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Reimagining Tailings

Setting the scene

The IEA has reported that critical minerals experienced strong growth in 2023, and that the combined market value of key energy transition minerals – copper, lithium, nickel, cobalt, graphite and rare earth elements – is expected more than double to reach USD$770 billion by 2040 in their net zero scenario.

Water use and tailings management, which are inextricably linked, represent risk and constraints as the mining sector looks to meet this increased demand. Societal and environmental concerns related to water and tailings have escalated globally as water supply and quality are threatened, and the volume of tailings expands significantly due to lower ore grades.

The International Council on Mining and Metals (ICMM) recently collaborated with MIT to host a Global Summit on Mine Tailings Innovation to seek industry input and collaboration in accelerating the development of solutions to reuse, reduce, and reimagine mine tailings. This white paper outlines ways to address and transform mine tailings, based on the panel discussions and comments by Satish Rao at the summit.

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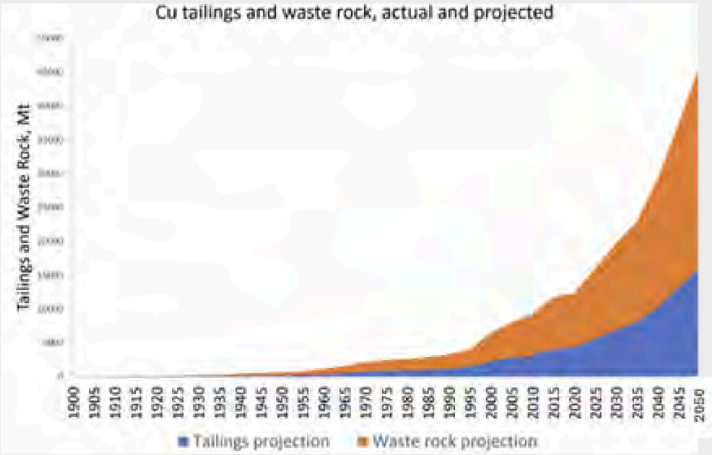
Context: Tailings as a Risk and Constraint to Meeting Minerals Demand

Water use and tailings-related challenges have surfaced as water supply and quality are often stressed in many mining jurisdictions.

Lower ore grades processed with conventional approaches result in a higher volume of tailings, a situation exacerbated by attempts to increase supply in response to market demand. A 2023 study in the journal Resources, Conservation and Recycling forecasts a dramatic increase in mining waste production through to 2050, depicted to the right.

The mining industry has recognized the risks associated storage of tailings and the absolute necessity of safety, and is acting to implement changes after catastrophic tailings dam failures at Mount Polley (Canada) in 2014, Samarco (Brazil) in 2015 and Brumadinho (Brazil) in 2019. The International Council on Mining and Metals (ICMM) supports adoption of industry standards on tailings management, and explores the development of breakthrough technologies through its tailings reduction roadmap.



Achieving the complete elimination of tailings

The Global Summit on Mine Tailings Innovation posed a thought-provoking question to the Re-Imagine panel on how we might consider and achieve the complete elimination of tailings, and which key knowledge gaps and obstacles remain to be addressed.

This can be a daunting task to consider as there is no silver bullet to eliminate waste and tailings, and challenges vary by commodity, deposit, geography, and operating legacy. We present the following continuum of approaches to address tailings that can form the basis for a technology and innovation roadmap for a mining company that wishes to embark on a zero waste and tailings optimization journey.

01 Optimize Recovery

Recover all the value that is possible from waste and tailings, including minerals and water. This can also improve safety through dewatering and dry stacking.

02 Eliminate Waste

Reject waste as early as possible in the process through precision mining, ore upgrading, and reducing or eliminating water in processing.

03 Process Everything

Derive value from the entire rock that has been extracted, and process all of it.

04 Transform Leaching

Improving the cycle time and recoveries from leaching can help make it a viable alternative, with reduced waste and ability to target lower ore grades.

05 Recover through In-Situ Extraction

Develop new approaches to extracting valuable minerals directly from the ore body without conventional mining methods, leaving waste behind.

Mining companies can develop a portfolio of initiatives based on the above approaches, to start providing value today, and address the risks and constraints of the future.

1. Optimize Recovery

There are several opportunities to improve recovery from waste.

Tailings can be repurposed for creating valuable materials. This typically involves chemical and physical alterations to remove contaminants and change their physical attributes to make them suitable for use, such as in building materials. Three conditions must be met to create value: suitability of tailings materials for use, cost-effective treatment, and strong local or regional demand for such products.

Tailings can also be reprocessed to recover valuable materials through chemical processing innovations. Mining companies should periodically review the potential for such recovery as technologies and economics may improve over time since the tailings were originally deposited, or future metals such as rare earth metals that might not have previously been considered valuable. Tailings can also provide for recovery of valuable salts or acids through chemical processes.

Dewatering of tailings can help reclaim and recover water for further use. This can be achieved through physical mechanisms like conventional filtration and dewatering rolls, or chemical additives to agglomerate solids together in tailings to make them easier to target and remove. Specialized chemistries and physical changes to the pump-pipeline network can enable pumping of thicker slurries and pastes. When coupled with effective thickening technology, these innovations can allow for more complete dewatering in an energy efficient manner.

Process water and acid mine drainage (AMD) can be treated through a range of technologies from membranes, thermal and non-thermal approaches, microbial systems, and chemical additives. Such solutions can also help recover valuable minerals in addition to the potential for reclaiming water and improving the environmental impact. This helps enable a closed loop and circular solution for water within mine operations.

2. Eliminate Waste

Early rejection of waste can unlock significant benefits – from requiring fewer inputs to processing due to selectivity, and lower generation of waste. The following opportunities can be utilized to eliminate waste.

Precision mining through technological advancements such as directional drilling and keyhole mining can reduce the waste that is brought to the surface to be processed. Many of these technologies were developed and improved in the oil and gas sector. Additionally, they show promise if they can be adapted for use in mining.

Bulk ore sorting and ore upgrading, such as through CRC ORE's Grade Engineering approach, enables early waste rejection and improving ore processing efficiency. Ore sorting systems have improved their sophistication, and that can lead to better grade control outcomes.

For certain commodities, dry processing can avoid and minimize the use of water, significantly lowering tailings production. Dry processing can include a range of technologies such as dry crushing and grinding, dry separation through air classification, and electrostatic, magnetic, or gravity-based separation, and dry flotation. However, dry processing is challenging due to differences in commodity and mineral types, and the technology is in early stages of development. Some iron ore and REE processing sites have been able to develop dry processing and beneficiation.

3. Process Everything

Processing everything encompasses deriving value from the entire rock that has been extracted, and processing all of it, leaving little to no waste behind. Several emerging technologies promise to deliver on this:

- Molten oxide electrolysis can be used to convert all ore grades to high quality liquid metal using renewable electricity with a one step process. This has been applied to selectively extract valuable metals from complex, low-concentration materials like slag that are currently considered waste.
- Supercritical fluids such as CO_2 can act as solvents to selectively dissolve metals at high pressure.
- Microorganisms can leach specific minerals from low-grade ores, selectively target metals like copper, gold, and nickel by promoting bacterial oxidation. The microbes release the metals into a soluble form, making it easier to extract. The appropriate mix or cocktail of microbes can address the extraction of multiple minerals.

The challenge with such approaches is to deliver value at scale through cost effective means. Certain commodities and minerals can be more readily targeted. They also represent starting points for mining companies. Many valuable minerals such as scandium, tellurium, REE, molybdenum, and sulfur are often left behind in copper tailings because current technologies cannot selectively target trace elements in low concentrations. These minerals can represent future processing opportunities.

4. Transform Leaching

Heap leaching is widely used for certain commodities like copper for its simplicity and relatively lower cost in treating low-grade ores. For commodities like copper, where declining ore grades pose a problem, heap leaching aids in the economic recovery of copper from the lower-grade ore, if the challenges related to chalcopyrite leaching are effectively overcome. The main challenge with chalcopyrite leaching is the passivation layer that acts as a barrier between the copper ore and the lixiviant, rendering the leaching process ineffective. Reaction kinetics at ambient temperatures often require long cycle times. The recovery from conventional heap leaching is also relatively lower than the concentrator circuit due to the larger particle sizes, as the ore being leached is not subjected to the grinding circuit.

Innovations with the potential to transform leaching include the following:

- Use of oxidants to accelerate the reaction kinetics and temperature which can help overcome the chalcopyrite passivation layer.
- Novel use of lixiviants and reagents that acts as solvent and oxidizing agents, facilitating leaching through enhanced dissolution.
- Use of catalysts to break through the chalcopyrite passivation layer.
- Biological approaches involve the use of microorganisms and bacteria, which are often naturally occurring and can aid the leaching process. Microorganisms can be utilized to trigger the ferric leach process for example.
- Hybrid approaches that combine disciplines, including physical and electrokinetic with chemical approaches.
- Heap design and operational considerations also influence recovery and cycle time, such as increasing temperature by the addition of heat, and heap leaching system monitoring and optimization.

If heap leaching can be transformed to achieve performance similar to the concentrator plants, in terms of cycle time and recoveries, it can provide a significant benefit of reducing water use, waste, and eliminating tailings.

5. Recovery through In-Situ Extraction

Recovery of minerals through In-Situ Extraction will not result in waste and mine tailings that conventional mining and processing produce. In-situ extraction is a method of extracting valuable minerals directly from ore deposits without the need for conventional mining. The key process steps for in-situ might include the following:

- Drilling wells into the ore body, which serves as pathways for the injection of the leaching solution into the mineral deposit.
- Once the wells are in place, the leaching solution is pumped through the injection wells into the ore body, where it permeates through the rock and dissolves the target minerals. As the solution moves through the ore, it becomes enriched with the dissolved minerals.
- This solution is then pumped back to the surface through recovery wells.
- At the surface, the mineral-laden solution undergoes processing to separate and recover the valuable minerals. For copper, this typically involves solvent extraction and electrowinning (SX/EW), where the copper is chemically extracted from the solution and then electrically plated onto cathodes to produce pure copper metal.

There are several technical challenges to in-situ extraction, including ore body characterization, permeability enhancement, effective lixiviants, solution flow, and effective monitoring and control systems. The current regulatory landscape also does not provide specific guidelines for in-situ extraction in many jurisdictions, and that can further complicate obtaining operational permits.

The complete elimination of mine tailings is a difficult endeavor, where many challenges and knowledge gaps remain, especially in dealing with the complexity from multiple commodities, minerals, geographies, and operational legacies.

We have presented a range of technologies to address technical challenges, however, new ways of working are also required. For greenfield opportunities, evaluate technologies to reject waste early and minimize water use, and develop a portfolio of technologies for inclusion during initial mine design and planning. However, capital projects favor risk minimization and leave little to no room for innovation, so this will require a new approach and mindset for derisking of these technologies.

Tailings management at legacy and brownfield expansion sites will require a technology portfolio that brings opportunities to increase value and recovery from both ore and waste. The challenge lies in achieving economic scale-up of promising technologies, and industry collaboration will be key, with sharing of costs, knowledge, and data ultimately benefitting the entire sector and impacted communities.