

Report N. 6

LIFTT TECHNOLOGY INSIGHTS

A whole-stack move in critical
minerals & metals: a shift toward
a semiconductor-like industry

May 2026

WHY NOW

The energy transition runs on rocks. So does the AI build-out, the chip industry, modern defence, every kilometre of grid being rebuilt across three continents. Lithium for batteries, copper for wires, nickel and cobalt for cathodes, rare earths for magnets, gallium and germanium for semiconductors. Material that has to be dug, refined, shipped and transformed before any panel, motor, server or grid line goes up. The pace of that physical pipeline is the constraint nobody priced in.

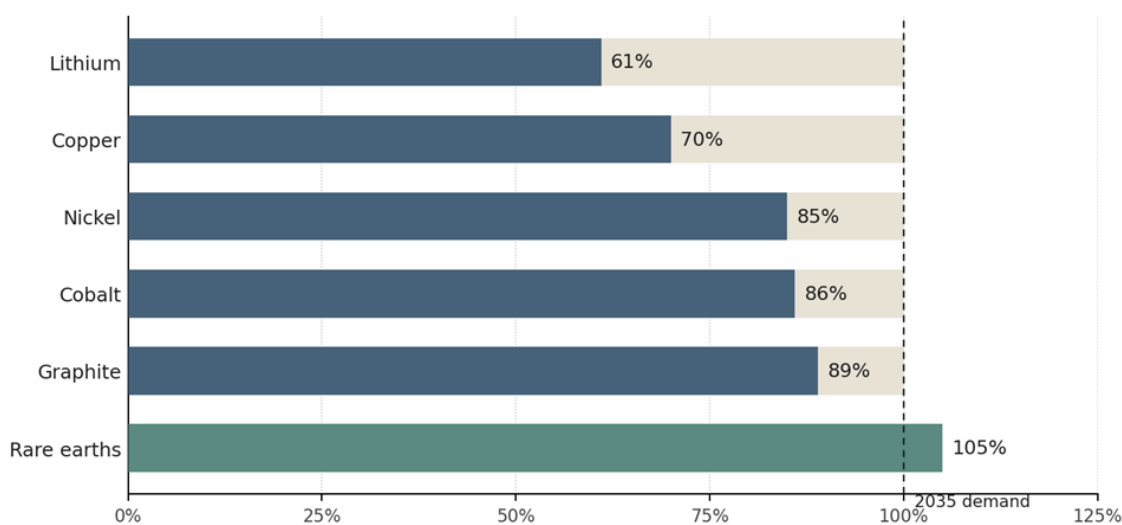
In 2024 the market told the opposite story. Demand for lithium grew nearly 30%. Prices fell anyway. Nickel, cobalt, graphite and rare earths each grew 6–8%, with 85% of battery-metal expansion coming from energy applications. Prices fell there too. Supply additions in China, Indonesia and the DRC outran demand for the second year running, and the surplus became the headline. (IEA, Global Critical Minerals Outlook 2025)

Look one cycle further out and the picture inverts. The IEA tracks every mine under construction, permitted or financed worldwide. Add it all up and projected supply at 2035 covers only 70% of expected copper demand, 61% of lithium, and 85–89% of nickel, cobalt and graphite. Surplus today, deficit a decade out.

Copper is where the squeeze shows up first. It belongs to no single end market: EV motors, the cables and switchgear of every new data centre, every kilometre of grid being rebuilt. Three of the largest infrastructure cycles of the decade pull the same metal at the same time, and the mines that should be feeding them are not under construction yet.

Expected mined supply vs 2035 primary demand

Base case: existing assets, projects under construction, and projects with permits / financing / offtake secured. STEPS scenario.



Source: IEA, Global Critical Minerals Outlook 2025 (p. 87). Bar = base case supply as a share of 2035 primary supply requirements.

Figure 1. Expected mined supply at 2035 as a share of projected primary demand (STEPS scenario, base case). Source: IEA, Global Critical Minerals Outlook 2025, p. 87.

By spring 2026 the surplus story has flipped, unevenly. Battery-grade lithium has roughly doubled from its 2024 trough. Cobalt has nearly doubled too, accelerating after the DRC's February 2025 export action. NdPr oxide is up more than 100% from a year ago, pulled by a tightening rare-earth licence regime. Copper traded through 2025 in elevated territory and closed the year at record highs, up almost 40%. Only nickel remains under pressure, still absorbing Indonesian oversupply. The single-explanation 2024 narrative of falling prices and Chinese pricing power has stopped working. Underneath, the long-cycle supply gap is intact.

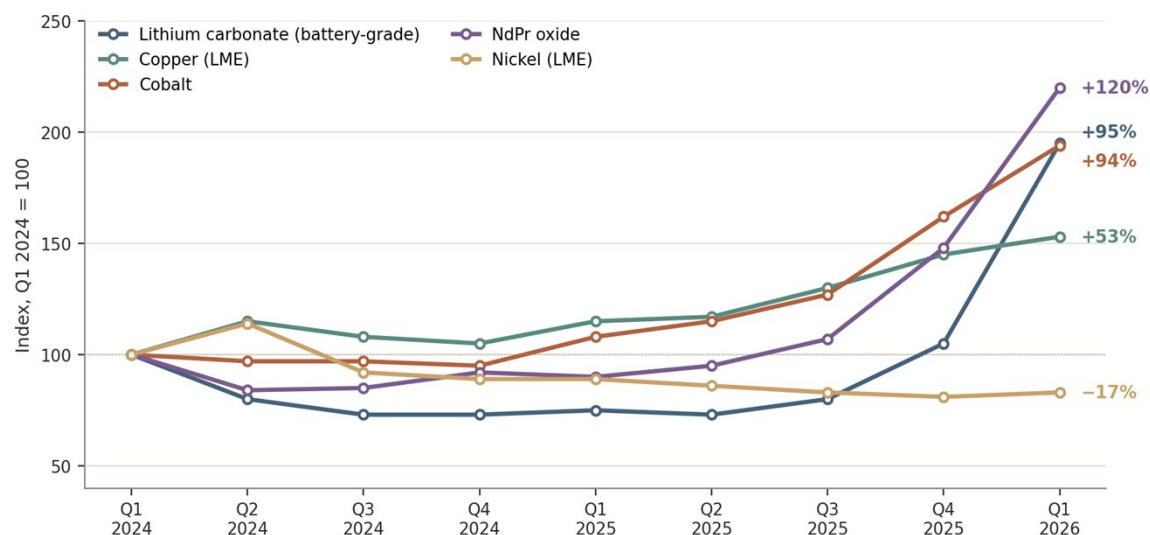


Figure 2. Five critical-minerals price benchmarks, indexed (Q1 2024 = 100). Lithium, cobalt and NdPr show sharp recoveries from 2024 troughs; copper rises steadily on tight supply; nickel remains depressed by Indonesian overproduction. Endpoints sourced from public reporting (LME spot prices for Cu and Ni; Benchmark Mineral Intelligence via Investing News for Li; Cobalt Institute and Investing News Q3 2025 review for Co; SMM, Asian Metal and Crux Investor for NdPr oxide). The intermediate quarterly trajectory between sourced endpoints is a LIFTT reconstruction, directionally consistent with the cited anchors.

The 2024 surplus was a head-fake. Demand grew, prices fell, and the market read abundance where the project pipeline was already short. The underlying arithmetic has not moved. Mined supply at 2035 still covers only 70% of expected copper demand, 61% of lithium, and 85–89% of nickel, cobalt and graphite. Surplus today, deficit a decade out. Sitting beneath those numbers is a different and harder asymmetry, and it is what this report is about. AI is racing on the clock of compute and capital, and it is already drawing copper into every new data centre. Electrification is racing on the clock of OEM product cycles and grid procurement. Robotics, defence and advanced semiconductors each run on their own short clocks. The mines, refineries and trained workforces that have to feed all of them do not. That gap, not chemistry, is the binding constraint of the decade.

DEEP SIGNALS

1. Direct Lithium Extraction moves from pilot to plant

On 24 December 2024 Eramet delivered the first lithium carbonate from its Centenario plant in Argentina, the first DLE facility built at industrial scale. From groundbreaking to first product in under three years, against seven to ten for a hard-rock mine. The technology platform is diversifying: ion exchange (Lilac), sorbent-based (Eramet), electrochemical (EnergyX), geothermal brine (Vulcan), each with a different fit to brine chemistry and grade.

The bottleneck is no longer chemistry. It is yield, recovery rate and uptime at industrial scale, plus access to brine concessions in jurisdictions now openly courting non-Chinese capital. If recovery rates hold across operating conditions, DLE alone reshapes the supply curve for the second half of the decade.

2. AI-led exploration becomes a competitive moat

Mining majors are signing exploration partnerships with AI-first juniors instead of running fully internal exploration. The signal is that probabilistic geology, vector models trained on global geophysical data, has become accurate enough to direct drill capital. The cost of a successful discovery is finally falling.

3. Refining is the real bottleneck, and it is moving West slowly

China refines roughly 60% of the world's lithium and cobalt, more than 90% of its rare earths, and over 95% of battery-grade graphite (IEA, Outlook 2025). Ore mined in Australia, Argentina or the Congo still travels to Chinese refineries before reaching any battery, motor or magnet plant. The Western response is finally dated: MP Materials began NdPr metal production at its Fort Worth Independence facility in January 2025, the first US-refined magnet feedstock in decades, and the US Department of Defense took a 15% stake in July.

4. Battery recycling becomes industrial infrastructure, not a sustainability claim

Recycling has crossed from compliance theatre to dispatchable supply. Redwood Materials processed on the order of 80,000 tonnes of critical minerals across its Nevada and South Carolina campuses in 2025, with reported recovery rates around 80% on lithium and 95% on cobalt and nickel, and is estimated to handle close to 90% of all lithium-ion batteries recycled in North America. In Europe, Cylib (Germany, backed by Porsche and Bosch) and Altilium (UK) are moving past pilot scale.

The regulatory clock is the forcing function. By 31 December 2027 the EU Battery Regulation requires 90% material recovery on cobalt, copper and nickel, and 50% on lithium. From August 2031 every new battery placed on the EU market must contain at least 16% recycled cobalt, 6% recycled lithium and 6% recycled nickel. The supply that meets those thresholds is being financed and built today, not in 2030.

5. Modular refining becomes supply-chain insurance

New mines reach production in five years. New refineries take a decade and a thousand permits. The deep-tech opening is solvent-free hydrometallurgy, electrochemical separation and modular plants that can sit at the mine gate or near port, refining processes designed to be replicated outside Chinese vendor ecosystems. With Beijing's export-control suspension expiring on 27 November 2026 and military end-use restrictions already permanent, a kilogram of refined product that never crosses Chinese territory is not just diversification. It is supply-chain insurance.

6. Mineral sovereignty becomes industrial policy

Stockpiling, friend-shoring and sovereign equity stakes have moved from rhetoric to budget lines. The clearest dated example: on 3 February 2026 Washington launched 'Project Vault', a \$2 billion private and \$10 billion Ex-Im-backed strategic stockpile spanning every USGS-listed critical mineral (rare earths, lithium, uranium, copper, more than fifty in total). It sits inside a wider toolkit: Defense Production Act invocations, EU Critical Raw Materials Act enforcement, IRA supplemental funding, and bilateral partnerships across Japan, Korea and Australia. Public capital is now de-risking parts of the value chain that private capital had walked away from after the 2023–2024 price collapse: refining, magnets, separation.

Europe's mirror move sits in southern Norway. Rare Earths Norway has revised the Fen complex resource estimate to roughly 15.9 million tonnes of rare-earth oxides, eight times the size of Sweden's Kiruna and the largest deposit known in Europe. The plan is underground mining starting in 2031, with about €1 billion of upfront investment. Oslo has signalled that Fen's subsoil will stay under Norwegian control. If Rare Earths Norway hits its 5%-of-European-demand target by 2032, the EU's stated 10%-by-2030 sovereignty target becomes reachable from a single mine.

7. Bioleaching displaces the smelter

Bioleaching has crossed from research curiosity to industrial deployment. Rio Tinto's Nuton technology, deployed at the Johnson Camp mine in Arizona, uses naturally occurring microorganisms to leach copper directly from low-grade ore. The output is 99.99% pure cathode at the mine gate, with no concentrators, no smelters, no refineries.

The signal is not the chemistry. Microbial leaching has been studied for decades. The signal is what falls out of the value chain: the smelter, the long-haul concentrate logistics, the secondary refinery. Mid-grade and waste-rock copper that conventional pyrometallurgy ignores becomes economic. If Nuton-class processes scale, the cost curve of copper itself shifts, and the geographic concentration of refining loses some of its grip.

8. Software-defined mining and the dormant-site restart

On 28 April 2026 Mariana Minerals reopened Copper One in Utah, idle since 2024. What makes it the first of its kind is not the mine but the operating model: a single

software stack governing mining, refining and project delivery, with autonomous haul trucks, autonomous drilling and patrolling robots all reporting into the same system. The deep-tech reading is not the individual robot. It is that integrated autonomy changes the unit economics of mid-grade and dormant sites that the labor-heavy model can no longer carry. Permitting a new mine still takes a decade. Re-engineering an existing one with a software-first operating model compresses that to a fraction. In a market with a structural copper deficit and a closing window, brownfield restart with autonomous operations becomes the most realistic source of near-term supply.

9. AI-designed materials enter the demand equation

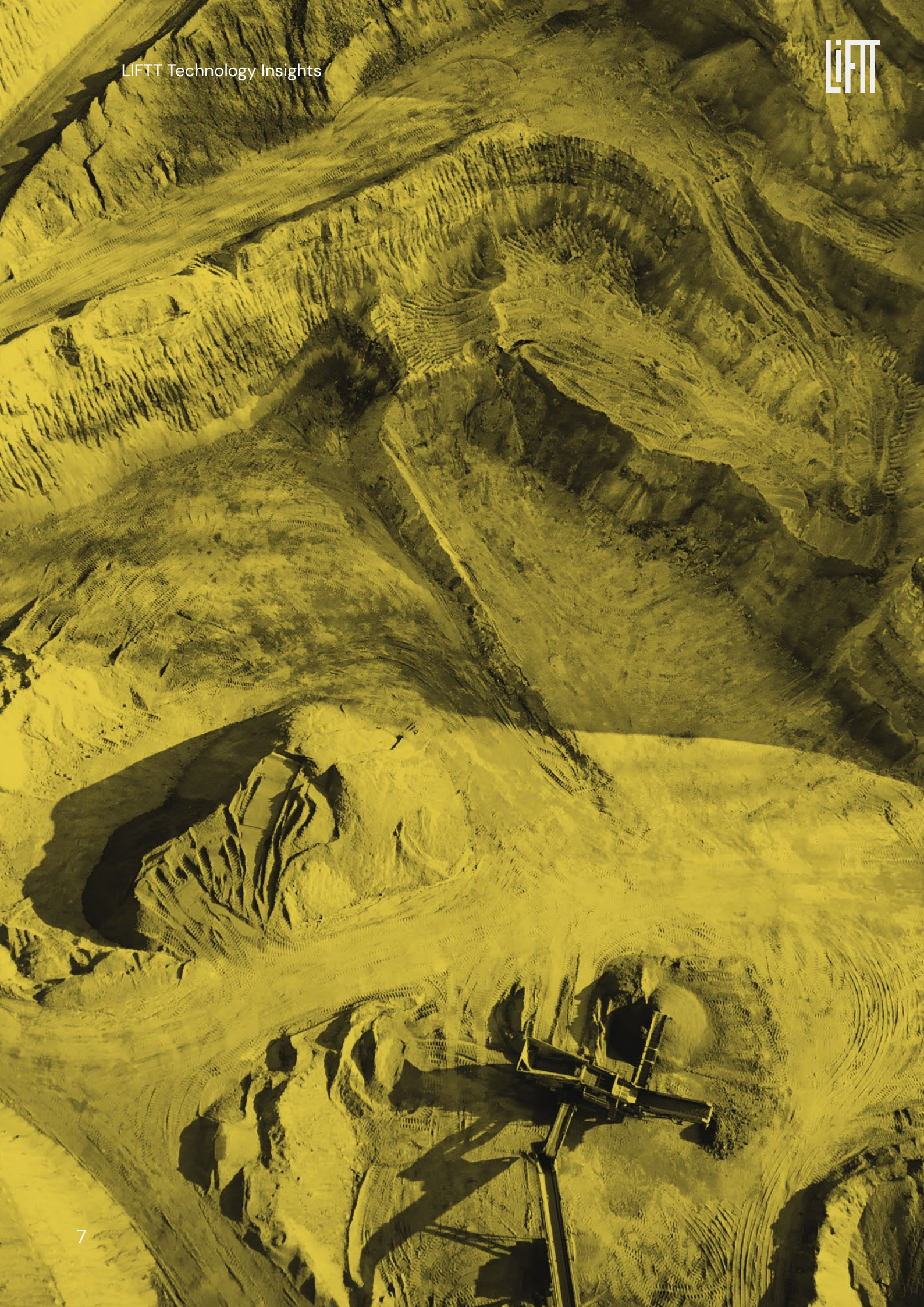
AI-driven materials discovery has moved from research curiosity to operational pipeline. DeepMind's GNoME identified over 200,000 stable new compounds in 2023, and Microsoft's MatterGen generates candidate materials directly from text prompts. A first generation of startups is now building commercial platforms on top of these foundations, designing new compounds in days rather than years. None of this displaces a critical mineral on the next-five-year horizon. The signal is that the demand-side risk to today's critical-minerals list has stopped being theoretical.

WHAT DO THESE SIGNS TELL US?

The signals point in the same direction. Demand for critical minerals over the next decade is set to outrun the project pipeline that already exists, by margins that are structural rather than cyclical. The deep-tech response to that gap is not coming from where the mining industry has historically looked for it. The chokepoints, the moats and the rents are migrating away from the orebody and into the layers above it: the chemistry that turns ore into product, the software that runs the operation, the contract structure that connects miner to end-user, the policy framework that decides who has access to what. Owning the orebody is becoming necessary but no longer sufficient.

The next decade's competitive advantage in critical minerals will not come from finding more rocks, even though the gap on rocks is real. It will come from controlling the system that turns rocks into product and gets them to the end-user with verifiable provenance. The signals are not innovations in the old mining sense. They are the answers being engineered now, in real time, to a supply gap that cannot be closed by waiting fifteen years for new mines.

What is conspicuously absent from these signals is demand-side engineering. The absence is deliberate. When the binding constraint is the long-cycle physical pipeline, the answers that matter near-term are the ones that build supply. Substitution chemistry, sodium-ion, magnet-free motors all matter, but they sit on a different timeline. The deep tech of the next five years is not the next molecule. It is the new infrastructure that gets built to carry the molecules we already know about.



WHAT'S GOING ON IN THE MARKET?

Three forces are reshaping where capital flows in critical minerals between 2024 and 2026. State capital has come back as direct strategic investor, not just policy support. Industrial buyers, including auto OEMs and hyperscalers, are signing offtake and equity directly with miners and refiners. And venture capital, which spent the previous cycle financing exploration startups, is now backing process technology: extraction chemistry, autonomous operations, refining outside China, recycling at industrial scale. Each is a response to the same diagnosis. The classical capital model for mining and refining no longer works on its own.

The smelter exit

The clearest illustration of how the system is repricing itself is in copper smelting. Treatment and refining charges, the fees that miners pay smelters to convert concentrate into refined cathode, have collapsed. The 2026 annual benchmark settled at zero dollars per tonne in January, agreed between Antofagasta and the Chinese smelters' purchase team. Early-2026 spot rates have gone as low as minus seventy-eight dollars per tonne. Smelters are now paying miners to take their concentrate.

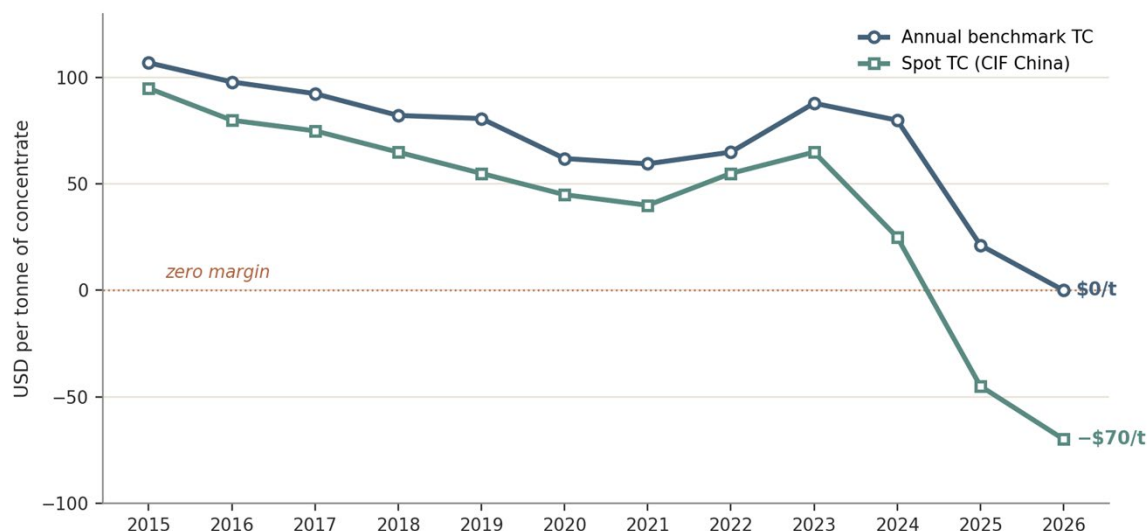


Figure 3. Copper concentrate Treatment Charge (TC), annual benchmark and CIF China spot, 2015–2026 (USD per tonne of concentrate). The 2026 benchmark settled at \$0/t; spot has gone below -\$70/t in early 2026. Annual benchmark endpoints sourced from CSPT and Antofagasta–Chinese smelter settlements (public reporting via Fastmarkets, Mining.com, Crux Investor); spot trajectory between sourced anchors is a LIFTT reconstruction, directionally consistent with cited prints.

The mechanism behind that price is structural, not cyclical. Chinese state-backed smelting capacity has expanded faster than global mine output, by roughly 2.5 million tonnes per year between 2023 and 2025. That capacity does not need a positive industrial margin to operate; commercial smelters do. The Western exits are visible. Glencore put its Pasar copper smelter in the Philippines (about 1.2 million tonnes per year of concentrate-processing capacity, around 200,000 tonnes per year of cathode) into care and maintenance in February 2025 and sold it in September. On 3 February 2026 Glencore Canada formally suspended all upgrade investment at the Horne Smelter in Quebec, the country's largest copper plant at roughly 300,000 tonnes per year of output, and the federal government is now negotiating to keep the site alive. In zinc, Nyrstar's Budel facility in the Netherlands (315,000 tonnes per year) has been on care and maintenance since January 2024 and operating at reduced rates since. Across the global base, 16.2% of smelter capacity sat inactive through the first seven months of 2024, against 13.9% the year before.

What is happening is not competitive disadvantage. It is structural expulsion. When the price of processing concentrate is set by counterparties for whom losing money on smelting is acceptable, because the country gains control of the processing layer, the commercial smelter loses by definition. The remaining Western survivors are integrated operators with recycling depth (Aurubis), zinc co-product economics (Boliden), or state backing. Pure-play primary smelting in the Western commercial model has stopped being a viable capital structure. Copper is where this shows up first because the price proves it. The mechanism applies wherever Chinese state-backed processing meets a Western commercial smelter under the same auction.

Sovereign & state capital

The headline move came on 10 July 2025, when the US Department of Defense became the largest single shareholder of MP Materials, taking a 15% stake through convertible preferred stock and warrants. The Pentagon is now both the buyer and the equity holder. Six months later, Washington launched 'Project Vault', a \$12 billion strategic stockpile spanning every USGS-listed critical mineral. The DOE Loan Programs Office had already closed a \$2.26 billion loan to Lithium Americas for the Thacker Pass project in March 2024. Across these instruments, the United States has committed direct public capital to critical minerals at a scale unseen since the strategic stockpile programmes of the mid-twentieth century.

The shape matters more than the size. This is not subsidy or tax credit. It is direct equity, project finance, and stockpile guarantees, with the state acting as strategic shareholder rather than as regulator. The pattern repeats across the OECD: Norway has placed the Fen rare-earth complex under national control; Japan's JOGMEC takes direct equity in foreign mining projects; the EU Critical Raw Materials Act, in force since May 2024, sets binding 2030 targets for domestic production, processing and recycling. The same logic operates with deeper pockets outside the West: Saudi Arabia's Manara Minerals took a 10% stake in Vale Base Metals for roughly \$2.5 billion in 2023; Indonesia owns its nickel processing build-out through state holdings such as MIND ID and Indonesia Battery Corporation. The fourteen-country Mineral Security Partnership coordinates the allied flow. The state is back as capital allocator, not as cheerleader.

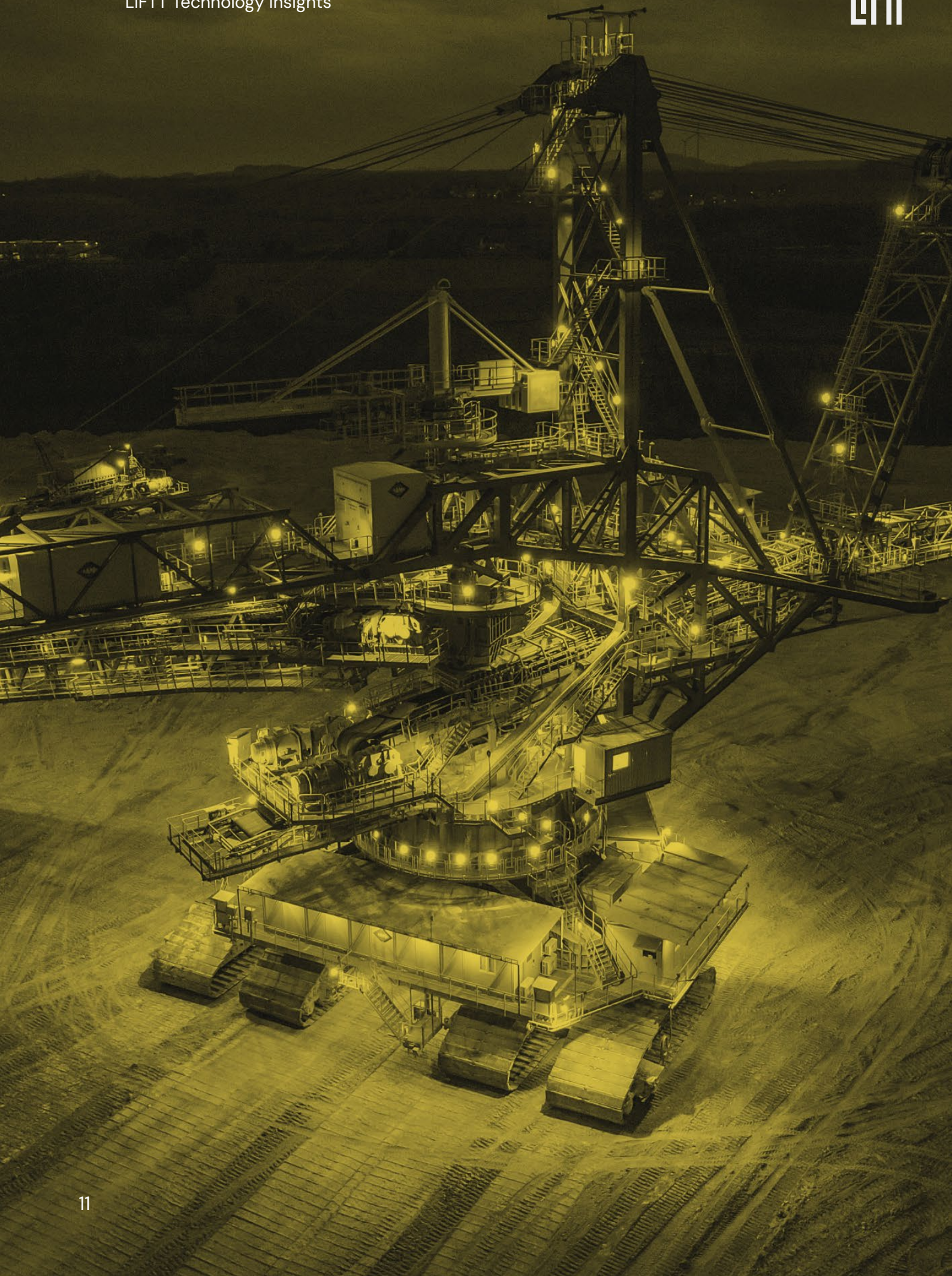
Industrial buyers as capital allocators

The deals that defined 2025 and early 2026 sit directly between end-user and producer. AWS became the first customer of Rio Tinto's Nuton bioleaching copper in January 2026. Vulcan Energy delivers multi-year lithium tonnage to Renault and Volkswagen, with Stellantis as equity-and-offtake

partner. General Motors holds a \$650 million equity stake in Lithium Americas' Thacker Pass project, the largest direct investment by an automaker in mineral production. Three drivers sit behind the same shape: supply security at volumes the spot market cannot guarantee, provenance and carbon profile that traders cannot certify, and an industrial logic that treats minerals as a strategic input alongside cells, motors and silicon. The structural consequence is that LME and benchmark spot pricing increasingly reflect a residual market, while the strategic flow moves through bilateral contracts. For a non-Chinese miner with a green or geopolitically clean asset, this changes financing economics more than any subsidy. The buyer is no longer downstream of the trader. In critical minerals, the buyer is increasingly also the capital allocator.

Mining tech VC

Venture capital in critical minerals has moved from exploration to process. The 2024–2026 funding flow clusters in four buckets. Digital mining spans AI-led exploration and real-time ore sensing: KoBold Metals raised \$537 million in Series C in January 2025 at a \$2.96 billion valuation, with Mitsubishi among the strategic backers; Earth AI operates in the same exploration lane; HYPERMINE brings laser-based hyperspectral sensing into the pit for real-time ore-grade decisions. Novel extraction and process chemistry is the second bucket: Hades (Munich) raised €20.5 million in under six months, including industrial backing from Viessmann Generations Group, for fiber-laser in-situ recovery; Endolith raised \$13.5 million in seed in late 2024 for AI-guided microbial copper extraction, with Giraffe Bio and Magmatic Bio on adjacent biomolecule platforms; Maverick X attacks the same recovery problem with a precision lixiviation chemistry stack rather than microbes. Industrial-scale recycling is the third: Cylib closed a €55 million Series A in early 2024 with Porsche Ventures and Bosch Ventures co-leading, and Tozero raised €11 million seed in November 2024 for lithium recovery. AI-developed materials is the fourth and most speculative bucket: Periodic Labs (Eric Schmidt-backed, founded by ex-DeepMind GNoME and ex-OpenAI principals), Orbital Materials (Toyota Ventures among the backers), CuspAI, RARA Factory, Altrove and Milvus Advanced build generative platforms that design new compounds in days rather than years, betting that post-2030 demand will move toward materials that look nothing like today's critical-minerals list. The thesis has stopped being find more rocks. It is process the rocks we already have, with chemistry, biology or software, and design new ones from scratch.



TECHNOLOGY AND MARKET CHALLENGES

Capital cycles vs technology cycles

Mining tech needs ten to fifteen years from pilot to commercial scale. Venture capital has half that horizon. The 2023–2024 price collapse defunded a generation of deep-tech projects that had been in development since 2018, and the capital that has come back in 2025–2026 is concentrated in a smaller number of late-stage names. Many earlier-stage process and chemistry plays will not survive this cycle.

Permitting and infrastructure

A new mine in the US or EU takes seven to fifteen years from discovery to first metal. A new refinery takes a decade. Grids, ports and rail lines that have to carry the output sit on similar timelines. None of these are technology problems. They are scheduling problems, and the AI build-out and electrification cycles are not waiting.

Western cost structure vs Chinese state capacity

Even with new technology and state-aligned capital, refining outside China is structurally 30 to 50% more expensive on a unit-cost basis. Closing that gap requires either sustained policy support that outlasts political cycles, or process technology that materially changes refining economics. Both are open bets.

Workforce

The skilled workforce that built the Western mining and refining base aged out without being replaced. Mariana Minerals cited recruitment difficulty as the reason for idling Copper One in 2024. Capital and technology can move quickly. People take a generation.

Incumbent procurement and process risk

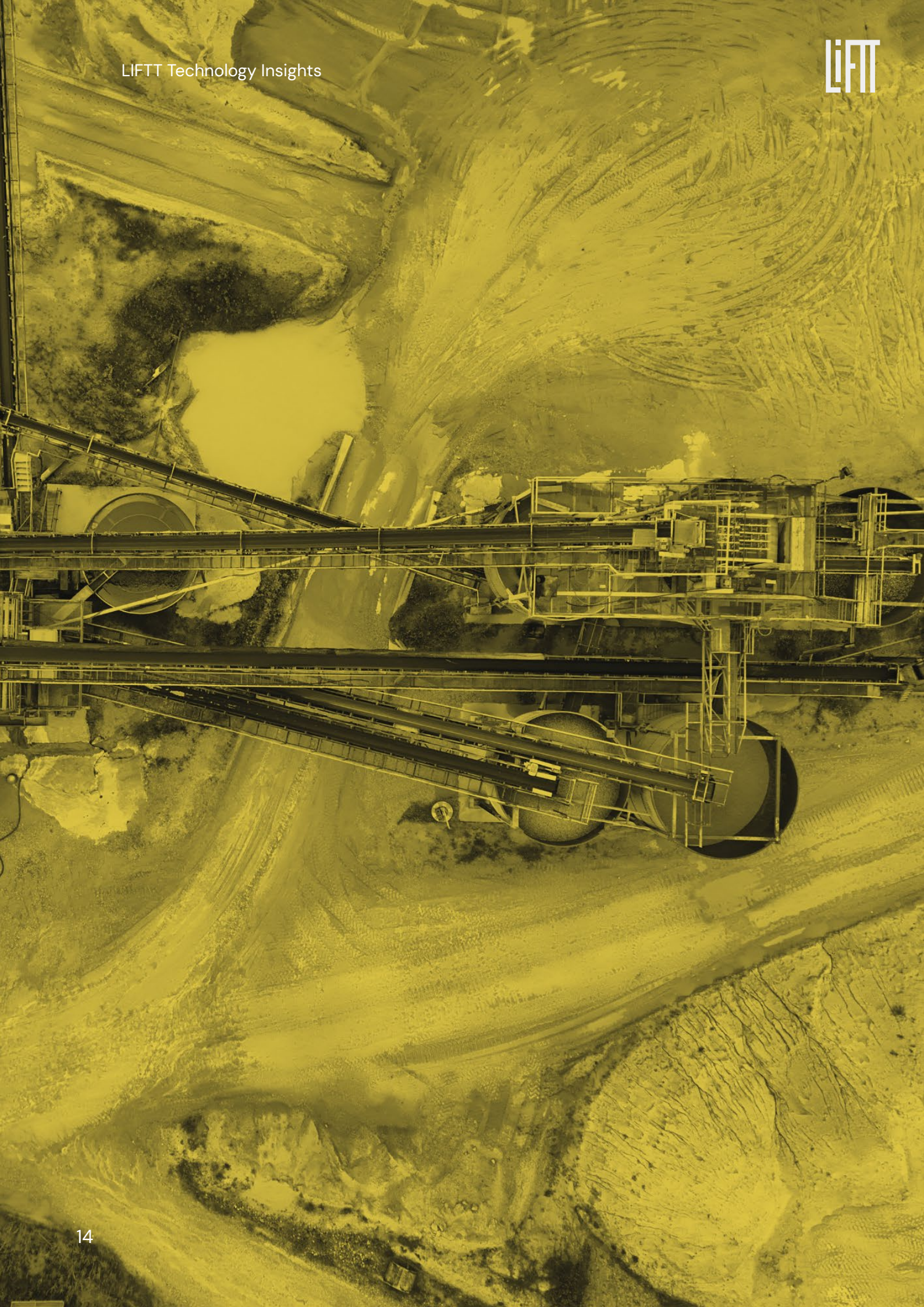
Mining majors are among the slowest industrial buyers to adopt new technology. Procurement cycles run two to four years before a startup's process gets a single deployment trial, and process disruption is treated as operational risk that can idle a mine for weeks. The deep-tech vendors that survive build with the operator, not for the operator. Rio Tinto's Nuton was developed inside Rio Tinto for nearly a decade before it became a customer-facing product. Startups outside that orbit face sales cycles longer than their funding runway.

WHAT TO EXPECT NEXT

The biggest single date on the calendar is 27 November 2026, when Beijing's one-year suspension of export controls on rare earths, gallium, germanium and antimony expires. A short extension with tighter licensing is the most likely outcome, but a hard reset cannot be ruled out, and either way procurement teams across magnets, semiconductors and defence will be operating under a different supply regime by Q4 2026 than they are today. In parallel, Project Vault's first tonnage commitments will reveal the United States' actual priority order across the \$12 billion programme: expect early flows on rare earths and uranium, with lithium and copper following in 2027.

On the operational side, the Glencore Horne smelter in Quebec is the first live stress test of whether Western public capital can rescue an asset that the structural pricing of the global concentrate market has expelled, with resolution expected by mid-2026. Eramet's Centenario plant should reach its 24,000-tonne design capacity in the same year, and Vulcan Energy is contracted to begin commercial deliveries to Renault and Volkswagen in 2026; together these are the twelve months that decide whether DLE becomes a real supply category or stays at pilot. AWS-Rio Tinto was the first direct hyperscaler copper deal in January 2026, and a second comparable agreement from Microsoft, Google or Meta inside the year would confirm hyperscaler-miner integration is a structural pattern.

More broadly, expect a wave of on-field collaboration announcements between mining-tech startups and Tier-1 incumbents; most will be pilots, and the signal that matters is whether any survive the procurement-to-trial gap that has historically defined this sector.



DEEP IMPACT

This is a scenario, not a forecast. If the signals in this report play out, the mineral system of the mid-2030s will look very different from the industry that built it. Direct extraction, modular refining and bioleaching will have removed the smelter from a meaningful share of copper output. Recycling will supply between 15 and 25 percent of base-metal demand for most non-iron critical minerals.

Western processing will have rebuilt at smaller, distributed, modular scale, sited near mines or near end-users rather than concentrated in single nodes. China will retain dominance of classical pyrometallurgy but lose share of premium provenance-verified product, where the price differential will sit. AI-generated materials will have started to obsolete entire mineral categories: cobalt-free cathodes scaled, magnet-free motors deployed, sodium-ion competitive in stationary storage. New mineral categories that are not on today's strategic list will have entered it.

Around that physical system, the industry structure will have re-formed. The vertical integrator, owning two or more stages of the chain, will be the dominant business model; the pure-play upstream miner and the pure-play smelter will be price-takers in a commodity market that no longer rewards them. Capital will move through structures that did not exist at scale in 2024: sovereign equity, hyperscaler offtake, public-private stockpile funds, multi-year forward contracts with carbon-and-provenance riders.

The deep-tech moats will sit not in the orebody but in the software stack that runs the mine, the chemistry or the biology that recovers the metal, the contracts that route the offtake, and the policy framework that decides access. The mineral system, by then, will look less like the mining industry of the twentieth century and more like the semiconductor industry of the twenty-first. That is the long-cycle picture as we read it.

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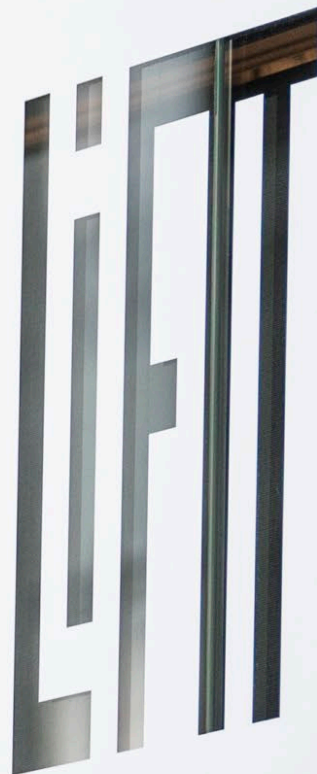
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