

Bottlenecks in Lithium Recovery: From Spodumene Processing to Sustainable Battery Recycling

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Several mineralogical and process-related bottlenecks limit the efficiency and sustainability of Li extraction from spodumene, an important Li-bearing mineral. In its natural form, spodumene occurs as α -spodumene, a highly stable and refractory phase with low chemical reactivity. To aid effective Li extraction, it must first be converted into the more reactive β -spodumene through calcination at temperatures above 1000 °C [1]. This high-temperature treatment results in significant energy consumption and represents one of the major economic and environmental constraints of conventional spodumene processing.

Following thermal activation, Li is extracted through acid roasting with H₂SO₄, which converts Li into soluble Li sulphate [2]. This method is widely used industrially and involves large quantities of corrosive reagents, generating acidic effluents, and producing waste residues that require proper management.

The recycling of Li-ion batteries presents additional bottlenecks in the recovery of critical raw materials. Examples include complex and evolving cathode chemistry, difficulties in safe handling and dismantling, operational costs and economies of scale, and inefficient recovery. Although metals such as cobalt (Co), nickel (Ni), manganese (Mg) and Li can be recovered through hydrometallurgical or pyrometallurgical processes, other battery components remain challenging to recover, such as graphite, which accounts for about 12–21 wt% of batteries [3]. High energy and reagent consumption, as well as inefficient recovery or lack of purity of the metals (Li, Ni, Co, Mn), are limiting the circularity of battery materials.

To address these challenges, alternative approaches were investigated to reduce energy consumption and reagent use in spodumene processing. Mechanical activation (high energy milling) has been studied to induce structural disorder in α -spodumene, potentially lowering the temperature required for the follow α -to- β phase transformation. Other strategies include the use of CaCl₂ roasting to produce LiCl, as an alternative to H₂SO₄, reducing the dependence on strong acids. Additionally, leaching processes at or near room temperature are being explored to minimize thermal requirements. In battery recycling, process integration and flexibility, through correct design of hydrometallurgy flows and operations, is being pursued. These aim to reduce energy demand, minimize waste generation, and improve the sustainability of Li supply chains.

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