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Enhanced Mineral Carbonation for CO_2 Sequestration and Arsenic Immobilization in Legacy Mine Tailings: Insights from Croydon, Australia

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Australian mining operations generate 50–70 million tonnes of tailings and millions of litres of saline mine-affected water (MAW) annually. These pose significant environmental risks, including acid and metalliferous drainage (AMD), with site rehabilitation costs estimated at $1–5M per facility. Current remediation technologies, such as reverse osmosis and lime neutralization have high operational costs and carbon intensities. This study evaluates an integrated mineral carbonation strategy to neutralize acidity and sequester arsenic. By utilizing alkaline brine lixiviants derived from MAW, reactive waste minerals are transformed into secondary carbonate minerals such as magnesite and dolomite, facilitating carbon storage and tailings stabilization.

A quantitative metric was developed to estimate theoretical storage capacity based on the abundance and reactivity of calcium (Ca) and magnesium (Mg) minerals. This metric was applied to a 3D geostatistical model of the Croydon mine tailings in Queensland, constructed from field mineralogical and geochemical data.

Reactive transport simulations were conducted to evaluate a dual-phase injection strategy: an initial high-flow acid flush to promote mineral dissolution, followed by a lower-flow alkaline/carbonated brine injection to enhance secondary carbonate precipitation.

Long-term simulations (up to 50 years) tracked the dissolution of primary siliciclastic and sulfide minerals and the simultaneous formation of magnetite and dolomite. Sensitivity analyses indicated that injection within the phreatic zone using a high concentration of oxidizing agents yielded the highest carbon mineralization potential for arsenopyrite devoid tailings and arsenic immobilization in arsenopyrite enriched tailings. Results suggest that the 19 Mt of Croydon tailings could theoretically sequester 145 kt of CO_2. However, the simulations, which account for complex geochemistry and ion exchange, yielded lower estimates of 25-60 kT of CO_2 and ~30T of As sequestration. To achieve these yields at scale, a distributed network of fluid sprinklers is recommended to optimize fluid-mineral interaction. This study provides a foundational framework for carbon-neutral mine closure, offering a scalable methodology to mitigate approximately 100 kt of CO_2 -e annually across regional sites while significantly reducing long-term environmental liabilities.