Electrochemically based processes for critical raw materials recovery: the case of Co and REEs

P. Guedes[1,2], N. Couto[1,3], E. P. Mateus[1], A. N. Alshawabkeh[2], S. Pamukcu[3], A. B. Ribeiro[1]

[1]CENSE – Center for Environmental and Sustainability Research & CHANGE - Global Change and Sustainability Institute, NOVA School of Science and Technology, NOVA University Lisbon, Campus de Caparica, 2829-516 Caparica, Portugal
[2]Department of Civil and Environmental Engineering, Northeastern University, Boston, MA 02115, USA
[3]Department of Civil and Environmental Engineering, Lehigh University, Bethlehem, PA 18015, USA
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Presenting author email: epm@fct.unl.pt

The transition to low-carbon energy systems, which includes renewable energy technologies, electric vehicles, and battery energy storage systems, is underway. This transition is estimated to require 3 billion metric tons of materials for low-carbon technologies, representing over 1000% growth in demand for critical raw materials (CRMs) by 2050 (Hund et al., 2020), triggering the most significant demand increase for CRMs in history (Karali and Shah, 2022), alongside with increasing population and living standards.

CRMs are raw materials that are economically and strategically important to an economy but carry high supply risk due to factors such as insufficient production capacity, geopolitical concerns, and market price dynamics (European Commission, 2023). Furthermore, there are concerns about the environmental and socio-economic impact of mining CRMs in countries with lighter regulations than Europe, also raising questions about environmental justice. Both the EU and the USA have been releasing and updating a CRMs list, which differs between them, as some minerals not critical to the EU can be critical in the USA, such as aluminium and arsenic (European Commission, 2023; U.S. Geological Survey, 2022). Thus, the criticality of these materials calls for developing technologies that allow their recovery from secondary sources, helping to security issues. Electrochemical methods appear as a green(er) alternative as they allow to overcome some of the limitations involved in the traditional methods. Electrochemical methods offer a modular approach that, through the integration of renewable energy sources, can be a sustainable and delocalized CRMs recycling alternative (Ramprasad et al., 2022).

In this work, we highlight electrochemical technologies designed to recover CRMs. For this, we selected CRMs from the list considering their commonality to the EU and the USA, supply risk, and economic importance, namely their impact on the energy transition (Tkaczyk et al., 2018). This resulted in the selection of cobalt and rare earth elements (REE). We provide insights into the application and mechanisms for the electrodialytic (ED) process applied for the selective recovery of REEs (Couto et al., 2020) and Co from secondary sources (Guedes et al., 2024). REEs were recovered from coal ashes and Co from tungsten carbide scrap powder, using an electrodialytic reactor (Figure 1).

For the REEs recovery, it was identified that the limiting step for HREEs was their solubilization rate from the ash (electrochemical leaching), whereas, for the LREE, it was the mobilization (electromigration) (Couto et al., 2020). This work allowed to observe a clear separation pattern depending on the REE position in the periodic table. At the best-tested conditions (50 mA, 72 h), more than 70% of REE were extracted from the ash with the catholyte enclosing up to ≈ 50% of LREE and HREE (Couto et al., 2020). For the Co recovery, the strategy was adapted, and ultrasound-assisted extraction (UAE) was coupled to the ED process aiming to increase the leaching

step efficiency (Guedes et al., 2024). In this case, 99% of Co were leached (200 mA, 24 h) was applied in combination with UAE, with 90% of the total Co recovered in the catholyte (Guedes et al., 2024).

In both cases, the electrodialytic (ED) process, without the use of acid as a chemical adjuvant, proved to be an efficient method for the selected CRMs recovery.

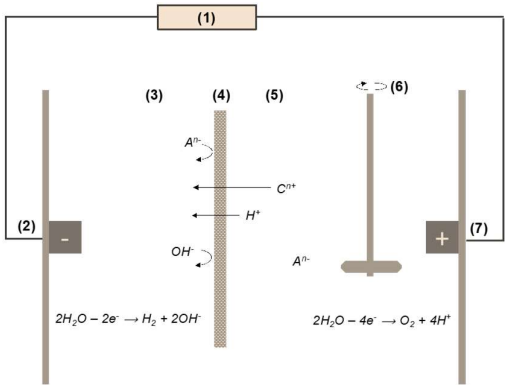

Figure 1. Electrodialytic reactor schematic representation: (1) power supply (2) cathode, (3) cathode compartment, (4) cation exchange membrane, (5) anode compartment (CRMs secondary source compartment), (6) stirrer and (7) anode (adapted from Guedes et al., 2024).

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