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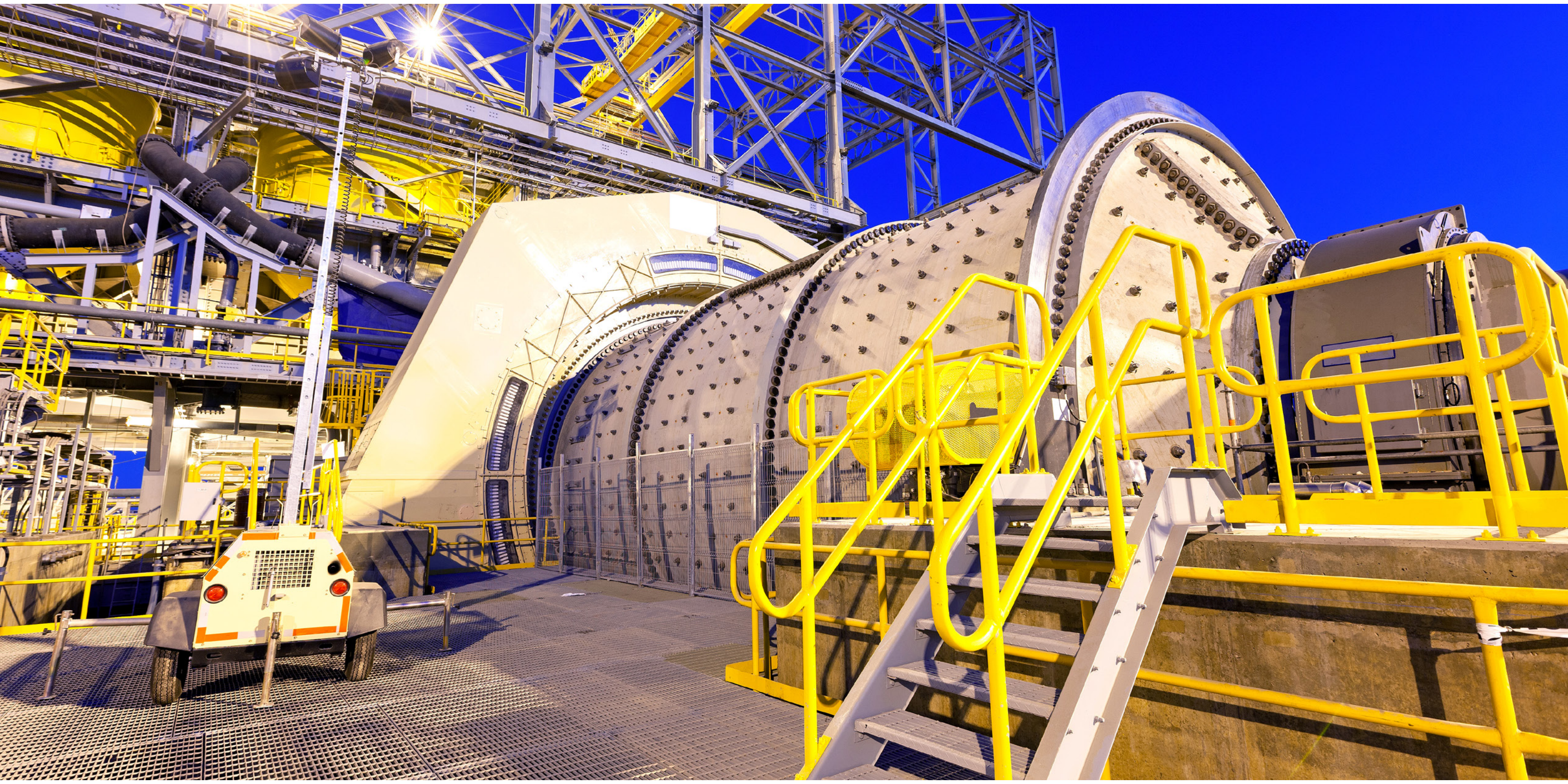
Metals & Mining Practice

Bridging the copper supply gap

With metals demand ramping up rapidly in the face of the energy transition, new processing technologies can help meet the supply shortfall from existing operations.

This article is a collaborative effort by Scott Crooks, Jonathan Lindley, Dawid Lipus, Richard Sellschop, Eugéne Smit, and Stephan van Zyl, representing views from McKinsey's Metals & Mining Practice.



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Decarbonization is one of the greatest challenges of the 21st century. In 2015, governments around the world committed to binding targets, with the goal of limiting global warming to 2°C. Achieving this goal is heavily dependent on rapidly rolling out widespread electrification, which would help to replace hydrocarbons with renewable power sources. And innovation across commodities will play a critical role in helping mining companies respond to these challenges.

One such commodity is copper, which is an essential ingredient for this process. In fact, electrification is projected to increase annual copper demand to 36.6 million metric tons by 2031. Although current supply projections based on restarts, certain or probable projects, and recycled production offer a pathway to 30.1 million metric tons, another 6.5 million metric tons of capacity (an additional 20 percent) remain to be found.

However, the adoption of new emergent technologies—including coarse particle recovery, sulfide leaching, and process optimization with machine learning—has the potential to close a significant portion of that gap (Exhibit 1). The obstacles to commercialization and widespread adoption are not trivial, and the numbers presented in this article are an estimate of full potential, not a forecast. But technological levers should be recognized alongside new mine development as part of the solution.

The trend of declining copper head grades is well established and unlikely to be reversed. Similarly, oxide ore bodies, which do not require concentrators and can be processed through less capital-intensive routes, are being exhausted. The mining industry has responded to these challenges by processing ever-increasing volumes of sulfide ores. In fact, over the past ten years, the volume of ore sent to concentrators has increased by 1.1 billion metric tons, representing 44 percent growth.

Nevertheless, to supply via traditional methods the copper needed for the energy transition, miners will have to repeat this feat again, increasing the volume of ore processed by another 44 percent by 2031 (see sidebar, "About the research"). Of the 1.6 billion additional metric tons of ore required, 0.6 billion metric tons can be provided by recently announced mines or expansions. However, a gap of one billion tons per annum remains. There is an imperative to extract more metal from the ore being mined.

About the research

The analysis in this article was enabled by MineSpans, which is a proprietary McKinsey solution that provides mining operators and investors with robust cost curves, commodity supply and demand models, and detailed bottom-up models of individual mines.

For copper, MineSpans offers mine-level data on 390 primary copper mines and 170 secondary mines and tracks more than 300 active development projects.

Developing and scaling new mineral-processing technologies

Three technological developments are gaining acceptance and scaling across the industry and can contribute meaningfully to bridging the supply gap: coarse particle recovery, sulfide leaching, and process optimization with machine learning.

Coarse particle recovery

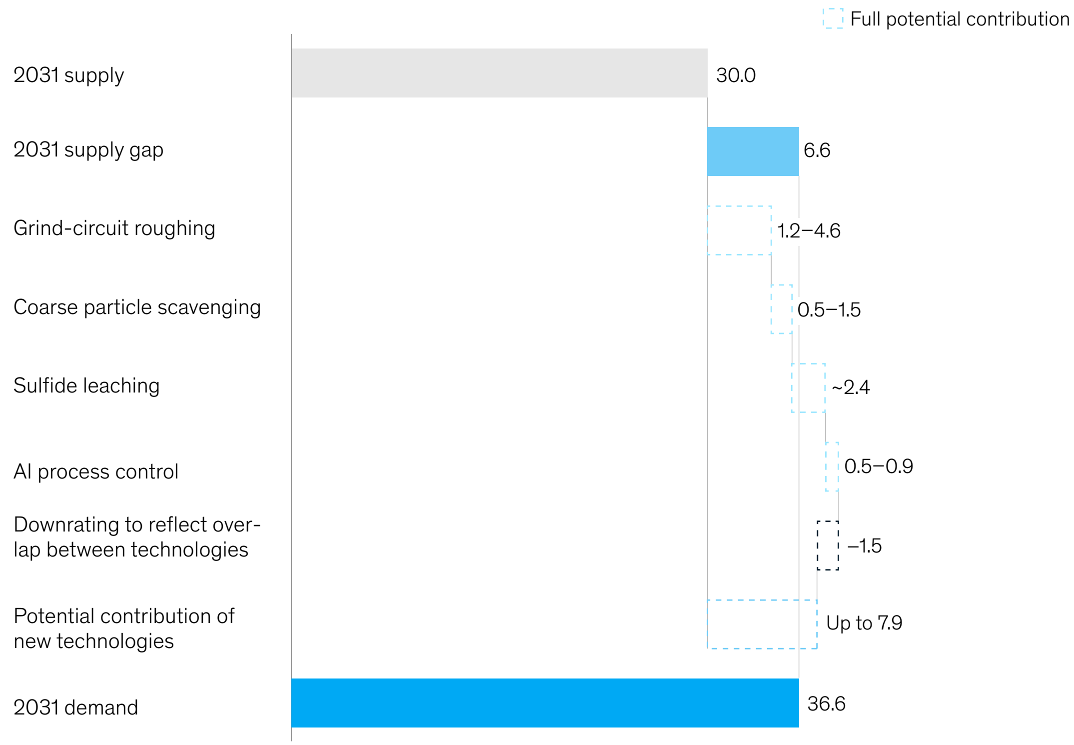
Conventional sulfide flotation circuits are most effective at recovering metal-bearing particles from slurry when those particles are sized between 50 and 150 microns.[1] Above or below this range, recoveries fall away significantly, with the steepest rate of decline for coarse particle recovery (Exhibit 2).

[1] Equivalent to one one-thousandth of a millimeter.

Exhibit 1

If successfully commercialized and adopted across the industry, new technologies could cover a significant portion of the copper supply gap.

Copper supply contribution totals, million metric tons



Note: Figures do not sum to 100%, because of rounding.
Source: McKinsey analysis

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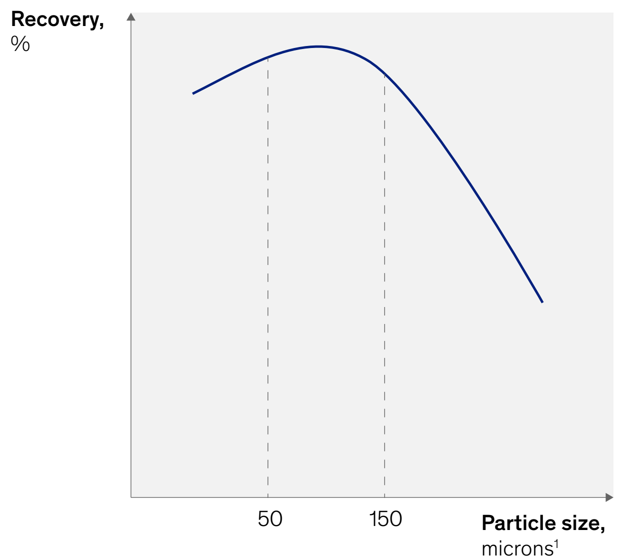
Exhibit 2

Metal-bearing particle recovery falls away steeply for particles coarser than 150 microns.

Recovery of metal-bearing particles by particle size



[1]One micron is equivalent to one one-thousandth of a millimeter.
Source: McKinsey analysis

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There are technologies aimed at expanding the acceptable particle size range for both fine and coarse particles. The most interesting recent developments have targeted the coarse fraction.

Recovering the metals in the coarse fraction has been an objective for flotation metallurgists since the first commercial application of flotation separation in the early 20th century. Most developments focused on improving control of the grinding process to ensure that more of the recoverable metal falls within the critical range. However, this approach is reaching its natural limits and frequently comes at the cost of reduced throughput or higher capital expenditures to build increasingly complex regrind systems.

Two lines of development offer the possibility of taking us beyond this dynamic: grind-circuit roughing and coarse particle scavenging.

Grind-circuit roughing, such as the CiDRA P29 system,[2] addresses the challenge by recovering particles directly from the grind circuit. The system is based on the development of an innovative new material that acts as a so-called copper sponge, attracting and holding mineralized particles based on the same hydrophobic properties that cause them to float during flotation. Unlike systems that take effect further downstream, grind-circuit roughing offers the possibility of directly reducing the recirculating load in ball mills, increasing ball mill throughput by as much as 20 percent at a constant grind size.

[2] Can also be employed in a scavenger role at the end of the flotation circuit.

Operators will need to decide how to take the dividend of increased ball mill efficiency, which could be seen as an opportunity either to drive throughput or to reduce grind size and increase recoveries at a constant throughput. The optimal choice will depend on the properties of the ore body and the existing configuration of the processing plant. However, even with allowances for further cleaning of the concentrate pulled by P29 and consideration of other common system bottlenecks, grind-circuit roughing could add 1.2 million to 4.6 million metric tons of annual copper production by 2032. In addition to these production gains, proportionately reducing energy consumption per metric ton of metal will likely have significant environmental benefits.

The additional copper production would also likely have a limited incremental environmental footprint and could represent significant economic value creation. If the potential production uplift is extended across all metals produced from sulfide ores using a similar production process, while valued at forecast market prices (minus additional processing costs),[3] an annual value pool of $20 billion to $85 billion emerges.

Coarse particle scavenging focuses on extending the range of particle sizes during flotation by adding equipment to the end of the circuit. One example is Eriez's HydroFloat system,[4] which combines the principles behind two conventional separation technologies: density separation and flotation. During conventional flotation, air bubbles are introduced into the ore slurry, at which point the bubbles attach to the mineral-bearing particles, lift them to the top of the tank, and create a metal-rich froth that can be skimmed off. However, the coarser the ore particles, the greater the chance they will shake off the air bubbles and sink back into the slurry before they can be skimmed off. HydroFloat addresses this problem by introducing layers within the cells that prevent the coarser particles from sinking, thereby improving their chances of recovery.

Regarding the impact of this technology, it was employed as a scavenger at the end of a processing plant, where it was possible to improve recovery by 2 to 6 percent, assuming a constant grind size and depending on site-specific factors. Applied across the industry, improved coarse particle flotation can result in an additional 0.5 million to 1.5 million metric tons of annual copper production by 2032. If applied across all metals found in sulfide deposits, the technology represents potential value creation of $9 billion to $26 billion per year.

The benefits of grind-circuit roughing and coarse particle flotation extend beyond their primary roles in augmenting operating concentrators to improve recoveries and throughput. First, the increased-tolerance coarse particles that those technologies create imply an opportunity to reduce water and energy consumption while still achieving the same production targets. Second, grind-circuit roughing and coarse particle flotation also open the possibility of reprocessing old tailings facilities and making other brownfield expansions for near-end-of-life mining operations economical, extending production at low capital and environmental cost and with reduced regulatory uncertainty. Finally, these technologies grant an opportunity to rethink greenfield mine design, reducing the grind-circuit requirements for same production and thereby offering savings across capital requirements and water and energy usage.

Sulfide leaching

Leaching-based technologies have traditionally been applied to oxide or secondary sulfide ore bodies. However, recent developments can help extend this processing pathway to primary-sulfide ore bodies.

Primary sulfides are typically processed at plants using flotation-based systems. Flotation is generally economical for ores with levels of copper that are greater than 0.25 percent,[5] from which flotation can recover 85 to 90 percent. Ores lower than this grade

[3] Based on a copper price of $10,000 per metric ton and a range of forecasts across other sulfide-borne metals.
[4] Can also be employed in the role of grind-circuit roughing before material enters the flotation circuit.
[5] As an average copper grade for a single commodity mine. Cutoff grades will often be lower, particularly if supported by significant by-product revenues.

are normally discarded as waste. Yet primary-sulfide leaching offers a pathway to recover copper from material that is currently below mill head grade and considered waste.

Several distinct technologies are opening up the primary-sulfide leaching space. Some have focused on chloride-based solutions, while others, such as Rio Tinto's Nuton system, have focused on bioleaching. Technical results in trials at Kennecott and other sites are reportedly encouraging, but Nuton is also notable for innovation in the business model it has adopted.[6] Taking advantage of the environmental benefits and the lower capital requirement for mine development compared with conventional sulfide flotation, Rio Tinto entered into agreements with juniors such as McEwen Mining and Arizona Sonoran to use Nuton technology for greenfield mine development.

Beyond the developments within major mining houses, Jetti Resources, an independent service provider, is working with mine owners to use a catalyst-based system to leach primary sulfides at their sites. In December 2022, Jetti reported 23 active projects, working with a range of major mining houses. A $100 million series D financing round in October 2022 valued the company at $2.5 billion and attracted participation from major miners and manufacturing companies.

Practical limitations related to the construction and operation of heap leach pads may limit the application of this technology in the first instance to run-of-mine mineralized waste instead of tailings or existing mineralized waste stockpiles. There is still ground to cover to reach commercialization. However, if current barriers are overcome by the end of the decade, there could be an additional 2.4 million metric tons of refined-copper production per annum by 2032, with a lower water usage and tailings risk profile than is associated with current flotation-based production pathways. This could represent a $45 billion per annum opportunity across all sulfide-borne metals.

Process optimization with machine learning

One of the key challenges of mineral processing is that, to some extent, every ore body is variable. Day by day—and sometimes hour by hour—the characteristics of ores being fed into the processing plant will vary, responding to the process setup in different ways. Thus, maintaining the optimal plant configuration to recover the most metal while ensuring the required purity of concentrate produced remains a perpetual challenge.

Traditionally, adjusting the plant configuration was the province of plant metallurgists, who drew on a combination of academic study, professional experience, and knowledge of the specific ore body. As with any human-controlled process, human factors exert significant influence on outcomes, which sometimes resulted in not only excellence but also lost production due to suboptimal decision making.

The development of machine learning and its application to mineral-processing control over the past five years has added a level of rigor and consistency.[7] Best-in-class applications tend to retain the central role of an experienced plant operator, but they also provide prompts and data for the operator to act upon. Keeping a human in the loop ensures that decisions remain focused on the bigger picture and do not become purely algorithmic, while capturing the speed and consistency that machine learning and AI can provide.

By ensuring that processing plants are consistently working in the upper range of their capabilities, machine learning can add 2 to 4 percent to metal recoveries and 5 to 15 percent to throughput. Such improvements offer an increase in global production from existing and planned mines of half a million to one million metric tons of refined copper by 2032, creating $9 billion to $18 billion in value per annum across all sulfide concentrators.

[6] Daniel Gleeson, "Rio Tinto's Nuton ready to leverage its leaching R&D Legacy," *International Mining*, October 14, 2022.
[7] For more on this application, see Red Conger, Harry Robinson, and Richard Sellschop, "Inside a mining company's AI transformation," McKinsey, February 5, 2020.

The way forward

There are a number of actions stakeholders can take to capture the full potential of these opportunities.

Mine operators

For major mining companies, the new technologies mentioned, such as coarse particle recovery, sulfide leaching, and process optimization with machine learning, highlight the importance and potential contribution of internal innovation groups. Such roles can go far beyond incremental improvements—at their best, they stand alongside exploration and capital projects as drivers of future growth—and will likely be the key to taking these technologies from promising pilots to standard industry practice. Major miners can also continue to look for flexible, agile ways to work with juniors or service providers to ensure that they are drawing on the best ideas from across the industry.

In addition, these technologies reaffirm the importance of brownfield developments. The potential to maximize the benefits in this space—with a lower environmental footprint and continued livelihoods for local communities—remains attractive. As commodity prices increase and technology makes more possible, even sites that have fully ceased production can once more generate economic value.

Developers

To juniors, service providers, and research institutions, major mining companies are open for business, looking for partners, and creating opportunities. In this way, major companies can provide access to scale projects and support the growth of mining-tech unicorns.

These technologies also offer new options for greenfield projects. The "mine of the future" could require much lower ball mill capacity for the same output based on grind-circuit roughing technology, reducing capital requirements, water usage, and CO_2 emissions. Likewise, sulfide leaching offers the possibility of an incremental, low-capital-expenditure approach to the development of low-grade copper deposits that previously required the construction of capital-intensive concentrators. This approach can enable an incremental development model similar to that often used for gold deposits—particularly in high-risk areas, where the capital at risk and the payback period are critical investment criteria. Similarly, for local communities that would accept some mining but are not sure they want to commit to a megaproject, the option for an incremental mine development pathway could be attractive.

Metal buyers

For buyers of metals, the supply constraints facing the metals necessary for the energy transition can appear daunting, but new mineral-processing technologies are an indication that human ingenuity and the market economy tend to find a way to provide. However, this is not an invitation for passive optimism: buyers have a role in working with the supply chain by funding and promoting technological breakthroughs where they can. This requires careful analysis and staying abreast of industry trends.

As the world electrifies, the demand for copper will be difficult to meet. However, with innovative new mining and processing technologies, there is hope. Players from across the industry, from mine operators to developers to metal buyers, can make moves today to support the implementation of these new technologies and to innovate further. If they do, they could provide humanity with the key resources it needs for the future.

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