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Strategic Minerals, Circular Economy, and the Future of Sustainable Materials Processing

OSCAR JAIME RESTREPO BAENA

Department of Materials and Minerals, Universidad Nacional de Colombia.



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In recent decades, the global economy has entered a phase of accelerated demand for strategic minerals, driven by the widespread deployment of clean technologies, electric mobility, and digital infrastructure. Metals such as lithium, cobalt, nickel, rare earth elements, and even copper are no longer commodities of purely industrial interest, but key enablers of the energy transition and the sustainability agenda. This shift has brought both opportunities and critical challenges for the mining and materials.¹

One of the most pressing concerns is the environmental and social footprint of conventional extractive processes. Traditional mining and metallurgical operations are often resource-intensive, energy-consuming, and generate significant amounts of waste.^{1,2} In many countries of the Global South, including those in Latin America, mining remains both a vital economic engine and a source of environmental tension and territorial disputes.

In this context, the concept of the circular economy offers a compelling framework to rethink how we extract, process, use, and recover mineral resources. For materials science and metallurgy, this implies going beyond efficiency gains to fundamentally redesign processes: integrating clean technologies, minimizing emissions, recovering value from industrial residues, and enabling longer material life cycles through reuse and recycling.

The emerging field of green metallurgy represents a step forward in this direction. It encourages low-carbon processing routes, hydrometallurgical alternatives, selective leaching, and the use of renewable energy in pyrometallurgy. Furthermore, innovations in material characterization, data-driven optimization, and waste valorization are enabling the transformation of liabilities into resources.

CONTACT Oscar Jaime Restrepo Baena ✉ ojrestre@unal.edu.co 📍 Department of Materials and Minerals, Universidad Nacional de Colombia.



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Academic institutions, especially in resource-rich countries, have a crucial role to play. As educators and researchers, we must foster interdisciplinary training that merges metallurgy, environmental sciences, economics, and social understanding. Future professionals must be not only technically proficient but also ethically committed and socially aware.

In Colombia, initiatives such as the IGNEA research group at the Universidad Nacional de Colombia are advancing experimental and theoretical work in the recovery of critical metals from industrial waste, the environmental assessment of mining districts, and the design of sustainable metallurgical flowsheets adapted to local realities.³ These efforts underscore the potential of Latin American science to contribute meaningfully to global sustainability challenges.^{4, 5}

To ensure real impact, however, stronger collaboration is needed between academia, industry, and government. Public policies must support innovation, incentivize responsible production, and promote knowledge transfer. International cooperation can also facilitate access to technology and strengthen regional capabilities.⁶

Conclusion

The future of strategic minerals is not solely determined by geological availability but by our capacity to produce them in ways that respect the planet and empower communities. Circular economy principles and sustainable materials processing must become central pillars in the transformation of the extractive sector.⁷ Through science, education, and cooperation, we can reimagine the role of materials in a just and resilient future.

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