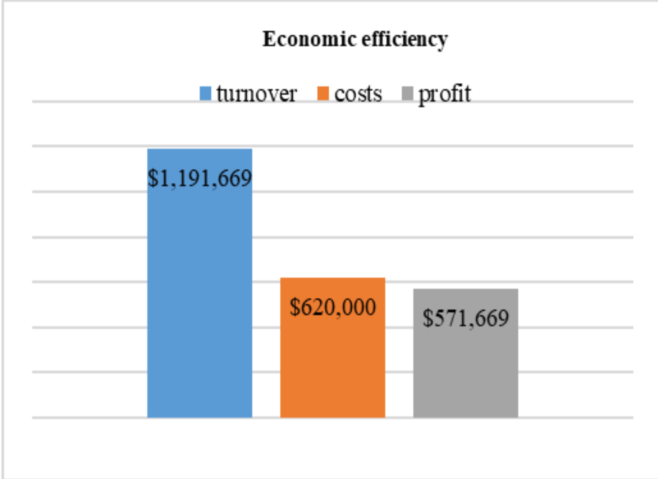
Product	Price [9] ($/kg)	Estimated quantity (kg/year)	Annual turnover ($/year)	Weight (%)
Lithium carbonate	32.6	2,375	77,425	6.50
Cobalt	72.5	10,688	774,844	65.02
Nickel	24.4	7,125	173,850	14.59
Manganese	1.48	7,125	10,545	0.88
Copper	10	13,063	130,625	10.96
Aluminum	2.6	5,938	15,438	1.30
Graphite	0.02	22,563	36.1	0.00
Plastic	0.5	9,500	4,750	0.40
Metal housing	0.5	8312	4,156	0.35

As can be seen from Table 2, cobalt is the most valuable element in batteries, followed by Ni, Cu and Li. If cobalt had not been considered, recovering these types of batteries would not be cost effective.

2.4. Cost evaluation

The associated production costs with the processing of spent LIBs are estimated from the data of a hydrometallurgical recycling facility at 4.96 $ / kg of processed waste [22].

Fig. 2 represents the turnover, cost and profit from the processing of spent LIBs, taking into account a degree of recovery of 95% of the waste.



In the supposed recycling system, a profit of $ 571,669 can be generated. The proposed technological process removes waste of Li-ion batteries from landfills; improve manufacturing costs by recycling materials from LIBs and reusing them in the process of making new batteries and will eliminate carbon emissions using environmentally friendly processes.

3. Conclusions

In the future, LIBs manufacturers will use more and more raw materials from spent batteries [23].

Due to the evolution of the prices of the metals (lithium, cobalt, nickel, manganese, and copper) used in the manufacture of LIBs, recycling is not only a profitable business, but a way to conserve the natural resources.

Last but not least, the recycling of spent LIBs, in the conditions in which their volume will increase exponentially is a sustainable alternative, part of the circular economy with positive impact on the environment.

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