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Novel frontiers in circular and sustainable brine mining

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Abstract

Global desalination capacity generates approximately 90 million m³/day of industrial waste brine: a potential source of minerals and raw materials, currently totally unexploited. While, conventional minerals extraction is hindered by high environmental costs and geopolitical dependencies, particularly for Magnesium (classified by EU as a Critical Raw Material), novel frontiers in sustainable brine mining advocate for a shift toward the circular processing of brine and bitterns (concentrated brines remaining after natural salt crystallization) to secure access to these materials while adhering to the highest environmental standards. In this framework, the University of Palermo (UNIPA) has played a central role in developing cutting-edge technologies, validated at the pilot scale, to recover CRMs and other valuable resources from brine, within international EU projects as SEArcularMINE, Water Mining and MareMag LIFE.

The technological core of this approach involves magnesium recovery through Multiple Feed Plug Flow Reactors (MF-PFR), within circular schemes ensuring full sustainability by in-situ chemicals generation via Electrodialysis with Bipolar Membranes (EDBM), which produces sodium hydroxide (NaOH) and hydrochloric acid (HCl) solutions directly from brine, achieving a circularity potential of over 99%. These systems enable the production of magnesium hydroxide (Mg(OH)₂) with high purity (>99%) and exceptional process yields (>99.9%), yet keeping the specific electrical consumption to very low values (2-3 kWh/kg of Mg(OH)₂ produced), providing a sustainable alternative to traditional mining.

The gained experience from lab-scale research to pilot plants operating in real operational sites in Lampedusa and Trapani will be presented, demonstrating the technical feasibility in operational environments and technology readiness levels advancements from TRL 4 to TRL 7.

Finally, Life Cycle Assessments (LCA) indicate how these circular approaches can reduce the emission of relevant amounts of CO₂ and save significant freshwater volumes shifting from traditional mining to circular brines valorisation, thus paving the way for a resilient, "water-smart" economy, transforming industrial waste into a strategic resource for Europe.