Reconfiguring the Techno-Economic-Environmental Landscape for Low-Grade Ore Extraction: A Strategic Analysis of Stope Leaching Systems

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ABSTRACT

As the mining industry confronts escalating pressures to meet global demand for transition metals while upholding rigorous Environmental, Social, and Governance (ESG) standards, the progressive shift towards low-grade, complex, and deep-seated orebodies is exposing inherent limitations of conventional mining systems. In this context, stope leaching (SL) has re-emerged as a more sustainable solution, potentially enabling the extraction of metals from low-grade, deep-seated deposits with a reduced environmental footprint and project dynamics showing reduced sensitivity to grade. Yet, the current lack of robust quantitative tools for strategic optimisation and scenario evaluation in SL systems restricts our capacity to evaluate extraction strategies.

Stope leaching systems require modifications to conventional underground stoping optimisation strategies, as project value creation becomes intrinsically governed by complex interactions between mineralogy, specific surface area, stope geometries, leaching kinetics, column flow dynamics, and overall recovery rates. This integrated system introduces spatiotemporal dependencies that transcend traditional stoping considerations, fundamentally modifying the time structure, process cycles, risk profiles, and uncertainty within the SL process—all critical elements of strategic planning.

This study identifies the key techno-economic and environmental parameters that shape operational viability in SL systems. Through an integrated analysis of geological, hydrometallurgical, ESG, and mine optimisation parameters—coupled with data-driven approaches—this research bridges fundamental gaps in understanding SL strategic performance and underpins essential strategic optimisation requirements. This analysis provides critical insights and system requirements to support strategic decision-making in SL implementation, establishing a theoretical foundation essential for robust quantitative optimisation and positioning SL as a transformative solution for sustainable mining practices.