Material flow and economic analyses of Lithium-ion batteries recycling processes in Europe

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Introduction

Current European legislations support the electrification of transport systems to cut off GHG emissions. However, the sustainability of Lithium-ion Batteries (LIBs) is strongly dependent on the recycling processes, fundamental in limiting raw materials' demand to reduce the economic, environmental, and social impacts associated with mining activities. Currently, European LIBs' recycling capacity relies on pyrometallurgical and hydrometallurgical processes, and literature analyzed the financial and environmental impacts of such processes (Ali et al., 2021). Still, a specific analysis of the economic tradeoff between the costs and potential revenues due to full-scale LIBs' recycling treatments hasn't been performed. This work compared current state-of-the art LIBs' recycling technologies at full-scale through material flow and economic analyses of the European Electric Vehicles (EVs) recycling infrastructure.

Materials and Methods

This study considered 720,913 new circulating EVs in Europe (EU27, Iceland, Norway and the UK) (EEA, 2021), assuming a 10 years expected LIBs lifetime (Chen et al., 2019), and 318 kg average weight per battery (Iclodean et al., 2017) to estimate the amount of end-of-life (EoL) LIBs expected in Europe by 2030. Different cathodes' chemistries were included in the analysis (% of EVs): 2% LFP, 19% NCA, 24% NMC111, 45% NMC622 and 10% NMC811 (Statista, 2021). The material composition of different batteries has been accounted according to previous studies (Gaines et al., 2018). European LIBs' recycling capacity, according to existing full-scale facilities, and material recovery efficiencies of recycling processes (pyrometallurgy and hydrometallurgy) have been assessed according to literature. Specific data to estimate operative parameters (energy demand, input materials requirements and amount of produced waste), their costs, and market values of recovered material streams have been collected in the Ecoinvent 3.8 database. The revenues considered in this study entailed the sales of the recoverable cathodes' metals (Al, Cu, Li, Co, Min, Ni, Fe and P). Energy costs for non-households consumers (0.086 €/kWh) and landfill fees (22 €/t) have been estimated for European countries (Eurostat, 2021; Statista, 2017). Other costs (e.g., mechanical pre-treatments energy demand, labour cost, maintenance) have been excluded from this analysis, as they could be considered equivalent comparing the recycling processes.

Results and discussions

Considering the European EVs' fleet, market shares of different battery chemistries, and their material compositions, 229 Mt of EoL LIBs are expected by 2030. This amount corresponds to 5.7 Mt of plastic components (PE and PET), 34.7Mt of electrolytes (DMC, EC and $LiPF_6$), 6.8 Mt of organic binder, 46.9 Mt of graphite and 38 Mt of Cu for the battery anodes and 19 Mt of Al, 5.6Mt of Li, 9.3Mt of Co, 25.5Mt of Ni, 7.6Mt of Mn, 0.5Mt of Fe and 0.3Mt of P for the battery cathodes.

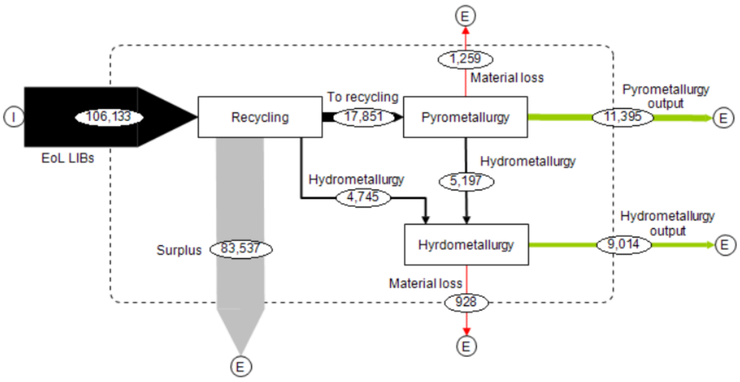

Figure 1. Material flow analysis of European LIBs' recycling infrastructure based on 2020 EVs' sales

Current European LIBs' recycling capacity sums 48.8Mt, 56% treated by pyrometallurgy, 23% by pyrometallurgy followed by hydrometallurgy, and 21% by hydrometallurgy only. A shortage of current recycling capacity with respect to the waste streams is expected in the next years (Figure 1). According to material specific recovery efficiencies of the full-scale recycling treatments, the recovered materials has been estimated: 3.5 Mt of Al (87% of input to recycling), 7.8 Mt of Cu (96% of input), 0.5 Mt of Li (42% of input), 1.8 Mt of Co (90% of input), 5.3 Mt of Ni (98% of input), 1.5 Mt of Mn (90% of input), and 39 t of Fe (35% of input). The lowest recovery rates have been observed for Li and Fe, which are lost in the slag phase of pyrometallurgical processes. According to current market values, the metals recovered by

LIBs' recycling will correspond to 53.6 M€, mainly due to the high incomes from the sales of Co (18.8 M€), Cu (27.7 M€), Li (3.4 M€) and Al (2.9 M€) (Figure 2). The main costs (Figure 3) are associated with energy (particularly for pyrometallurgical processes) and input materials, estimated as 9.5 Mt 50% NaOH solution and 2.7 Mt water for pyrometallurgical plants; 1.2Mt lime, 2.4 Mt sulphuric acid and 0.7Mt water for hydrometallurgical plants and 3.8Mt 50% NaOH solution, 1.3Mt lime, 2.5Mt sulphuric acid and 1.9Mt water for combined pyrometallurgical and hydrometallurgical plants. The energy demand is: 21.8 GWh for pyrometallurgical plants, 14.5 GWh for hydrometallurgical plants and 10.3 GWh for combined pyrometallurgical and hydrometallurgical plants.

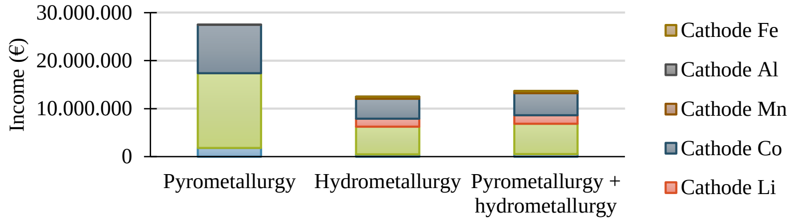

Figure 2. Income (€) from sales of recycled metals according to 2020 EVs sales and actual European treatment capacity by recycling process

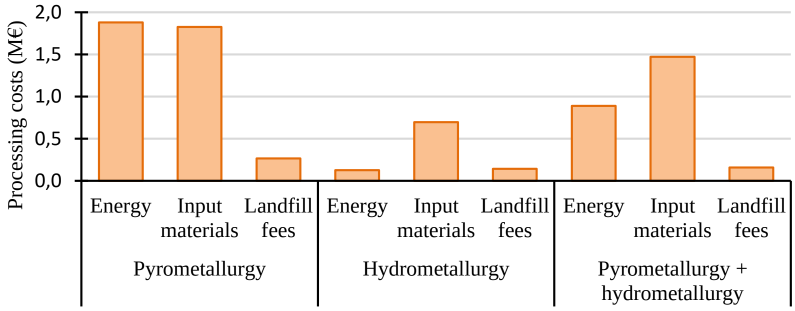

Figure 3. Processing costs (M€) related to recycling processes according to 2020 EVs sales and actual EU treatment capacity

Conclusions

The European LIBs' recycling infrastructure is not prepared to face the amount of EoL batteries in the next future. However, the recycling efficiencies of currently operating plants are high, and allow to recover up to 90% of the metals (Al, Cu, Li, Co, Mn, Ni, Fe, P) from battery cathodes and generate 53.6 M€ of revenues. The combination of pyrometallurgy followed by hydrometallurgy brought the highest revenues (1242 €/t) but also in the highest operative costs (230 €/t), whereas hydrometallurgy presented the best trade-off between revenues (1200 €/t) and operative costs (92 €/t), especially when compared with pyrometallurgy alone, characterized by limited revenues (1006 €/t) and relatively high costs (145 €/t).

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