

An aerial, high-angle photograph of a massive open-pit mine. The landscape is characterized by deep, terraced excavation levels. Several large conveyor belt systems are visible, snaking across the mine's surface. In the lower-left quadrant, a large haul truck is parked. The overall scene conveys the scale and industrial nature of copper mining.

Deep Dive Extract: Copper

Copper Deep Dive Table of Contents

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Teaser Report

This document contains selected pages from our full 29-page report. Request access to the complete analysis at ir@twynam.com

Executive Summary

Sector Overview

Copper is the foundational metal of electrification, underpinning power grids, renewables, EVs and digital infrastructure. Demand growth is expected to reach ~36Mt pa by 20240, but demand is long-dated and infrastructure-driven, supported by grid expansion and rising power intensity from AI and industrial electrification.

Supply growth, however, is increasingly constrained by declining ore grades, rising impurities, permitting challenges and long mine development timelines. Average ore grades have fallen to ~0.5% Cu, with deposits below ~0.3% Cu only viable at exceptional scale. Despite large discovered reserves, industry forecasts point to a ~14 Mt primary supply shortfall by 2040, driven by permitting delays, declining grades and refining concentration adding geopolitical risk.

Process Overview

Copper production is capital and energy-intensive, with downstream concentration and refining dominating lifecycle cost and emissions. As grades decline, more material must be mined and processed per tonne of copper, increasing energy use, waste volumes and regulatory exposure. Crushing and grinding for example represent ~30–40% of mine-site electricity consumption,

Sulphide ores, the majority of future supply, rely on emissions-heavy, centralised pyrometallurgical processing, while lower-temperature hydrometallurgical routes remain limited in their applicability. As a result, processing constraints are emerging as the primary bottleneck to future copper supply.

Innovation Pathways

Innovation is shifting from discovery to unlocking harder-to-process resources. Key pathways include technologies that enable recovery from lower-grade ores, tolerate impurities, reduce grinding intensity and bypass traditional smelting steps.

Mining generates approximately 100 billion tonnes of waste annually, with tailings and slag representing a significant untapped secondary resource. Additional opportunities exist in reprocessing legacy mine waste and improving recycling and urban mining systems. These approaches can expand supply at lower capital intensity, although dispersed material and aggregation costs limit full substitution of primary supply.

The Investible Opportunity

Execution risk dominates in copper innovation. Investable technologies must work across varied mineral systems, integrate with incumbent operations and 30-10y assets and deliver step-change improvements in cost or recovery.

The strongest opportunities lie in modular, capex-light processing solutions that unlock stranded resources, reduce energy intensity or enable distributed production. As ore quality declines and environmental constraints tighten, processing innovation is likely to become the most defensible investment wedge in the copper value chain.

An aerial, high-angle photograph of a massive open-pit mine. The landscape is a complex of terraced rock faces and deep, winding paths. Several large-scale mining vehicles are visible, including a prominent yellow haul truck in the center-left and a conveyor belt system snaking across the upper right portion of the frame. The overall scene conveys the immense scale and industrial nature of the mining sector.

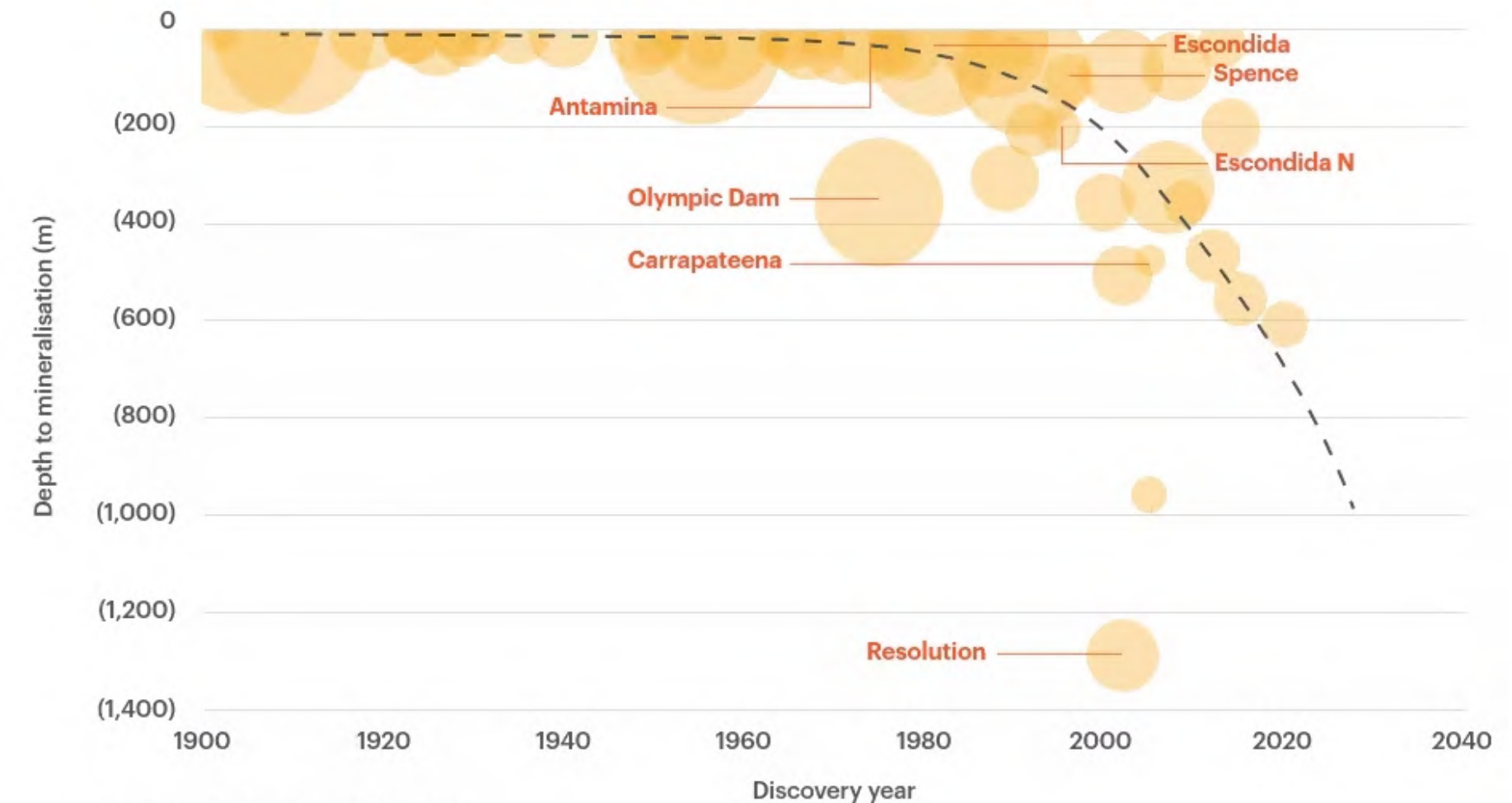
Sector Overview: Understanding the market for the electronics metal

Structural constraints define Copper Supply

- **Declining ore grades:** ~0.5% Cu concentration now average, <0.3% Cu only viable at exceptional scale, fueling the need to dig deeper
- **Increasing impurities:** lower quality ores are now mined to keep up with demand, often high in iron and arsenic
- **Long development timelines:** 20–30 years from discovery to production
- **Rising environmental constraints:** water stress, tailings management, social licence
- **Refining concentration:** china dominates refined copper capacity

Major copper discoveries are becoming less common and getting deeper...

(Selected major deposits, >3Mt contained copper)



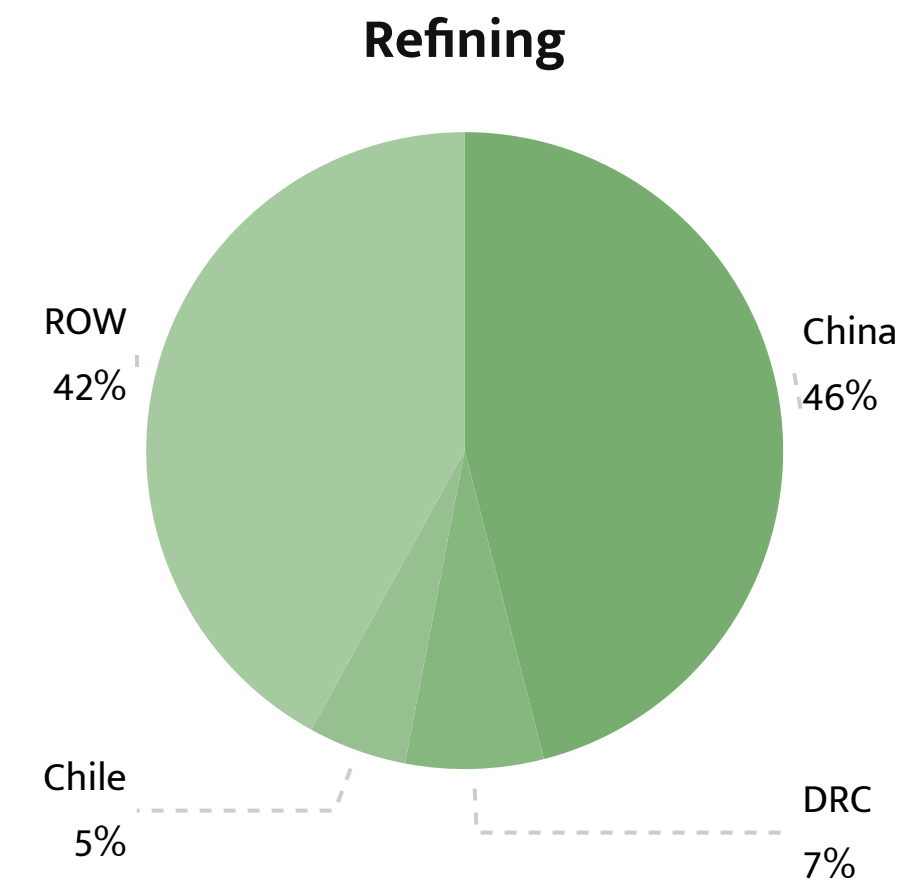
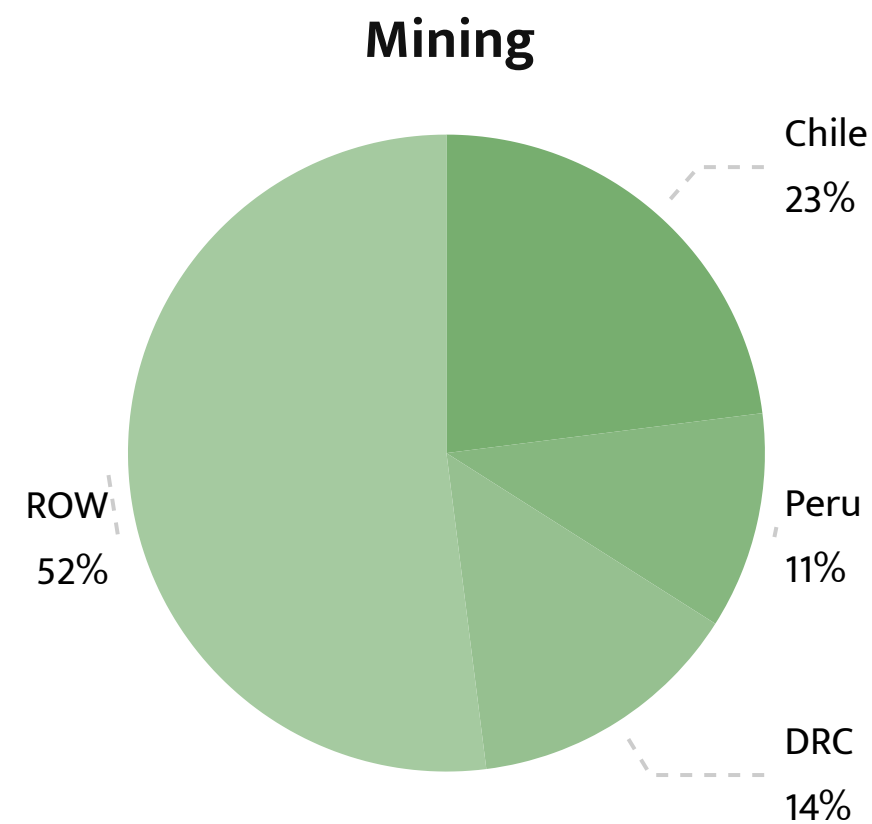
Source: MinEx Consulting; BHP analysis.

Sources: IEA, USGS, USGS, IEA, Arthur Little, IEA

A dominated supply chain

- 3 Countries control almost half of mined Copper and over half of refining.
- This creates geopolitical, logistical and decarbonisation risk

Copper share by Country



Insight: Copper risk sits at the mine, but even moreso downstream, with China controlling 46% of refining capability

**Source: IEA Global Critical Minerals Outlook 2024*

An aerial, high-angle photograph of a massive open-pit mine. The landscape is a complex of terraced rock faces and deep, winding paths. Several large pieces of heavy machinery are visible, including a prominent yellow front loader and a large yellow articulated haul truck. A long, elevated conveyor belt system stretches across the upper right portion of the image, transporting material from the mine face. The overall scene conveys the scale and industrial nature of the mining process.

Processing Overview: From Rock to Cathode

Geology determines processing routes and economic viability

Copper deposits vary widely in mineralogy, grade and impurity profile, which in turn dictates how copper can be economically extracted. Across all deposit types, ores broadly fall into **oxide** and **sulphide** categories - a distinction that fundamentally shapes processing methods and economics.



Sulphide Ores

Chalcopyrite & Bornite

Primary Copper ores typically bonded with sulphur

Smelting & Flotation Process



Oxide Ores

Cuprite, Tenorite, Azurite & Malachite

Secondary Copper ores formed through weathering

Leaching & Electrolysis Process



Mixed Ores

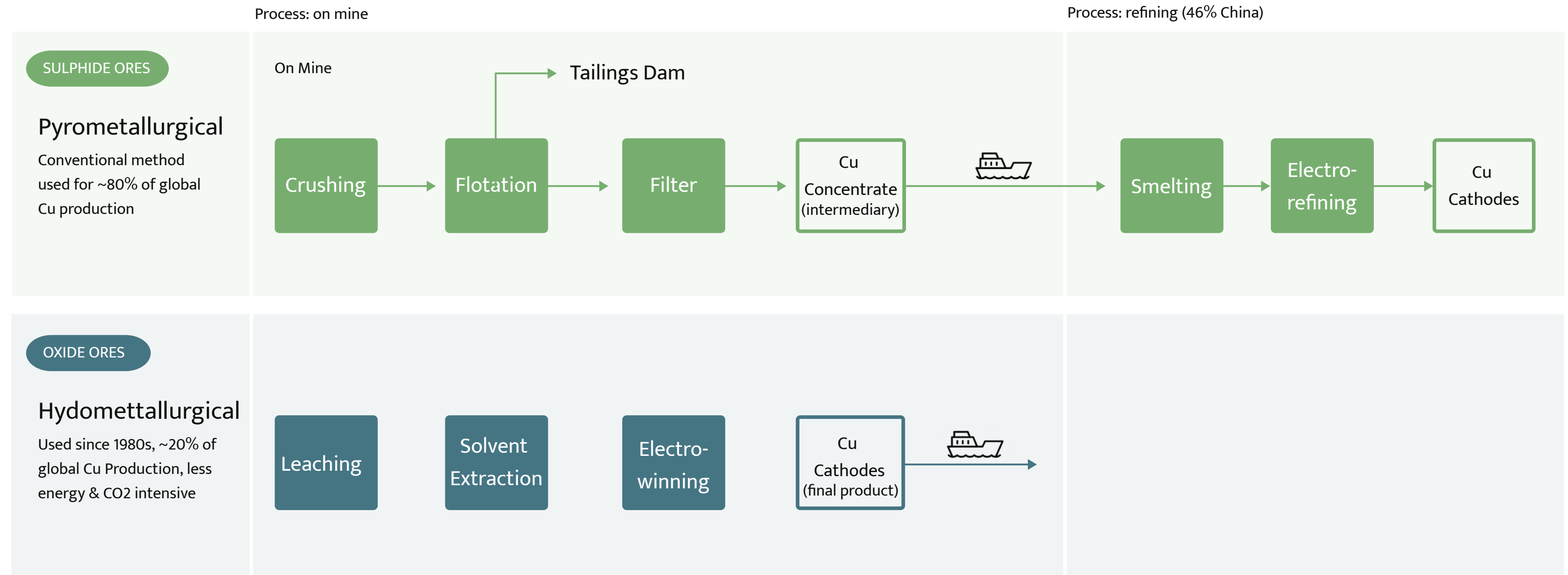
Blended

Combination ores often found in deposit transition zones

Smelting & Flotation Process

Insight: Copper is not one commodity - it is many mineral systems with radically different processing constraints.

Two major processing pathways



Insight: Copper supply is sulphide-dominated - but sulphide-compatible hydromet routes remain underdeveloped.

Ore & processing constraints are the supply constraint

Declining ore grades

- ~0.5% Cu now considered average
- <0.3% Cu only economic at exceptional scale
- Drives:
 - Higher energy intensity
 - More material moved per tonne of copper
 - Larger tailings volumes

Impurities as a hard constraint

- Arsenic and iron are the most problematic impurities
- China (the dominant refiner, 46%) imposes strict impurity thresholds
- Concentrates exceeding these thresholds face:
 - Penalties
 - Blending requirements
 - Outright rejection

Result: **“Dirty copper” becomes stranded copper**, regardless of geology.

Energy, emissions and waste

- Grinding dominates electricity demand
- Smelters are emissions hotspots
- Tailings storage, acid mine drainage and water use create growing regulatory risk

An aerial, high-angle photograph of a massive open-pit mine. The landscape is a complex of terraced rock faces and deep, winding paths. Several large pieces of mining equipment are visible, including a prominent yellow front loader in the center-left and a large dump truck to its right. A long, elevated conveyor belt system stretches diagonally across the upper right portion of the image. The overall scene conveys a sense of large-scale industrial activity and earthmoving.

Innovation Pathways

Innovation Pathways in Copper

Extracting more from less

Unlocking lower-grade and higher-impurity ores.

Processing innovation

Rethinking how copper is liberated, concentrated and refined.

Reprocessing waste

Turning tailings, slag and mine waste into feedstock.

Urban mining & recycling

Recovering and extracting copper already embedded in the economy.

Demand-side relief

Reducing copper intensity where substitution is viable.

An aerial, high-angle photograph of a large-scale mining operation. The image shows a deep, terraced excavation site. In the upper left, a large conveyor belt system runs diagonally across the frame. Below it, a heavy-duty mining truck is parked on a dirt path. To the right of the truck, another piece of heavy machinery, possibly a loader or another truck, is visible. The ground is uneven and shows signs of heavy excavation, with various ridges and depressions. The overall tone is dark and industrial.

The Investable Opportunity

Where venture can and can't win in Copper

For a technology to be investable in copper, it must meet a higher bar than in many other climate or industrial sectors.

Approaches must:

1. **Work across a range of mineralogies**

Copper ores vary widely - single-ore solutions rarely scale.

2. **Be compatible with incumbent operations**

Mines are 30–100 year assets; wholesale process replacement is rarely viable.

3. **Deliver a step-change in economics**

Improvements must be material to justify adoption.

4. **Scale without requiring mega-smelters**

Capital intensity must be bounded and financeable.

Key execution requirements include:

- Demonstrated performance on **real ores**, not just synthetic feedstocks
- Referenceable pilots with credible operators
- Clear manufacturing and deployment pathways
- Working capital discipline through long project cycles
- Alignment with incumbent incentives and operating models

Insight: In copper & mining, execution risk often outweighs technology risk.

Finding a solution to primary mining constraints

Challenges

Declining Ore Grades: Average copper grades have fallen to ~0.5%, with many future deposits below 0.3%, requiring significantly more material to be mined and processed per tonne of copper.

Impurities as a Hard Constraint: Elevated arsenic, iron and other deleterious elements limit concentrate acceptance, trigger penalties, or strand supply entirely, particularly given China's tight refining thresholds.

Energy Intensity: Crushing and grinding alone account for ~30–40% of mine-site energy use, with smelting and refining adding further emissions and cost pressure as grades decline.

Waste & Environmental Burden: Tailings, slag and waste rock volumes increase as grades fall, amplifying risks around storage, acid drainage, water use and long-term liability.

High Transport & Logistics Costs: Low-grade ores, remote deposits and concentrate transport to distant smelters materially erode margins and increase geopolitical and execution risk.

Breakthroughs



Extracting More from Less: Technologies that unlock lower-grade ores and expand the economic resource base without requiring step-changes in mine scale.



Impurity-Tolerant Processing: Novel processing routes and chemistries that tolerate higher arsenic and iron levels, reducing penalties and unlocking currently stranded copper.



Reduced-Intensity Comminution & Processing: Innovations that lower grinding requirements, improve liberation efficiency, or bypass energy-intensive steps entirely.



Reprocessing “Waste” Streams: Tailings, slag and mine waste reprocessed using modern techniques, often with existing permits and infrastructure, offering lower-risk FOAK deployment.



Modular & Distributed Processing: Smaller, capex-light processing units and in-situ extraction processes that reduce reliance on mega-smelters and long-distance concentrate transport.

Insight: Technologies that reduce energy intensity, tolerate impurities, or unlock waste streams offer the most defensible investment wedge.

Let's have a chat...

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