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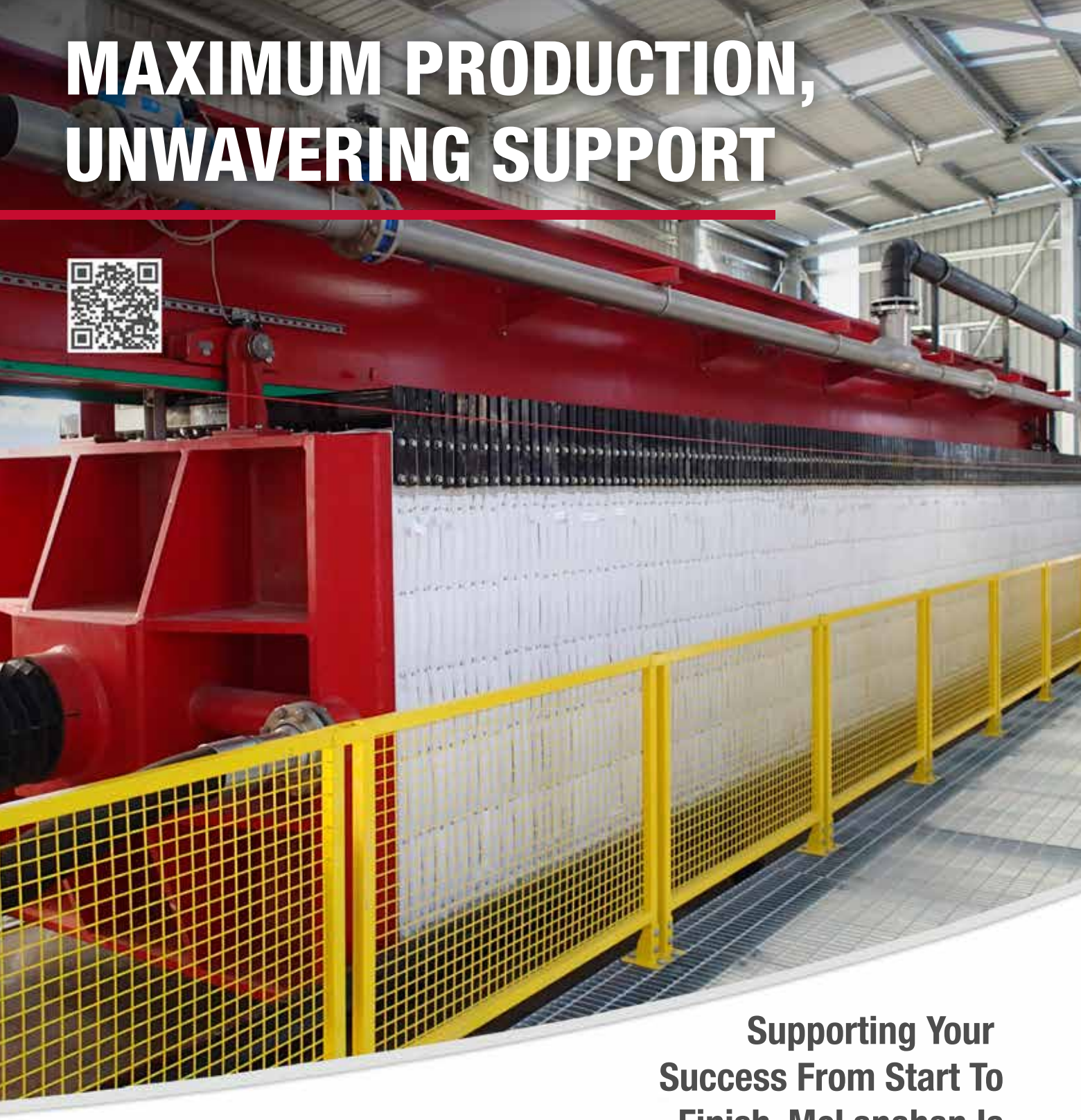
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Mineral resource governance for a project is a management framework that integrates the estimation process, the resulting estimates, documentation, oversight and public disclosure of a mining company's principal mineral assets. On page 16, A.R. Samal and G. Usero take a look at artificial intelligence to create a consistent framework for technical assurance of resource estimates. Photo credit: Shutterstock. Cover design by Ted Robertson.



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The power of individual influence;

The impact we have is up to us



Mary Korpi
2026 SME President

The word "influencer" has become a familiar part of today's vocabulary. It is interesting — and admittedly a bit disappointing — that many in the entertainment and social-media world now list "influencer" as their occupation. These titles often feel self-appointed and, at least to me, lack the substance that gives real influence its meaning.

During the Nevada Mining Association's annual conference, I was reminded of what genuine influence looks like. The keynote speaker was Jeff Civillico, a longtime Las Vegas entertainer known for his juggling. Like many in the audience, I initially wondered why a Las Vegas performer had been chosen to address a room full of mining professionals. It did not seem like an obvious fit.

But as his presentation unfolded, Civillico invited audience members into his story and gradually revealed a message that resonated deeply. He challenged us to recognize that, for many members of the public, we may be the only person they ever meet who works in the mining industry. Whether we realize it or not, we are the face, the voice and the representative of our profession. The impressions people form about mining may come from a conversation with one of us — at a community event, a school program, a business meeting, a neighborhood gathering or even a chance encounter with a stranger.

His message prompted me to reflect on influence and what it truly means. When I think about the people who have shaped my life, I do not think of celebrities or online personalities. I think of my parents, family members, teachers, mentors, coworkers and friends. Their influence did not come from a large audience or a digital platform. It came from their character, their actions, their words and the expectations they set through everyday examples.

Most of us can identify individuals who helped shape who we are. Sometimes their influence was intentional — a teacher encouraging a particular path, a supervisor challenging us to reach beyond what we thought possible, a parent instilling values that guide us decades later.

But the most powerful influence is often unintentional. People observe how we conduct ourselves, how we treat others, how we respond to challenges, and whether our actions align with our words. We rarely know when a simple conversation, a kind gesture or a moment of integrity will leave a lasting impression.

This carries an important responsibility. Each of us represents something larger than ourselves such as our families, our organizations, our communities and, for those of us in mining, our industry. Every interaction contributes to how others perceive the work we do and the values we hold.

True influence is not claimed through a title. It is earned through consistent actions and authentic relationships. It is measured not by the number of followers we have, but by the positive impact we have on those around us.

As I left the conference, I found myself thinking less about the modern concept of an influencer and more about the people who have genuinely influenced my life. Their examples remind me that each of us has the opportunity to make a difference, often in ways we may never fully realize.

Whether intentional or not, our words and actions matter. We are all influencers. The question is not whether we have influence, but what kind of influence we choose to have.

Till next month! ■

Safety Share | Mental wellness is as important as physical health in all industries, and it is important to know the best ways to offer help. Starting conversations and listening to your coworkers are important first steps in supporting someone who may need help, but is unable to ask for it. Breaking the silence by encouraging open discussions around mental health in the workplace can normalize the subject and make it easier for workers to speak about their own issues without embarrassment. Best practices for employers may include:

- Expressing a commitment to prioritizing employee mental health and well-being.
- Asking about workplace stressors and discussing what support or services are available and may be of help.
- Encouraging employees to share concerns and ideas with management without fear of retaliation.
- Encouraging employees to connect and support one another by providing opportunities to interact.

(Source: U.S. Department of Labor.) ■



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Denmark says US exploration must respect laws

DENMARK'S FOREIGN ministry said if the United States wished to explore Greenland's resources, it would have to do so within the framework of the Arctic island's legislation, adding that August's deal between the three parties did not change this, *Reuters* reported.

U.S. President Donald Trump said that "massive oil, gas and mineral exploration" was set to begin on Greenland, a contentious statement on a territory that has resisted his efforts to control it and has banned new drilling for crude.

Trump described the Danish Arctic island, which is run by a semiautonomous government, as "our new and beautiful Greenland" in a social-media post that hailed what he said were U.S. gains from a security deal signed in September.

The Danish foreign ministry said in a statement that "the agreement does not grant investors from the U.S. any preferential treatment compared with investors from other NATO countries, EU countries and NATO partners when it comes to access to natural resources in Greenland."

The Greenlandic prime minister's office declined to comment on Trump's statement, while Greenland's ministry of mineral resources did not immediately respond to requests for comment.

Greenland has been caught up in a confrontation with Trump, who has been saying since 2019 the United States should buy or take the strategically located and mineral-rich island for security reasons. On several occasions, he refused to rule out force.

Along with Denmark, the United States and Greenland reached an agreement in August to allow the United States to boost its military presence on the island — a deal that had appeared to settle the standoff.

The agreement did not allocate any rights for mining or drilling.

"Massive oil, gas, and mineral exploration is getting ready to begin," Trump wrote in a post on his Truth Social platform.

"There are experts that are saying that the amount of easily available oil is far greater than that of almost any land, anywhere in the world," he added without naming any specific deals or specific development.

Greenland banned uranium mining in its territory along with all future exploration of oil in 2021.

The government has said it is reviewing whether a Texas firm, Greenland Energy, can use permits predating that prohibition.

The company said in August that it had plans to drill for oil in 2027 at an untested basin on Greenland's east coast, although it lacked its own permit to do so. The previous owner, ARCO, spent heavily on seismic work in the 1970s but never drilled.

Independent Danish security policy adviser Jacob Kaarsbo said Trump's comments could be seen as a sign that his desire to control Greenland remained unchanged.

"It is extremely dangerous to view this agreement between the Trump administration and Denmark as something that has altered Trump's intentions," he said.

The 10-page deal between the United States, Denmark and Greenland paved the way for two new military bases and Trump's "Golden Dome" missile defense system, while reaffirming Danish sovereignty and Greenlanders' right to self-determination.

"Any future attack on the United States will have to come across Greenland, where our Defense will routinely knock down drones, missiles, or any other form of weapon not yet even conceived," Trump said in his post. ■

CMEI selects national laboratories for funding

THE U.S. Department of Energy's (DOE) Office of Critical Minerals and Energy Innovation (CMEI) selected 17 U.S. national-laboratory projects for $29.5 million in funding to accelerate the development of innovative technologies that expand and improve America's domestic mining capabilities. In accordance with President Donald Trump's Executive Order, Unleashing American Energy, the projects will reduce dependence on foreign supply chains, bolster national security and advance the technologies that will establish America's long-term energy independence.

"Today's investment is about unleashing the full innovative power of our national laboratories," said Assistant Secretary of Energy Audrey Robertson. "These projects will advance President Trump's effort to strengthen domestic mining, protect our supply chains and ensure the United States leads the world in critical mineral technologies."

The following national-laboratory projects have been selected for award negotiations:

- Ames National Laboratory (Ames, IA).
- Argonne National Laboratory (Lemont, IL).
- Idaho National Laboratory (Idaho Falls, ID).
- Lawrence Berkeley National Laboratory (Berkeley, CA).
- Lawrence Livermore National Laboratory (Livermore, CA).
- Los Alamos National Laboratory (Los Alamos, NM).
- National Laboratory of the Rockies (Golden, CO).
- Oak Ridge National Laboratory (Oak Ridge, TN).
- Pacific Northwest National Laboratory (Richland, WA).
- Sandia National Laboratory (Albuquerque, NM).
- Savannah River National Laboratory (Jackson, SC).
- SLAC National Accelerator Laboratory (Menlo Park, CA).

CMEI's Advanced Mining and Mineral Production Technologies Office will fund these selections through its Mine of the Future Initiative. ■



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Copper squeeze breathes new life into old mines;
Mt Lyell, Cobre Panama and Panguna Mine among potential restarts

IN 1899, the Mt Lyell Mine in Tasmania produced some 9.5 t (10,500 st) of copper. That made it the largest copper mine in the British Empire, though small by today's standards. In September, after 12 years idle, owner Sibanye-Stillwater approved a restart of Mt Lyell, putting it among a string of copper mines around the world being revived due to expectations for a structural shortage of the industrial metal.

Consultancy Benchmark Mineral Intelligence is tracking almost a million tons of potential annual copper production from mine restarts by 2030, equivalent to more than 4 percent of current output, *Reuters* reported.

About half of that is from the huge Cobre Panama project and the long-closed Panguna Mine in Papua New Guinea, but for both, a potential restart is as much a political as a market consideration.

While most idled mines are small, they have infrastructure, known orebodies and permitting histories, meaning they can produce copper many years sooner than discoveries in new locations, which take an average of 17 years to reach production, according to S&P Global Energy.

Johannesburg-based Sibanye, which paid $10 million for Mt Lyell in 2023, expects to spend around $340 million to restart it, with plans to ramp up to 26 kt (28,700 st) of annual production after it comes back online in 2029.

As part of its modernization of the facility, the company has digitized filing cabinets of hand-drawn geological and mine plans dating back more than a century. "It's all millimeter-perfect, but drawn by hand," Barry Harris, an executive vice president at Sibanye-Stillwater, told *Reuters*.

Record prices, with the benchmark London Metal Exchange copper contract hitting $14,875/t on Sept. 10, have made some idled mines viable again, but it is the prospect of medium- to long-term shortages that is prompting operators to restart them.

"Many of these operations are relatively small, but collectively they can make an important contribution to bridging the copper mine supply gap over the medium term," said Craig Lang, principal analyst at CRU.

Global copper demand is projected to rise 50 percent to 42 Mt (46 million st) a year by 2040, driven by the energy transition and data centers, S&P Global Energy predicts. It expects nearly half of new mine supply to come from restarts and expansions of existing resources, but even then the market could face a structural shortfall of 10 Mt (11 million st).

"Brownfield additions can buy the market valuable time, but they cannot replace the need for brand-new, world-class tier-1 discoveries to satisfy that scale of demand," said Eillen Grace Dela Cruz, principal analyst at S&P Global Energy.

In Zambia, partial production has restarted in the upper section of the Luanshya Mine, which was offline for more than two decades, and underground infrastructure is now being built, a Zambian mines ministry spokesperson said. The mine is majority-owned by China Nonferrous Mining Corp. and has a target production of 100 kt/a (110,000 stpy) by 2030.

In Argentina, global commodities trader and miner Glencore has said it plans to revive production at its Alumbrera mine, shuttered since 2018, in the second half of 2027 to produce a total of 75 kt (83,000 st) of copper over four years. ■

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Caterpillar announces leadership
transition in Resource Industries

CATERPILLAR INC. announced Denise Johnson, group president of Resource Industries, has elected to retire effective Feb. 1, 2027. Derrick York, who currently serves as president of Solar Turbines and Caterpillar senior vice president, has been appointed group president of Resource Industries, effective Nov. 1, 2026, at which time Johnson will assume an advisory role to ensure a seamless leadership transition.

Since joining Caterpillar in 2011, Johnson has transformed Caterpillar's mining business and advanced the industry, championing technologies that define the modern mine site. She assumed leadership of Resource Industries in 2016 during a historic mining downturn. Her leadership strengthened operations and the portfolio while maintaining a clear focus on long-term growth, returning the segment to profitability and ultimately delivering its strongest financial performance in more than a decade.

"Denise took on a critical role during one of the mining industry's most challenging times," said Joe Creed, Caterpillar chairman and chief executive officer. "Her disciplined leadership restored Resource Industries to profitability and positioned Caterpillar as an industry leader in mining autonomy and technology. We are deeply grateful for all she has done to strengthen our relationships with customers, develop our people and shape the future of our company. Her impact and influence will be remembered long after her retirement." ■



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RAISING SCHOLARSHIP DOLLARS

Chile's state-owned miner Codelco says restructuring plan, originally expected in October, may be delayed to end-2026

CHILEAN state-owned copper giant Codelco's restructuring plan may not be ready until the end of 2026, the company told *Reuters,* signaling a delay for a much-anticipated strategy meant to address years of stagnant production and mounting costs.

The turnaround plan was originally expected in October. Four sources with knowledge of the matter said it could entail a workforce reduction of between 5 and 20 percent, while Codelco said it was too early to speculate.

Any restructuring at Chile's largest company would resonate far beyond Codelco, given mining's outsized role in the Chilean economy, and run counter to President Jose Antonio Kast's pledge to lower unemployment to around 6 percent and recover at least 300,000 jobs by 2030.

"Codelco is currently working through a diagnostic process to figure out its strategic direction and develop a recovery plan. That's already underway and should be ready by the end of 2026," the company said.

Codelco's new chief executive officer, Jorge Gomez, joined the company in July, and the company said this sort of review was fairly standard when new leadership took over.

Asked about potential job cuts, Codelco added: "It's too early to speculate or get ahead of ourselves about what decisions might come out of this."

There has been a longstanding debate in Chile over whether the state miner's payroll has become bloated relative to private-sector peers.

The four sources, three of whom work at Codelco and one who is close to the company's top management and government, said the company's new management is reassessing the size of its nearly 77,000-strong workforce to restore competitiveness.

They said the workforce reduction could range from 5 percent to as much as one-fifth of the payroll, underscoring that no firm decision has been made.

Some job losses could come from Codelco selling or shutting down less profitable operations or delaying projects to ease cost pressures, the sources said. Contractors, who account for eight in every 10 jobs at Codelco, would likely be hardest hit.

Before joining Codelco, Gomez helped stabilize production at Anglo American and Glencore's jointly owned Collahuasi Mine, one of the world's largest copper mines.

Sources said Gomez is seeking to apply a similar turnaround strategy at Codelco, beginning with a more realistic production outlook after previous plans envisioned output reaching 1.7 Mt (1.9 million st) by the end of the decade.

Codelco chairman Bernardo Fontaine said in August output is likely to remain around 1.3 Mt (1.4 million st)in coming years. He also previously said the recovery plan would involve difficult decisions aimed at restoring the miner's competitiveness. In June, Fontaine had said the restructuring plan would be presented in three to four months, and in a later radio interview said it would come in October to November. ■

Canadian steelmakers offset some US tariff pain with domestic demand in mining, energy and data-center projects

CANADA'S STEEL industry, among the sectors hit first and hardest by U.S. President Donald Trump's tariffs, is starting to turn a corner thanks to an uptick in mining, energy and artificial-intelligence (AI) data-center projects as well as government support, although the impact has not been even across the country, *Reuters* reported.

While Canada is a small producer globally, and steel contributes less than 1 percent to national GDP, it is one sector in which Prime Minister Mark Carney's efforts to make Canada's economy less reliant on the United States appears to be having some success, albeit with a heavy dose of government intervention.

Steel companies have been diversifying away from the United States and focusing on domestic demand since Trump increased tariffs on imported steel from 25 percent to 50 percent in June 2025, steelmakers, analysts and union representatives said.

Canada used to send around 90 percent of its steel exports to the United States, but shipments plummeted by 60 percent in 2025, according to the Canadian Steel Producers Association. Hundreds of steelworkers have been laid off. But the share of steel used in Canada that was produced domestically rose to 51 percent in 2025, up from 41 percent in 2024, according to United Steelworkers (USW), the sector's main labor union. The import share declined from 59 percent to 49 percent. USW calculated the data based on World Steel data and Canada's imported steel data, said Guio Jacinto, an economic researcher for the union.

The green shoots are mostly appearing in western Canada, where some large industrial projects, including a 1.2-GW data center in Saskatchewan, are under construction. Carney said a new oil pipeline to the Pacific Coast would also boost demand for steel.

Canadian steel demand is estimated to have grown around 2.7 percent in 2025 and is projected to increase by about 0.9 percent in 2026, according to a July Organisation for Economic Co-operation and Development report. ■

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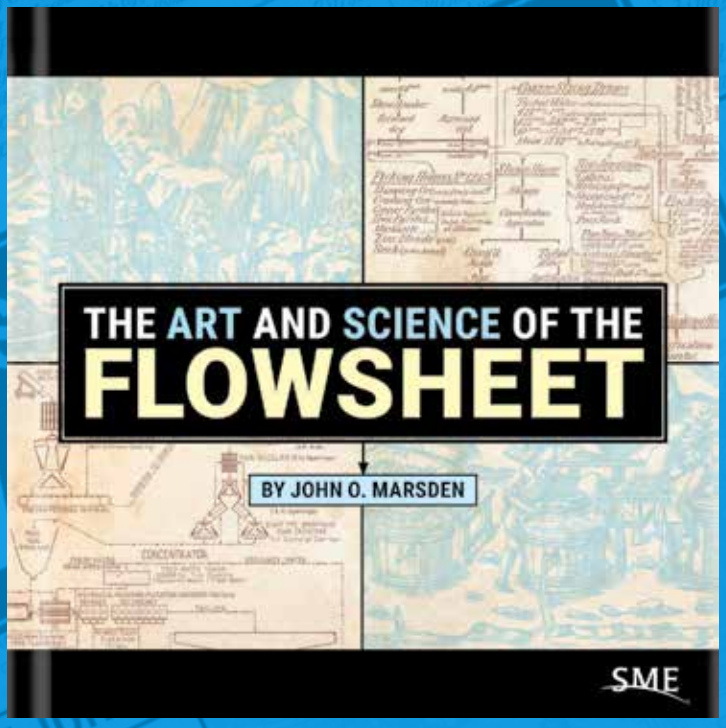
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Leaders in mining excellence honored by NMA;
20 operations recognized with Sentinels of Safety Award

THE NATIONAL Mining Association (NMA), the National Institute for Occupational Safety and Health (NIOSH), the U.S. Office of Surface Mining Reclamation and Enforcement (OSMRE) and the Bureau of Land Management (BLM) have honored 20 outstanding achievements in mine safety, technology, reclamation and stewardship.

The NMA's Sentinels of Safety Award recognizes coal and mineral mining operations in 10 categories for recording the most hours in a calendar year without a single lost-time injury. A minimum of 4,000 hours is required for award consideration. The award categories reflect the safety accomplishments of both small and large mines.

Twenty American mining operations — six coal mines and 14 mineral/metal mines — were honored for their extraordinary safety performance in 2025. "Safety is the foundation on which our industry stands," said Rich Nolan, NMA president and chief executive officer. "With mineral, material and electricity demand all rapidly growing, American economic and national security count on our ability to safely and responsibly mine. These winners are at the leading edge of today's modern, dynamic and safe mining industry that is working to meet the demands of the most materials and energy intensive period in American history."

Initiated in 1923 by then Commerce Secretary Herbert Hoover, a former mining engineer, the award program remains the nation's most prestigious recognition of mine safety and has helped foster a strong safety commitment on the part of U.S. mines. Recipients for 2025 include the following:

- Large coal processing: Cumberland Mine, Iron Senergy, Waynesburg, PA.
- Large underground metal: Hermosa Mine, South32 Hermosa Inc., Patagonia, AZ.
- Large surface coal: Eagle Butte Mine, Eagle Summit Resources, LLC, Gillette, WY.
- Large openpit: Phoenix Mine, Nevada Gold Mines LLC, Elko, NV.
- Large metal/nonmetal mill: American Soda LLC, Solvay Chemicals Inc., Green River, WY.
- Large bank or pit: 3M — FST Sand & Gravel Inc., Corona, CA.
- Large dredge: Independent Mine, E.R. Jahna Industries, Davenport, FL.
- Large quarry: Cumberland River Quarry, Pine Bluff Sand and Gravel Co., White Hall, AK.
- Large underground coal: Mine No. 44, Twin State Mining Inc., Princeton, WV. ■

Richemont, owner of Cartier, weighs joining
De Beers acquisition race, source says

RICHEMONT, THE owner of high-end jewelry brand Cartier, is in talks to join a consortium bidding for diamond miner De Beers, which has been put up for sale by controlling shareholder Anglo American and is valued at about $1 billion, a person familiar with the matter told *Reuters*.

A deal would give the Swiss luxury goods group greater influence over a core element of its supply chain as natural diamond player De Beers grapples with the rapid ascent of cheaper laboratory-grown gems.

Richemont, which is cash-rich and also owns luxury jeweler Van Cleef & Arpels, is discussing joining the Global Diamond Consortium, a group led by former De Beers chief executive officer Gareth Penny that is vying for Anglo American's 85 percent stake in the world's most famous diamond miner, the person told *Reuters*, confirming a *Bloomberg News* report.

Swiss-listed Richemont, worth around $113 billion, did not respond to requests for comment. Anglo American declined to comment.

Filings show Richemont had around 9 billion euros ($10.09 billion) in net cash at the end of June, a treasure chest worth several times the entire value of De Beers.

"We view Richemont's potential participation as strategically meaningful but more about optics and long-term natural diamond category positioning than a financial event," RBC analysts said in a note.

Bloomberg reported that negotiations were advanced, although there was no guarantee Richemont would join the consortium.

Other investors are lining up. Antwerp, Belgium-based diamond-manufacturing company Pluczenik is also bidding for a stake, the company told *Reuters*, without disclosing the size of the stake. And U.S. jeweler retailer Signet is in talks to join the consortium, said a source familiar with the company. Signet did not immediately reply to a request for comment. The company, which owns retail brands including KAY Jewelers, Zales and Jared, has worked with De Beers in recent years on natural-diamond marketing campaigns.

Any bid for De Beers would depend on Botswana's government, which owns 15 percent in the miner and has yet to say whether it intends to exercise a first right of refusal.

A spokesperson for Botswana's presidency said the government would not comment until a transaction had been concluded and signed. Officials said this summer a deal was likely to be completed in the fourth quarter of 2026.

Anglo American put De Beers up for sale in 2024 as part of a wider restructuring amid falling diamond prices and growing demand for synthetic stones. De Beers has mining and exploration operations in Botswana, Namibia, Angola, South Africa and Canada. ■

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EnergyX signs binding $2 billion lithium supply deal
with Trafigura, one of the largest deals tied to direct extraction

LITHIUM STARTUP EnergyX said it has signed a $2 billion binding offtake to supply commodities trader Trafigura with the battery metal from Chile and the United States, one of the largest deals ever tied to direct lithium extraction technology.

The 10-year agreement, which *Reuters* is first to report, comes as strong demand for lithium from the fast-growing stationary battery storage system market has offset uneven sales in the global electric-vehicle market, which had been the primary user of the ultralight metal for years.

Trafigura has agreed to buy 100 kt (110,000 st) of lithium from EnergyX over a 10-year period as part of a take-or-pay contract. The deal's value is tied to current lithium prices near $20,000/t.

"This agreement reflects our ability to help bring strategic critical minerals projects online and build secure, diversified supply chains," said Daniel von Arx, Trafigura's head of battery metals.

As part of the agreement, Trafigura will buy 5 kt/a (5,500 stpy) of lithium hydroxide and the same amount of lithium carbonate from EnergyX. Battery manufacturers typically prefer one version over the other, depending on what device the battery is powering.

EnergyX, which was formed in 2018 and is backed by General Motors and Italian energy company Eni, aims to start lithium production in 2028. It plans to initially produce 15 kt/a (16,500 stpy) of lithium hydroxide in Texas starting in 2029, meaning Trafigura will buy 33 percent of that output. In Chile, it plans to start producing 7.5 kt/a (8,200 stpy) of lithium carbonate in 2028, with Trafigura's share reflecting 66 percent of the South American output.

Switzerland-based Trafigura plans to initially sell the lithium to Chinese customers, with the long-term goal of being a large supplier to U.S. markets once the country's battery supply chain is developed.

EnergyX is among the companies pursuing direct lithium extraction (DLE), a broad classification of filtration technology comparable to household water softeners. Exxon Mobil, Vulcan Energy Resources and Lilac Solutions are among the others pursuing DLE.

While some are developing their own DLE systems, EnergyX has combined several known filtration technologies and built them with readily available equipment, a strategy that attracted Trafigura.

EnergyX has been testing its processes at its laboratory in Austin, TX. It needs to obtain additional funds to build the Chile and Texas facilities. ■

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China demands copper supply commitments
for Anglo Teck merger approval, sources say

CHINA'S ANTITRUST regulator has asked Anglo American to commit to supply the country with a steady flow of copper concentrate as a condition for approving its proposed $54 billion merger with Canada's Teck Resources, three people aware of the development said, according to *Reuters*.

The demand reflects China's struggle to feed its vast copper smelting industry, which refines up to 60 percent of the world's copper cathodes but faces its worst feedstock shortage in decades.

Chinese refined copper output is expected to grow at its slowest pace since at least 2000 this year as smelters compete for raw material, while falling prices for byproduct sulfuric acid squeeze profitability, analysts said.

China's State Administration for Market Regulation (SAMR) has asked for assurances on copper concentrate supply, including volumes sold through traders, said the people, who declined to be named due to the confidential nature of discussions.

The regulator has received feedback from Chinese smelters and is now negotiating remedies based on their concerns, one person said.

As a major consumer of both companies' copper, China has effective veto power over the merger, and has historically leveraged its antitrust power over megadeals to extract strict "behavioral remedies" to protect its domestic industrial supply.

Teck declined to comment on regulatory processes. SAMR did not immediately respond to a request for comment.

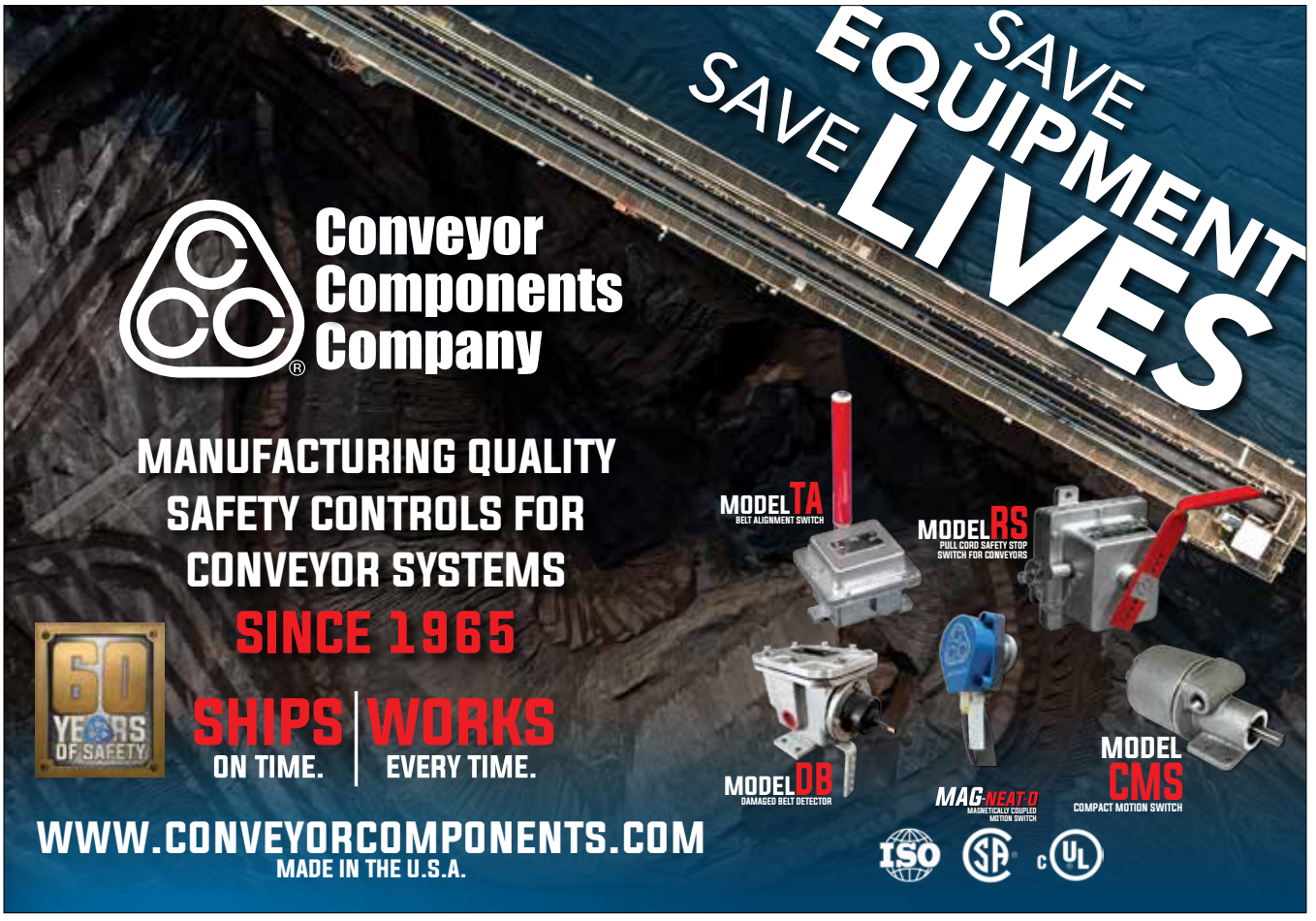
"We are making good progress toward completion and are working constructively with the Chinese regulator, SAMR, through its structured review process," an Anglo American spokesperson said, declining to provide further details.

Both Anglo and Teck have marketing teams in China.

Cutting off Anglo Teck's massive unrefined volumes from the open market could hasten the closure of some Western processing facilities, already under pressure from rising costs, industry analysts said.

Operating under state-mandated destination clauses could also accelerate a shift away from traditional annual benchmark pricing, as the industry would likely pivot to index-linked spot pricing, they said.

The bulk of Anglo American's copper output from Peru and Chile is sold as unrefined concentrate to international buyers, including Chinese, Japanese and European custom smelters. ■



Artificial intelligence in mineral resource governance: A framework for consistency, traceability and technical assurance of resource estimates

by A.R. Samal and G. Usero

Mineral resources are core assets of a mining company, and their governance requires a high degree of assurance. Audit processes are key activities in developing this assurance. The audit of mineral resources is a detailed and often tedious process that connects the estimation, evaluation, documentation, oversight and public disclosure of a mining company's principal mineral assets. Such audits often require reviewers to reconstruct workflows from native project files, parameter sets, batch macros, or scripts and incomplete reports. This article presents a human-directed approach in which specialized artificial-intelligence (AI) agents operate incumbent geological, geostatistical and mine-planning software, collect evidence and produce a reproducible audit record. Four anonymized applications illustrate the method: reconstruction of a legacy estimate during transaction due diligence; parameter review across 46 estimation domains; forensic recovery of settings from batch journal files; and reconciliation of medium- and short-term block models over common stope volumes. In one transaction, a reconstruction estimated to require about five weeks by conventional review was completed in two days. The more consequential result was evidence traceability, not speed alone. A three-level evidence-sufficiency framework classified audit questions as answerable, partially answerable or not answerable, and identified the additional information needed for unresolved items. The cases show that agentic systems can improve coverage and repeatability without replacing professional judgment. Competent Persons (CPs) and Qualified Persons (QPs) remain responsible for materiality, classification, estimation choices and public-reporting sign-off.

Figure 1

The MineMind system architecture.



A.R. Samal, member SME, is principal geologist at GeoGlobal LLC, Salt Lake City, UT and G. Usero is founder and chief executive officer of MineMind Inc., Miami, FL, email arsamal@gmail.com.

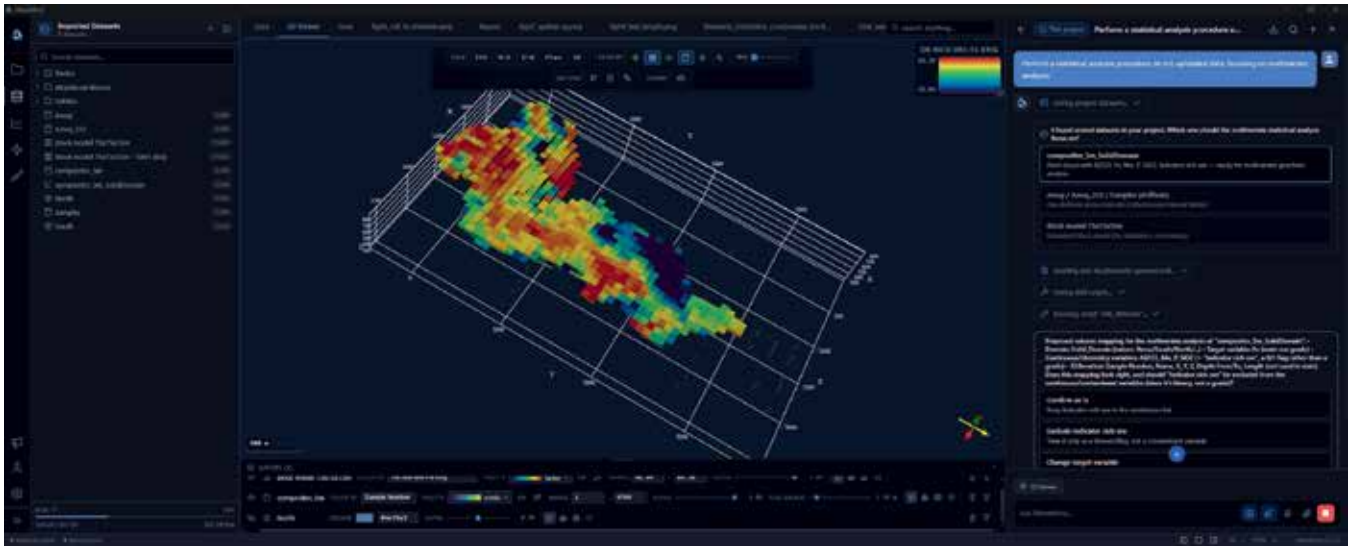
Introduction

Mineral resource governance for a project is a management framework that integrates the estimation process, the resulting estimates, documentation, oversight and public disclosure of a mining company's principal mineral assets. An efficient framework makes the resource estimation process auditable and transparent while keeping it compliant with the applicable internal technical standards and regulatory requirements of the operating jurisdiction.

The mineral resource estimation (MRE) process in any mining project evolves through

AI FOR MINING THAT SHOWS ITS WORK

From the resource model to the mine plan, MineMind runs technical work inside the software mining teams already use. On a recent copper project, a full resource estimate took 2 days against a typical 5 weeks, with every step recorded for review.



The agent proposes parameters and waits for the geologist to confirm before any calculation runs.

MineMind is an AI platform built for mining by a US company headquartered in Miami. It covers both halves of the technical workflow and works inside the software teams already use. For geology and resources, that means acQuire, Leapfrog, Vulcan, Datamine Studio RM and Isatis.neo. For mine planning, it means Vulcan, Deswik, Datamine Studio OP and UG, and GEOVIA Whittle.

The platform has three layers that act as one system. Intelligence understands the question, orchestration gathers the data and drives the right tools, and execution does the math.

In geology, professionals run kriging, simulation, QAQC and drill spacing studies in natural language with no scripting, so more of the team can do advanced analysis.

In mine planning, a dedicated team is bringing algorithms into the platform so engineers can run them the same way. Modules in development cover equipment hours and operating cost estimation from the mine schedule, for open pit and underground, and AI-assisted scenario setup for strategic planning.

The AI is white box. Every parameter and choice stays visible, and every step is recorded for audits, technical reviews, and resource and reserve reports. The Qualified Person or Competent Person still makes the final decision.

None of the figures comes from a language model.

Alongside the software, MineMind has technical teams in geology, geostatistics, mine planning and data science. They cover database management, geostatistical modeling, grade estimation, and resources and reserves reporting.

Customers range from Tier 1 majors to Tier 2 producers listed on the NYSE and TSX, with operations in the USA, Canada, Chile and Brazil. MineMind closed a $1 million pre-seed round at an $11 million valuation cap, backed by former Tier 1 mining executives and founders who sold their companies to Sandvik, Weir, Bentley Systems and Constellation Software.

For the method behind the platform, see "Artificial Intelligence in Mineral Resource Governance" by Samal and Usero on page [ ].

> "MineMind has come in to amplify value creation in resource evaluation. ... we get fast answers to tasks that would previously have taken a long time."
>
> Lucas Upa, Mineral Resources Manager, Ero Copper

THREE LAYERS, ONE SYSTEM

Intelligence: an AI assistant built on a mining knowledge base that understands geology, geostatistics, mine planning and reporting standards.

Orchestration: agents that pull drilling data, block models, schedules and reports, run pre and post processing, and drive your existing geology and planning software.

Execution: native compute. Bedrock, MineMind's own geostatistics library, does the math behind every estimate, and mine planning algorithms are being built in alongside it.

many cycles of data collection over time, geological interpretation, definition of estimation domains (domaining), exploratory data analysis (EDA), geostatistical modeling (variography), grade estimation, resource classification and validation of the estimates against the input data to confirm their quality. The technical data and records are commonly distributed across various databases and across resource modeling projects conducted over time. Each resource modeling project has its own data files, estimation parameter files, software-specific commands and workflow scripts for data manipulation and repetitive processes (macros or scripts) and reports. When a past project changes ownership or personnel, many details are lost because they were held only by the person or team that owned the project. Reviewers trying to understand the process and results of such a project must determine whether the reported estimate appears reasonable and whether the executed workflow agrees with its documentation (scope of work, standard operating procedures or a technical report).

Reviews depend on experienced professionals navigating multiple software interfaces and recording their findings manually. Repetitive checks across many domains can be slow and vulnerable to omission or fatigue. There is an opportunity for an AI-assisted system to perform these tasks systematically, accelerate information gathering and evidence retrieval, perform consistency checks and retain provenance while preparing reports for judgment by the CP or QP. This article describes an AI-assisted architecture and evaluates its practical application through four anonymized engagements.

The architecture

The approach complements established technical software through an integrated orchestration layer. This layer uses AI agents to translate plain-language instructions into coordinated workflows across existing technical tools, reducing manual handoffs between disciplines. MineMind (https://www.minemindai.com/#plataforma) converts user-defined methods into reusable workflows called skills. These skills can integrate different data sets and software tools, execute workflows repeatedly, maintain version histories, and document each step without relying on fixed software menus or difficult-to-maintain scripts. As shown in Fig. 1, a user defines what is needed as a bounded technical question. Specialized agents plan the required checks, call geological, geostatistical, database or mine-planning tools through available programming interfaces, and return results with references to the source files, parameters and executed steps attached. The generated report is reviewed by an expert geoscientist or engineer for validation and acceptance.

Evidence-sufficiency control

Each review project retains at least the project-file identity and version, the query or instruction, the software operation, the parameters extracted or applied, intermediate validation results, exceptions and the reviewer disposition, which together provide a complete, auditable and evidence-rich package. Each result has to be linked to a data source and a process. A result that cannot be linked to its source is treated as an unsupported assertion.

Deterministic computations, such as drill-hole interval validation, block-model aggregation or domain assignment, are traceable and reproducible. When a user asks the MineMind system a question, the outcome falls into one of three categories. Accordingly, MineMind classifies questions in three ways:

1. An answerable question has direct, sufficient evidence for a bounded conclusion.
2. A partially answerable question has relevant evidence but requires explicit qualifications.
3. A question is not answerable when the available record cannot support the requested conclusion.

In the last two categories, the final results name the missing evidence or analysis. This is important because the explicit listing of missing items allows the user to go back, address the gaps and repeat the process.

Case studies

Four anonymized case studies, selected to represent different settings, are presented here. The case studies are observational engagements rather than controlled experiments.

Case A: Transaction due diligence. A copper-gold asset in Latin America was in an active sale process, and a third-party review was warranted. Because of legacy data issues, the review was taking much longer than planned. MineMind AI agents were deployed to complete the due-diligence process. Starting from simple plain-language questions, workflows were created to synchronize the data analyses, results and processes, and the original estimation processes



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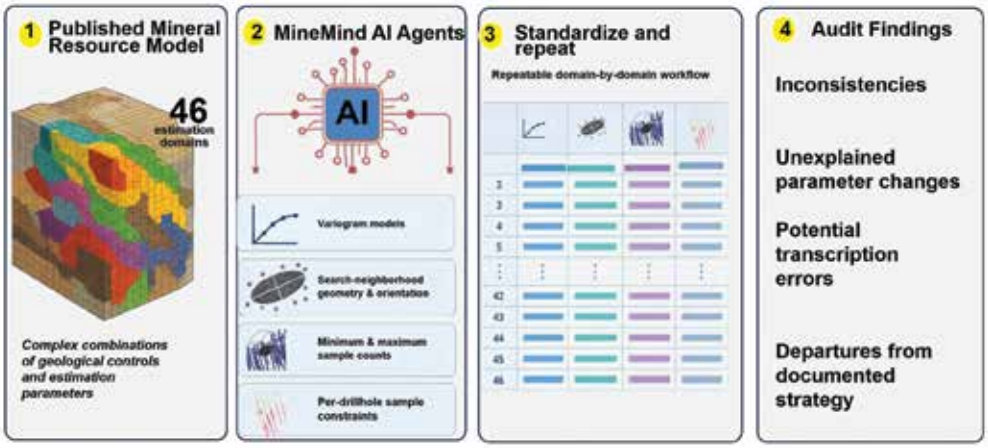
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Figure 2

A structured process for mineral resource model review.



were reconstructed. The numbers shown in the technical report were validated using several skills within MineMind. The reconstruction and validation were completed in two days, compared with an indicative conventional-review quotation of approximately five weeks. The stronger claim is not speed alone: each recovered parameter was linked to a project file and journal entry.

Fast data processing combined with evidence-based reporting resulted in an efficient review with reliable, traceable results.

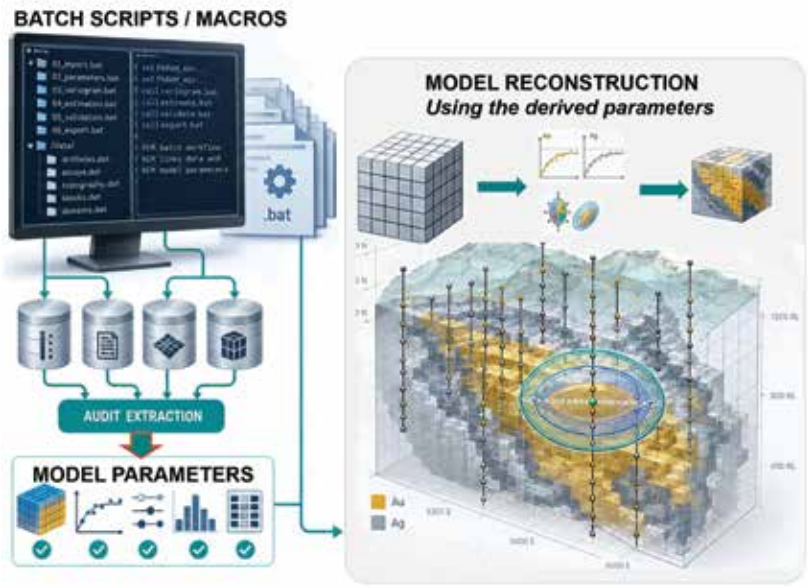
Case B: Review of a complex resource model for assurance. A resource model with complex modeling parameters was examined for consistency and assurance. The objective was to audit the configuration, internal consistency and traceability of the published model, not to generate or endorse an alternative mineral resource estimate. The model had 46 estimation domains, each with its own combination of estimation parameters and geological controls. It was an extremely complex review process.

The AI agents in MineMind systematically extracted, standardized and compared all parameters applied within every domain, such as variogram models, search-neighborhood geometry and orientation, minimum and maximum sample counts and per-drillhole sample constraints (Fig. 2).

Workflows were created for this detailed domain-by-domain comparison to check for inconsistencies, unexplained parameter changes, potential transcription errors, and departures from the documented estimation strategy. Once a workflow for extracting information and comparing it with the report was constructed for one domain and validated on another, the process could be repeated across all 46 domains, reducing the risk of oversight and maintaining a consistent level of review rigor throughout a repetitive process.

Figure 3

Model reconstruction from the parameters derived from the batch scripts and macros. The MineMind system can automate the process so that further sensitivity analyses can be conducted.



Case C: Reconstruction of models from internal scripts. In this case, a resource model for a gold-silver deposit was presented with computer-generated batch macros or scripts as the main source of information linking the data sets and parameters. From these files, the audit recovered all modeling parameters, including search ellipses, sector and octant settings, nested expanded searches, sample limits, gold and silver variogram structures, multiple-indicator-kriging cutoffs and post-processing steps. It also found evidence that a stored orientation variable locally rotated search neighborhoods. That observation was reported as indicative of dynamic anisotropy, not as formal confirmation, because the original method documentation was unavailable. The models could be reconstructed from the derived parameters (Fig. 3).

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Figure 4

Three-level evidence classification applied to seven audit questions (Case C).



The record could not quantify the resource effect of analytical bias, establish that a representative population free of high-grade bias had been analyzed, or reconstruct missing sample and assay-certificate status. The next evidence required included sensitivity reruns, declustering and capping studies, and access to sampling and certificate databases. A key audit principle is to report evidence limitations as clearly as the findings.

Of seven audit questions, two were classified as answerable, two as partially answerable and three as not answerable (Fig. 4).

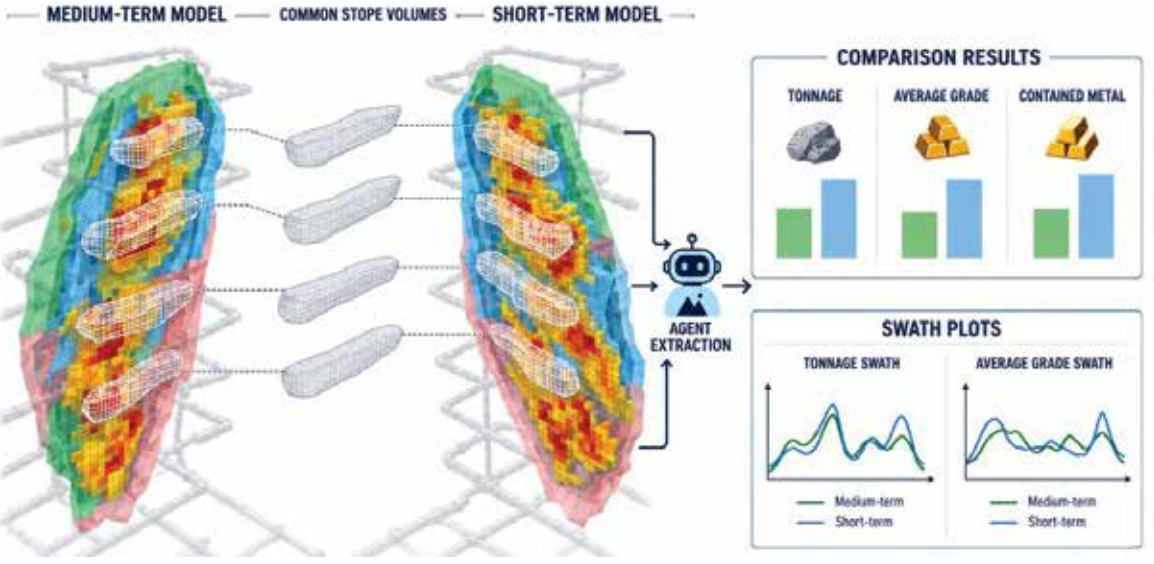
Case D: Block-model reconciliation. At an underground gold operation, medium-term and short-term planning block models were compared over common stope volumes. Agents extracted block populations; calculated tonnage, average grade and contained metal by geological domain and classification; quantified absolute and percentage differences; and produced tables, swath plots and domain statistics.

Approximately 8,000 blocks in one model were compared with approximately 5,000 in the other. Density and grade-field consistency were checked during extraction. The application extends the approach from one-time due diligence to a recurring assurance process (Fig. 5).

Summary of case studies. The four anonymized case studies discussed above demonstrate how AI-assisted workflows can support different types of mineral resource projects. In the first case, AI agents reconstructed a due-diligence analysis workflow from native project files and scripts and executed the process within two days, while also checking consistency between the executed workflow and the technical report. Case B reviewed resource modeling parameters such as search, variogram and sample-selection parameters uniformly across 46 estimation domains and delivered a consistent review within a few days. Case C reconstructed the forensic audit trail of a gold-silver estimate from batch scripts, reran the models and distinguished questions that could be answered from those that were only partially supported or remained unresolved. Case D compared medium-term and short-term mine planning models over common stope volumes at an underground mining operation, quantifying differences in tonnage, grade and contained metal by geological domain and resource classification.

Figure 5

Reconciliation of medium- and short-term block models over common stope volumes (schematic).



Implications for compliance: Reporting codes and professional responsibility of the QP/CP

It is important to note that the methods discussed support, but do not themselves establish, compliance with CRIRSCO-family reporting codes. For instance, data-integrity checks provide evidence relevant to drilling, sampling and data-verification disclosures, and audits of resource modeling parameters support disclosures on estimation and modeling methods, including domains, variography, search strategy and sample selection. The AI system keeps the reference to the source to support transparency and assists the QP or CP in making judgments on materiality. The system is jurisdiction-neutral and can be used to support compliance with major reporting codes and guidelines such as the JORC Code (https://www.jorc.org/docs/JORC_code_2012.pdf), NI 43-101 (https://mrmr.cim.org/media/1017/national-instrument-43-101.pdf) and S-K 1300 (https://www.ecfr.gov/current/title-17/chapter-II/part-229/subpart-229.1300).

While the AI may identify inconsistent parameters, missing records or unexplained differences, it cannot accept professional accountability. Tasks such as geological interpretation, treatment of outliers, estimation method selection, classification, reasonable-prospects considerations and public-reporting sign-off remain the responsibility of the QP or CP.

Discussion and conclusions

The four case studies show that AI-assisted auditing can improve the speed and consistency of mineral resource reviews and audits. Automated workflows can apply the same checks across every geological domain or mining area in a mine plan, reconstruct technical records from project files and scripts, and compare successive models more efficiently. Importantly, regular model reconciliation can also become a continuous feedback process, which is vital for improving productivity in any mining project.

However, there are system limitations that need improvement over time. The case-study results do not provide statistical proof of performance. Legacy files may be incomplete, damaged or unclear, and scripts may show what was executed without explaining why particular decisions were made. An AI system may also misinterpret technical terms or overstate conclusions unless its outputs remain linked to evidence and subject to professional review. Organizations should therefore establish clear requirements for data access, version control, validation, exception thresholds and record retention.

A risk-based approach provides a practical way to adopt these methods. Deterministic database and calculation checks can be tested against known results, while extracted parameters can be compared with samples reviewed manually. Interpretive conclusions should require approval by an experienced reviewer, and material findings should receive independent confirmation. This approach uses automation for repeatable evidence-based tasks while preserving professional judgment under applicable reporting codes.

The main contribution of this article is an evidence-sufficiency framework that separates audit questions into answerable, partially answerable and not answerable categories and identifies the additional work needed. Combined with reliable calculations, traceable evidence and mandatory professional review, this framework is more important than speed alone. AI should therefore serve as an audit accelerator and assistant, not as a substitute for a CP or QP. ■

(The authors acknowledge the technical teams and clients whose anonymized engagements informed this paper. Client and project identities have been withheld. Quantitative case information is reported with the anonymized descriptors supplied for publication.)



Florence Copper and in situ copper recovery for sustainable copper mining

by Sophie Dessart



Photos and figures courtesy of Florence Copper

Located in Florence, AZ, midway between Phoenix and Tucson in the heart of Arizona's Copper Corridor, Florence Copper is a first-of-its-kind, greenfield in situ copper recovery (ISCR) project. Instead of mining through traditional openpit or underground processes, Florence Copper eliminates the need for large-scale blasting, waste rock piles, tailings storage facilities, heavy machinery like haul trucks and other traditional facets of the mining industry through the innovative and proven ISCR process. Made possible by the hydrogeologic conditions found in its deposit, Florence Copper's use of the ISCR process brings significant water, energy, carbon and cost savings while simultaneously allowing for opportunities to redevelop the land when the project is complete.

History and background

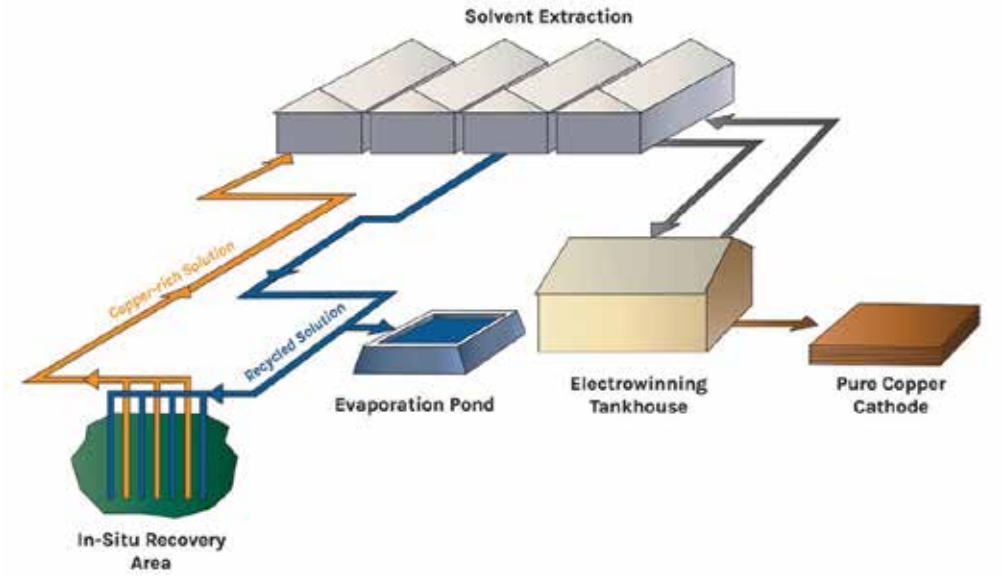
The Florence Copper project is wholly owned by Trekor Metals Ltd. (formerly Taseko Mines Ltd.), a Vancouver-based copper mining company. The project has a rich history, with more than $135 million invested by former owners. The copper deposit on the property was first discovered in 1969 by a geologist from the American Smelting & Refining Co. (Asarco). While the Continental Oil Co. (Conoco) looked at mining the deposit using traditional mining methods in the 1970s, it was quickly discovered that the deposit's hydrogeologic conditions made this development path unfeasible. In the 1990s, the possibility of using ISCR was explored, and at the end of the decade, BHP Copper conducted a pilot test of ISCR on site, installing 67 injection, production and monitoring wells and ultimately proving the safety, effectiveness and environmental responsibility of the ISCR process. When copper prices fell in the 2000s, BHP Copper deferred mining operations, and the land changed hands several times before Trekor acquired the project in 2014.

After an extensive permitting process, Florence Copper received approval to operate a smaller-scale production test facility (PTF), which produced more than 1 million lb of copper between 2019 and 2020. In the fall of 2023, Florence Copper received its final major federal permit to expand into commercial operations,

Sophie Dessart, member SME, is manager of communications and public affairs at Florence Copper, Florence, AZ, email SophieDessart@florencecopper.com.

Figure 1

Solvent extraction and electrowinning (SX/EW) flow sheet.



initiating a construction period that was finalized in the fall of 2025.

In October 2025, commercial wellfield operations commenced, and Florence Copper produced its first copper cathode at the end of February 2026. Between then and Sept. 30, 2026, Florence Copper had already produced nearly 14 million lb of copper and is currently ramping up to full production.

At full production, Florence Copper will have an average annual production capacity of 85 million lb of copper per year for 22 years (Rotzinger, Tremblay and Weymark, 2023). The operation expects to reach its nameplate capacity of 85 million lb of copper per year in 2027, which will expand U.S. copper cathode production by approximately 5 percent over 2025 levels. Importantly, with a solvent extraction and electrowinning (SX/EW) plant on site, the facility will be able to plate LME Grade A copper cathode domestically, and it is expected to make Trekor the third-largest copper cathode producer in the United States (McDonald, 2025).

ISCR process

The ISCR process is possible on the Florence Copper site due to the deposit's hydrogeologic conditions. Florence Copper's operations recover copper from the copper oxide zone, located at a depth of approximately 121 to 365 m (400 to 1,200 ft) in the orebody. The copper oxide zone is a highly fractured, saturated and porous deposit made up of quartz monzonite, granodiorite and associated dikes (Rotzinger, Tremblay and Weymark, 2023). While not amenable to traditional mining methods, the fractured and permeable deposit allows for the ISCR process to occur without any modification or enhancement.

In the ISCR process, wells are drilled into the copper oxide zone. These wells utilize a cemented casing string extending from the ground surface to 12 m (40 ft) below the top of the copper oxide zone. Below this casing string, wells have a continuous screened interval or multiple intervals, which allows for the isolation of select zones within the copper oxide zone via the use of packers. Wells are constructed deliberately to allow for them to change service over the course of operations as the wellfield expands to different ISCR ore blocks, allowing perimeter and observation wells to transform into injection and recovery wells over time (Rotzinger, Tremblay and Weymark, 2023).

At the start of the ISCR process, injection wells travel a lightly acidic solution known as raffinate (similar in pH to common household vinegar) into the copper oxide zone. Over time, this solution dissolves the copper in the orebody, and the copper becomes a part of the solution. This copper-rich solution (referred to as pregnant leach solution, or PLS) is then pumped above ground through a series of recovery wells. A five-spot well arrangement is utilized as part of this process, with one center injection well pairing with four surrounding recovery wells.

Florence Copper maintains a pumping rate of 106 percent of the total injection rate. This establishes hydraulic control, where an inward hydraulic gradient is created around the wellfield, and water from the surrounding area is drawn into the wellfield, creating a closed-loop system. Both BHP Copper's pilot test and Florence Copper's PTF demonstrated the establishment and maintenance of hydraulic control within the ore zone (Rotzinger, Tremblay and Weymark, 2023). Observation wells installed around the perimeter of the ISCR production area are monitored continuously in real time to ensure hydraulic control is maintained at all times. Likewise, point-of-compliance (POC) wells are installed at the perimeter of the area as a further protection to ensure that hydraulic control is maintained and that ISCR process solutions remain in the production area. Florence Copper's wellfield operations are regulated by the Arizona Department of Environmental Quality (ADEQ), which recently received

Figure 2

Final product: LME Grade A copper cathodes.



regulatory primacy from the U.S. Environmental Protection Agency.

Once the PLS is extracted via the recovery wells, the solution travels in an above-ground pipeline to an on-site SX/EW facility (Fig. 1). The PLS is received at the PLS pond and sent to a series of two extractors (E1 and E2). As the PLS travels through E1 and E2, barren organic is mixed with the solution, which causes the copper in the PLS to chemically transfer into the organic (creating loaded organic), and the remaining raffinate is sent to a raffinate after-settler to fully separate out any remaining organic before being recycled back into the wellfield from a raffinate pond. The loaded organic is then sent to two strip settlers (S1 and S2), where it is mixed with lean electrolyte.

The acid concentration in the electrolyte strips the copper out of the loaded organic, resulting in rich electrolyte and barren organic coming out of the strip settlers. After the rich electrolyte is run through a rich-electrolyte after-settler and electrolyte filters, rich electrolyte and lean electrolyte are mixed in an electrolyte recirculation tank to create commercial electrolyte, which is sent to the tank house for the copper to be plated, while the barren organic cycles back through the process.

In the tank house, Florence Copper uses electricity to pull the copper molecules from the commercial electrolyte solution and plate the copper onto stainless-steel blanks, creating Florence Copper's final product: LME Grade A copper cathodes (Fig. 2). The remaining lean electrolyte is then recycled back into the process.

At full production, Florence Copper will have an average annual production capacity of 85 million lb of copper per year for 22 years.

Benefits of ISCR

Florence Copper's ISCR process brings significant environmental and economic benefits. By eliminating the need for large-scale blasting, the hauling and conveying of large quantities of mineralized material, the use of heavy equipment like haul trucks, and tailings storage facilities, Florence Copper's wellfield looks considerably different compared to a traditional mine site (Fig. 3) and has a very small environmental footprint as a result. Over the project's 22-year mine life, the full wellfield footprint will be only 212 acres in size. Likewise, the process emits significantly less dust and carbon and uses less energy compared to traditional mining operations. Overall, ISCR produces 75 percent less carbon emissions and uses 65 percent less energy (compared to conventional openpit copper mines in Arizona), meaning Florence Copper is projected to be the lowest greenhouse-gas and energy-intensive copper producer in North America during commercial operations.

In addition, Florence Copper recycles the majority of the water it uses in the ISCR process. Once the copper is extracted from the PLS in the extractors, the remaining raffinate (mostly water-based) can be recycled back into the process. As a result, ISCR consumes 78 percent less water per pound of copper produced compared to conventional openpit copper mines in Arizona, and also uses two to three times less water compared to what housing or agriculture would use on Florence Copper's land.

Aside from the direct water savings associated with the ISCR process, Florence Copper is constantly innovating to explore further water conservation opportunities. The site comprises more than 1,300 acres, and due to the limited footprint of the ISCR process, Florence Copper is able to lease approximately 25 percent of the land to a local farmer, who cultivates alfalfa. Florence Copper has received state authorization to complement existing irrigation water resources with surplus process water from operations to help satisfy a portion

Figure 3

Florence Copper wellfield.



of the farmer's water demand. This use of surplus water, which meets State of Arizona water-quality standards for irrigation, could conserve up to 1,466 acre-feet of water used for irrigation yearly (Taseko Mines Ltd., 2025).

Upon concluding copper recovery operations in each ISCR ore block, Florence Copper will conduct a period known as "rinsing," in which the aquifer water quality of the block is brought back to baseline levels. This rinsing process had previously been successfully completed at BHP Copper's pilot facility and Florence Copper's own PTF. Likewise, upon closure and decommissioning of rinsed blocks, Florence Copper's property will closely resemble its current state and could potentially be repurposed for various future uses, including parkland, residential development, manufacturing or a return to its natural desert landscape.

In 2022, Florence Copper was a finalist for two environmental awards — in the Circular Economy Solutions and Technology Innovation categories — from the environmental nonprofit Arizona Forward due to the project's innovative and proven ISCR process and water management.

Aside from its significant environmental benefits, the ISCR process boasts significant cost savings. Florence Copper's average cost per pound produced of copper will be in the lowest quartile globally over the mine life. According to an economic and fiscal impact study by the L. William Seidman Research Institute (2024) at Arizona State University, Florence Copper is forecast to create $4.3 billion in economic activity for the state of Arizona over the course of its operations and support an annual average of nearly 820 direct, indirect and induced jobs.

Florence Copper represents a new economic engine for Arizona and a crucial domestic source of copper for the United States at a time when the country is dependent on foreign sources of copper to fill nearly half its annual copper demand (U.S. Geological Survey, 2025). Over the mine life, Florence Copper will bring an additional 1.5 billion lb of sustainable copper produced for the nation.

Conclusion

Florence Copper's limited environmental footprint, energy and water savings, low cost and ability to redevelop the land upon mine closure represent a unique opportunity to provide a new domestic source of sustainable copper. This opportunity is especially critical at a time when the United States is increasingly dependent on foreign copper sources, and global copper demand is rapidly growing due to industrialization, electrification, data centers, national defense and other related drivers.

Florence Copper's expansion into commercial operations marks a turning point for this first-of-its-kind, greenfield ISCR project and a pivotal development for the copper industry as a whole, providing a new major source of sustainable copper in the United States. ■

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Mining Water Tech Pilot Pathway Program: Connecting the industry to startup innovation

by Andjela Radmilovic



Photo courtesy of Nomadic Venture Partners

Program tour of the Schwartzwalder Uranium Mine water-treatment plant outside Golden, CO.

Overcoming organizational inertia, high capital costs and complex permitting are just some of the hurdles to adopting new technologies at a mine site. Yet, as critical issues around water quality and quantity, discharge compliance and waste liability grow, startup innovation remains an underutilized resource for addressing these challenges.

Startup companies are independent technology providers advancing solutions to industry needs. Operating on a smaller, more agile scale early on, startups can rapidly prototype, test and refine solutions that are specific to customer needs. Despite the breadth of innovation emerging from the startup ecosystem, there exists a significant gap between startup solutions and their deployment in real mine operations. Startups face substantial barriers to entering the mining industry, while mine operators miss opportunities to access technologies that could address their most pressing challenges. These barriers reflect the unique risks and uncertainties of mining, including capital-intensive infrastructure, commodity price volatility and geological constraints. They also reflect a broader structural challenge: mining long predates many of the innovation networks and investment frameworks that now help connect emerging technologies with established industries.

When considering what might be required for mines to adopt external innovations, it becomes clear that some intermediary or formal connection between the two would be beneficial. What if a mine operator had an extended team of experts that could screen hundreds of technologies and make introductions to only those that fit their operational needs? An effective intermediary would understand both mining and startups, helping identify technologies that are relevant and ready for a particular operating environment while creating the conditions for both parties to evaluate their fit. The Mining Water Tech Pilot Pathway Program serves as one such intermediary.

Now in its second year, the Mining Water Tech Pilot Pathway Program is a collaboration between Nomadic Venture Partners and Current that helps industry and startups work together to advance practical solutions for the mining industry. Nomadic Venture Partners is an early-stage venture capital firm specializing in mining and metals technologies, and Current is a nonprofit water innovation hub. Together, these organizations bring mining, water and venture expertise to help startups and mining stakeholders navigate the path from promising technology to real-world application.

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Photos courtesy of Nomadic Venture Partners

Funded in part by the U.S. Economic Development Administration's Build to Scale program and the National Science Foundation's Great Lakes RENEW Engine with strategic support from Rio Tinto, the program demonstrates a commitment by government, industry and investors to bolster innovation in the mining industry.

While traditional accelerator programs provide valuable standardized curricula, the Mining Water Tech Pilot Pathway Program uses a flexible framework to deliver tailored coaching and mentorship aligned with each company's specific needs. For example, program participants receive targeted education on mining industry priorities and opportunities to visit real mine and water-treatment operations. Participating startup founders regularly engage with mining companies, local communities, Tribal governments and state and federal agencies to better understand the practical considerations involved in deploying new technologies. These experiences help founders refine their technical and economic propositions and better prepare their solutions for commercial deployment. In parallel, the program guides mining companies through the process of evaluating and engaging with startups, providing curated introductions and hands-on support at each step along the way.



For many technologies, an on-site demonstration is a critical requirement for commercialization. The Mining Water Tech Pilot Pathway Program aims to establish a trusted, repeatable model for piloting technologies in the mining industry. Pilots allow both the mining company and the startup to evaluate a technology under real operating conditions at a commercially relevant scale, reducing uncertainty and establishing success metrics for economic and operational performance.

"Mining leadership knows they need innovation, but a mining company and an early-stage startup usually run on totally different clocks," explained Tem Tumurbat, a mining engineer, former SME Colorado board member, and co-founder of Nomadic Venture Partners. "The mismatch on speed and scale extends the massive valley of death for startups right at the pilot stage. This program gives miners a structured way to evaluate tech while minimizing site risk as much as possible and giving founders the speed and feedback they need to get pilots done on their accelerated timelines."

The case for effective pathways from innovation to deployment is particularly evident in mine water management, where operational demands and environmental realities create a range of complex challenges. Water quality and quantity are among the most pressing issues facing mine operations, making water a natural focus for the program. The recent "Global Metals and Mining Water Dataset" published by the International Council on Mining and Metals

Tour of the Bonita Peak Superfund site's Gold King Water Treatment Plant in Silverton, CO, during the 2026 Rocky Mountain Mining and Reclamation Conference (top), and sludge bag at the treatment site (bottom).

(ICMM) highlights the magnitude of water risk that mining operations are facing — nearly two-thirds of all mining and metals facilities globally are exposed to high levels of at least one physical water risk indicator (flooding, drought, baseline water stress, baseline water depletion, interannual variability). The data set emphasizes that "water is a defining factor in the geography, cost structure and resilience of the mining and metals sector," and "water stewardship is a key part of responsible mining." Similarly, many common challenges emerge from our conversations with mine operators, including tailings impoundment liability, discharge compliance, acid rock drainage and a need for real-time water monitoring. For these reasons, the program focuses on emerging technologies in four categories: water treatment; real-time sensing and monitoring; water efficiency; and resource recovery and waste valorization.

This year, approximately 200 companies with relevant technologies in those categories were evaluated, and 65 program applications were received. From the strong pool of applicants, five companies were selected to participate in the six-month program:

- BANiQL — San Jose, CA: A proprietary atmospheric leach process enabling the low-energy, selective recovery of Class 1 nickel and cobalt mixed hydroxide precipitates from leach solutions at significantly reduced temperatures and pressures compared to conventional high-pressure acid leaching (HPAL). The process enables reuse of pregnant leach solution for multiple cycles, greatly reducing water uptake and carbon emissions while improving resource recovery. The team has established international traction and was recently invited by the U.S. Trade and Development Agency to participate in the inaugural Luzon Economic Corridor Investment Forum.
- FAST Metals — Stamford, CT: A patented hydrometallurgical chemical process that extracts valuable metals such as iron, aluminum, titanium, scandium and other rare earth elements from mine tailings, including red mud and iron-rich tailings. The company was founded by mining industry veterans with Ph.D.s from Colorado School of Mines and experience at Glencore, bringing deep expertise in chemical operations to the development of a process designed to recover valuable materials while eliminating tailings waste liability.
- KIRA — Boston, MA: A software-defined heat-pump humidification-dehumidification system that returns clean distillate for on-site reuse and concentrates dissolved metals into a brine or solid stream for the low-cost recovery of copper, lithium and other critical minerals. Coming out of the Massachusetts Institute of Technology, the team has previously deployed commercial desalination and autonomous robotics systems.
- Kunin — Chattanooga, TN: A novel ion-exchange system designed to selectively recover various metals (including scandium, gallium, germanium, rare earths and platinum group metals) from residues, effluents, recycled process streams and flotation tailings from mines and smelters. The technology is designed to integrate with existing operations and target metal streams that can be difficult to recover economically, with the company reporting 10 times faster kinetics and up to 90 percent lower capital expenditure compared with conventional approaches.
- PAGE Technologies — Boulder, CO: An automated electrochemical sensing platform that provides frequent, low-cost measurements of water chemistry at active and legacy mine sites. The system combines automated sampling and calibration, on-device analysis and cloud-based monitoring with data designed to integrate into process-control systems and digital twins to support water reuse, treatment optimization and discharge monitoring.

To maximize their chances of securing a successful pilot, program participants engage with the industry through a combination of strategy sessions, field exposure and direct stakeholder interaction. Each startup goes through intensive strategy sessions designed to identify and mitigate business and technological risks. To gain ground-level insight into real-world operations and pain points, founders visit mine sites and water-treatment facilities, present at conferences and key industry events (including the Rocky Mountain Mining and Reclamation Conference in Durango, CO, and the Mining and Energy Expo in Minneapolis, MN), and attend expert-led sessions on a variety of topics, including mining technology evaluation and



Photo courtesy of Nomadic Venture Partners

Program tour of the Edgar Experimental Mine in Idaho Springs, CO.

regulatory landscapes. Founders also receive targeted feedback from Rio Tinto's copper research and development team.

Halfway through the program, this year's cohort is already seeing encouraging progress, including federal grant awards, invitations to exclusive government events, significant fundraising traction and new partnership opportunities. Last year's cohort, comprising Stalagmite and Tikal Industries, also demonstrated the potential of the program, with both companies validating their technologies at a larger scale and identifying appropriate pilot partners, including a pilot agreement signed by Tikal thus far.

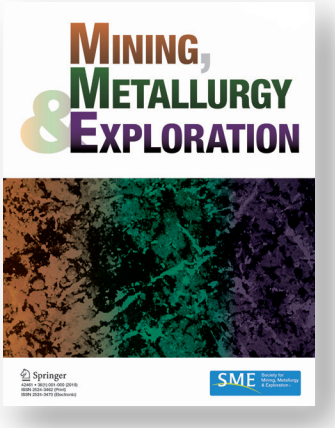
As the program continues to evolve, the team is evaluating and synthesizing what makes relationships between startups and mining stakeholders successful: building trust, communicating in a language that everyone understands and appreciates, de-risking technology and strengthening economics. These lessons emphasize the importance of creating an innovation pathway that works within the realities of mining while helping startups and mine operators navigate the differences between their respective environments.

Overall, the goal of the Mining Water Tech Pilot Pathway Program is to establish a trusted, repeatable model for advancing innovations in the mining industry, making it easier for startups to validate their technologies and for mine operators to adopt impactful solutions that increase the sustainability of mining. ■

(If you are interested in engaging with the program, contact the author at andjela@nomadicvp.com. The program cohort will also attend the MINEXCHANGE 2027 SME Annual Conference & Expo in Denver, CO, and welcomes the opportunity to connect in person.)



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Invited Extended Abstracts

Collection on The Uptake of Innovation in the Mining Industry

Eliminating barriers for the implementation of automation in the mining industry

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Keywords: Equipment autonomy, Sensors, Artificial intelligence, Communication, Mining automation

The integration of emerging technologies into U.S. mining is essential for improving worker safety, operational efficiency and continuous improvement, yet adoption of autonomy in the U.S. mining industry has progressed more slowly than in other nations. This study systematically identifies and quantifies barriers to mining automation in the United States using a workshop-based data collection model. Nine workshops conducted between 2022 and 2024 involved professionals from 480 companies, with 146 participants. Additional virtual meetings with leaders from the Mine Safety and Health Administration (MSHA), National Institute for Occupational Safety and Health (NIOSH), Society for Mining, Metallurgy & Exploration Inc. (SME) and academia involved approximately 139 participants. Five major barriers were identified: regulation, economics, technology readiness, corporate willingness and social license. Weighted rankings showed that econom-

ics (37.9 percent), technology readiness (17.4 percent) and regulation (16.6 percent) are the most significant barriers. While economic and technological challenges can largely be addressed by industry, regulatory barriers require government–industry collaboration. A regulatory review identified approximately 98 U.S. mining regulations that present potential barriers to automation or innovation in the U.S. mining industry.

Table 1 — Workshops (WS) held between 2022 and 2024 (SME = Society for Mining, Metallurgy & Exploration Inc., PCMIA = Pittsburgh Coal Mining Institute of America, NSSGA = National Stone, Sand, and Gravel Association, MSHA A&CC = Mine Safety and Health Administration Approval and Certification Center).

WS	Month Year	Location (US)	Conference	Attendees
1	Dec. 2022	Tucson, AZ	SME Arizona Conference	21
2	Feb. 2023	Denver, CO	MINEXCHANGE 2023 SME Annual Conference & Expo	17
3	April 2023	Virginia, MN	SME Minnesota Conference	15
4	June 2023	Boston, MA	Rapid Excavation and Tunneling Conference	16
5	Aug. 2023	Phoenix, AZ	Hydrometallurgy 2023	24
6	Oct. 2023	Canonsburg, PA	SME PCMIA Conference	17
7	March 2024	Nashville, TN	NSSGA Conference	12
8	April 2024	Triadelphia, WV	MSHA A&CC and NIOSH Federal Advisory Committee	14
9	June 2024	Elko, NV	Elko Mining Expo	10

Table 2 — Meetings held to discuss regulatory barriers to mine automation (MSHA = Mine Safety and Health Administration, SME = Society for Mining, Metallurgy & Exploration Inc., NIOSH = National Institute for Occupational Safety and Health).

Month Year	Meeting/event	Location	Attendees
March 2024	Meeting with MSHA Group	MSHA Offices, Arlington, VA	9
July 2024	SME Membership Mixer	Online virtual meeting hosted by SME	30
Sep. 2024	NIOSH Automation Partnership Meeting	Online virtual meeting hosted by the School of Mining Engineering and Mineral Resources, University of Arizona	50 (estimated)
Oct. 2024			50 (estimated)

Background

Due to safety concerns and economic implications of introducing new technology into existing operations, the mining industry is in many cases reluctant to adopt new, innovative technology, as compared to other industries such as computing and manufacturing. In particular, the additional financial risk associated with disruption to production is a disincentive. Consequently, adoption of automation in the U.S. mining industry has been slow compared to other nations. To encourage the rapid integration of new technology into U.S. mining operations and to promote worker safety, better resource utilization and greater economic utility, a comprehensive review and analysis of the regulatory framework and external factors influencing technology integration in mine and plant development and operations is needed in order to characterize the potential barriers that exist and the causation factors that govern why these barriers exist and how they evolve.

Methodology

A workshop-based data collection model was employed to collect qualitative and quantitative data. Nine in-person workshops were organized in conjunction with existing conferences (Table 1). This cost-effective approach allows for sector-specific workshops, except for the MINEXCHANGE SME Annual Conference & Expo, which attracts a broad audience. The participants at the various workshops coalesced quickly around a set of barriers affecting the uptake of automation in the U.S. mining industry. In addition to the nine in-person workshops, meetings were held with MSHA leadership and miscellaneous professionals from NIOSH, SME and academia (Table 2), with a total of 139 participants. These online virtual meetings were conducted with a focus on unraveling the regulatory barriers to mining automation in the United States.

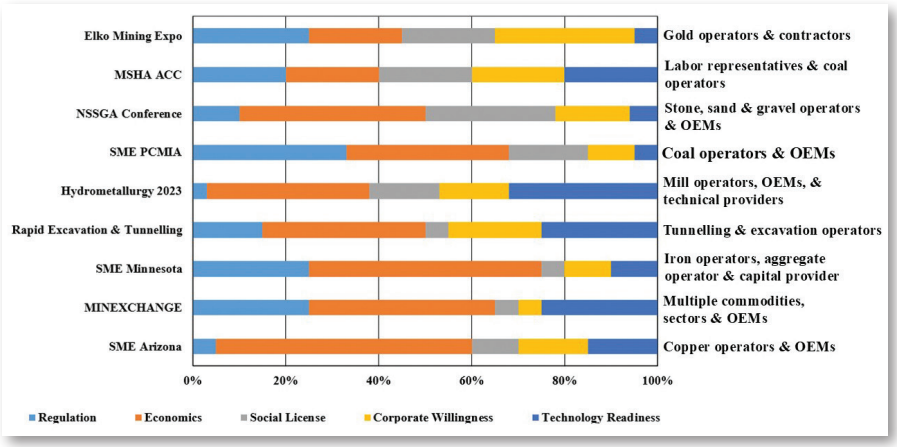


Fig. 1 Contributions of each of the five identified barriers to the uptake of automation in the U.S. mining industry, with primary sectors indicated (OEMs = original equipment manufacturers).

Results and discussions

Based on the nine workshops, five major barriers to the uptake of automation in the U.S. mining industry were identified, and their relative contributions were quantified (Fig. 1). The participants' weighted averages of the nine workshops are presented in Fig. 2a. It

can be noted that, economics, technology readiness and regulation are the three most significant barriers to the acceptance of automation in the U.S. mining industry (Fig. 2a). Based on the review of mining regulations, approximately 98 regulations (including subregulations) dealing directly with extraction activities were identified as presenting some potential barriers to automation or innovation in the U.S. mining industry (Fig. 2b).

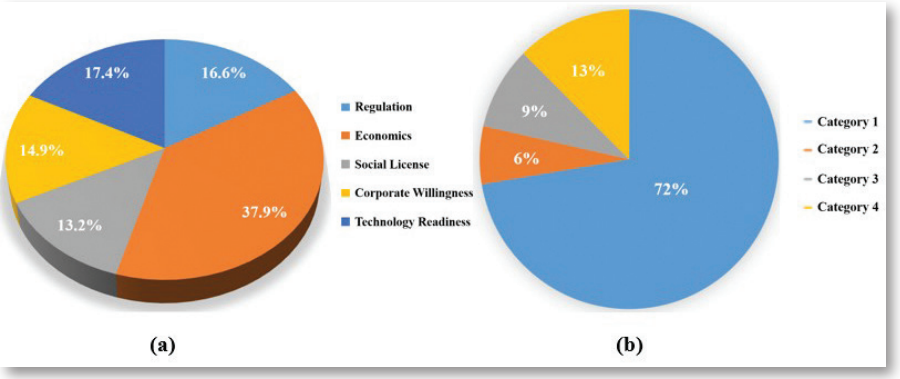


Fig. 2 (a) Participants' weighted averages of barriers to uptake of automation in the U.S. mining industry (b) Categories of regulation barriers to mining automation in the United States (as of April 14, 2025): Category 1: The regulation requires that a "person" conduct or be present for a particular regulatory function; Category 2: The regulation requires that equipment be "attended"; Category 3: The regulation requires that ancillary features such as seat belts or rollover protection be installed in equipment with no exception for fully automated equipment; Category 4: Regulations that could be considered to impede automation but are not easily placed in one of the categories above.

Conclusions

- Economics is the leading barrier to mining automation, accounting for 37.9 percent of the weighted ranking.
- Technology readiness (17.4 percent) is the second most significant barrier to U.S. mining automation.
- Regulation (16.6 percent) is not the primary barrier, challenging the assumption that regulatory constraints are the main impediment.
- Approximately 98 U.S. regulations may constrain automation, particularly in coal and gassy mines.
- Federal support and workforce upskilling could accelerate automation adoption by reducing investment risks and addressing technology and workforce challenges. ■

Funding

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A list of all references is available in the full paper.

Grouting and sealing bed separation by overlapping mine gobs in multiple seams for improving oxygen in longwall face

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Keywords: Overlapping gob, Mitigate low oxygen, Bed separation, Air leakage

Multiseam mining under shallow burial conditions causes repeated disturbance of overlying strata, leading to enhanced fracturing and air leakage from upper gobs to lower working faces, resulting in lowoxygen hazards. To address this, a "manmade isolation layer" is proposed by grouting and sealing the interlayer separation. Using rock movement models, numerical simulations and porosity/permeability calculations, the deformation and gas transport behavior before and after grouting are investigated. Results show that grouting effectively reduces subsidence, porosity and permeability, blocks interlayer crack pathways and physically isolates the upper and lower gob sections. Interlayer air leakage is reduced by 40.9 percent and 32.8 percent, respectively, significantly improving oxygen concentration at the working face.

Background

Coal production bases are characterized by shallow burial and the presence of multiple coal seams. The overlying strata are subjected to disturbances from multiple mining operations, resulting in greater fragmentation and more extensive fracture development. This leads to the formation of interconnected voids between adjacent gobs. When abnormalities occur in the advancement of the working face, or when air leaks between closely spaced coal seams or from

the surface, spontaneous combustion of residual coal can occur, along with the discharge of gases from the upper to the lower gob. This results in gas concentrations exceeding safety limits and a drop in oxygen levels in the working area below 20 percent, leading to low-oxygen hazards. Currently, low-oxygen conditions at the working faces of coal mines seriously impede normal production operations. Therefore, elucidating the gas migration patterns in compound gobs and providing a basis for addressing these low-oxygen issues at compound gob working faces hold great practical significance.

Research methods

Rock strata movement and artificial barrier formation. Grouting in the bed separation creates a manmade barrier layer that transversely fills and seals longitudinal fractures, blocking gas migration between upper and lower gobs while bonding with broken rocks to enhance support and occupying interlayer height to minimize overburden settlement. The postgrouting rock movement model recalculates the load equation using measured grout properties (compressive strength 3.15 MPa, elastic modulus 7.26 MPa, density 1,530 kg/m^3) and updated layer thickness and vertical position, identifying key strata 10, 20 and 23 as grouting targets. Displacement analysis shows that grouting at $z = 23$ m below the critical layer, with a filling height of 1 m at 100 m face advancement, reduces criticallayer settlement by about 0.75 m, effectively controlling further subsidence.

Porosity and permeability reduction via grouting. Before grouting, the composite gob exhibits high porosity (up to 25 percent) and permeability (up to 4.0×10^{-6} m^2), with fracture channels present on both sides between the upper and lower workings. After grout filling in the bed separation, porosity decreases by 6.5 to approximately 12.5 percent, while permeability in the grouted zone drops by 50 percent

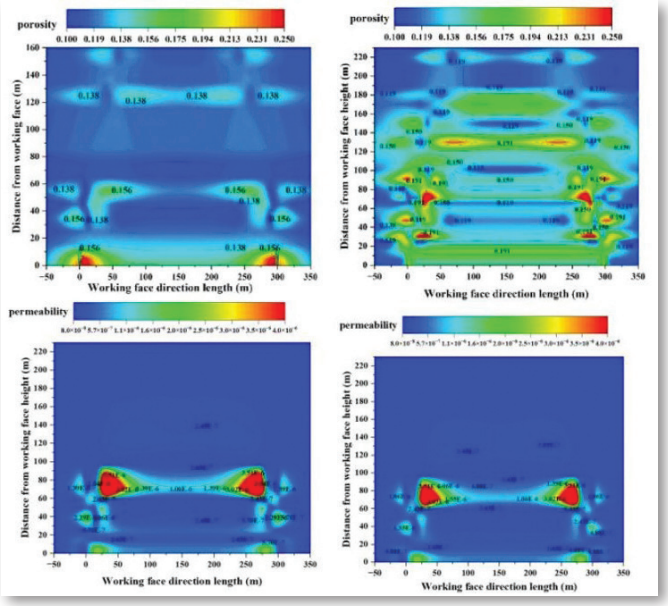


Fig. 2 Contour plots of porosity and permeability distributions in the overlying strata.

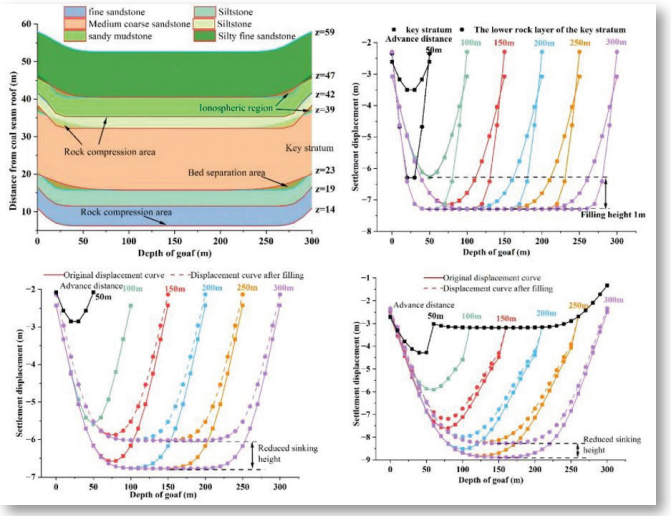


Fig. 1 Strata structure and settlement displacement curves under different advance distances and filling heights.

(a reduction of 2.5×10^{-7} m^2), and high-permeability areas shrink markedly. Grouting also reduces fracture connectivity across the two gobs, diminishing gas seepage pathways and enhancing the sealing and isolation of the overlapping minedout area.

In the end, through the analysis of strata movement, porosity and permeability changes, the grouting method successfully forms an effective barrier layer, reduces subsidence and significantly improves the isolation of the compound gob, thereby mitigating the low-oxygen risk and ensuring safe mining operations.

Results

Impact on air leakage and gas flow paths. Before grouting, the surface air leakage (50 m^3/min) enters the gob through the left surface crack, travels downward via interlayer fractures and eventually reaches the upper corner, forming multiple distinct leakage paths with relatively high flow velocities. After grouting and filling, the porosity in the bed separation is significantly reduced, which increases the resistance to airflow through the fractured zones; consequently, although the same surface leakage rate remains,

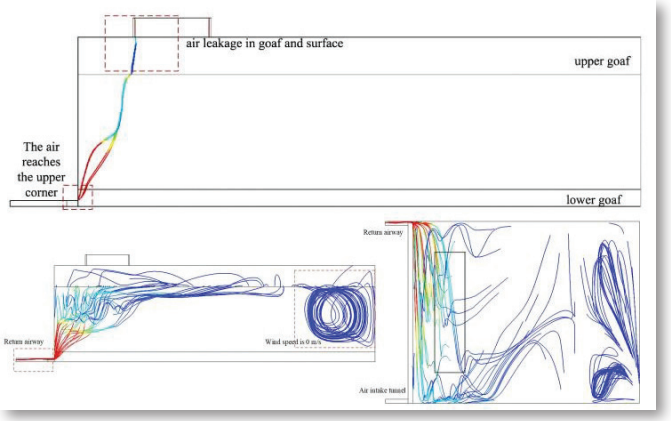


Fig. 3 Streamline distributions of air leakage pathways in the goaf and surface.

much less air passes through the interlayer cracks and flows toward the working face. In the upper gob area, the increased permeability resistance under the same negative-pressure ventilation leads to a marked decrease in the number of streamlines that migrate toward the face, and the region with airflow velocity exceeding 0.24 m/min shrinks considerably, while the cooling zone also becomes narrower. Meanwhile, the vertical circulation in the deep part of the gob, where velocities are close to zero, remains essentially unchanged and does not contribute to gas seepage toward the working face, regardless of grouting. Overall, grouting effectively weakens the hydraulic connection between the surface and the gob, reducing the risk of low-oxygen gas being carried into the active mining area.

Impact on oxygen concentration distribution. In the lower gob, the oxidation zone is noticeably wider on the intake side (about 100 m) than on the return side (about 30 m). Before grouting, this oxidation zone is broader and the oxygen concentration is generally lower, resulting in an enlarged heat-dissipation zone. In the upper gob, surface air leakage mixes with the gob atmosphere, but the maximum oxygen concentration due to leakage is only 16 percent, and this low-oxygen gas tends to migrate downward to the lower gob and then emerge from the upper corner toward the return airway, causing an average oxygen concentration as low as 18.2 percent before grouting. After grouting, the interlayer leakage is reduced by 40.9 and 32.8 percent at different levels compared with the original conditions, and the asphyxiation zone shifts closer to the working face, while the area with oxygen concentration above 19 percent on the return side expands noticeably. At the working face itself, the low-oxygen zone is substantially diminished after grouting, and the average oxygen concentration in the return airway rises to 19.7 percent, an improvement of 1.5 percentage points. These changes confirm that grouting not only physically isolates the upper and lower gobs but also effectively mitigates the low-oxygen hazard by blocking gas seepage pathways and enhancing the oxygen supply to the working area.

In summary, the numerical simulation results demonstrate that grouting in the bed separation successfully reduces air leakage, alters gas flow patterns and improves oxygen concentration distribution, thereby ensuring safer mining conditions in the overlapping gob environment.

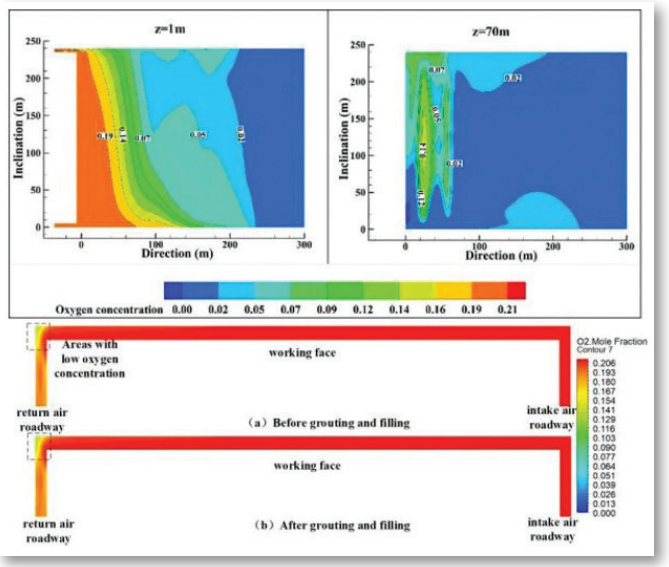


Fig. 4 Oxygen concentration distribution and the effect of grouting and filling on air leakage prevention.

Conclusions

This study demonstrates that grouting and sealing the bed separation in overlapping gobs effectively reduces subsidence, porosity and permeability, thereby blocking interlayer crack communication and physically isolating upper and lower gob sections. Both theoretical calculations and numerical simulations confirm that the proposed method significantly decreases air leakage (by 40.9 and 32.8 percent) and raises oxygen concentration at the working face (from 18.2 percent to 19.7 percent). This provides a practical engineering approach to mitigate low-oxygen hazards in multi-seam mining conditions. ■

References

A list of all references is available in the full paper.

Rare earth elements from primary, secondary and tertiary sources: Extraction technologies, resource distribution and sustainability

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Full-text paper:
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Keywords: Rare earth minerals, Mining, Extraction, Metallurgy

Rare earth elements (REEs) are the materials upon which the energy transition physically depends — such as magnets in electric-vehicle motors and wind turbines, phosphors in lighting and displays, and catalysts in refining — yet their supply is among the most concentrated of any industrial commodity. This review establishes that the concentration is not primarily

geological but industrial. China holds roughly 49 percent of listed reserves but about 70 percent of mining and 91 percent of refining capacity, and is projected to retain 92 percent of refining by 2040. The paper's practical contribution is to show that this bottleneck can be addressed in the waste stream rather than only at new mines. It assembles within a single framework the grades, recoveries, energy and reagent intensities, costs and environmental burdens of three source classes — primary ores, industrial residues and end-of-life products — so that an engineer or policymaker can judge which route is worth pursuing for a given feedstock. For India, which holds the third-largest reserves yet supplies under 1 percent of world production while generating vast volumes of coal, fly ash and overburden, the framework converts a waste-management liability into a candidate domestic supply option.

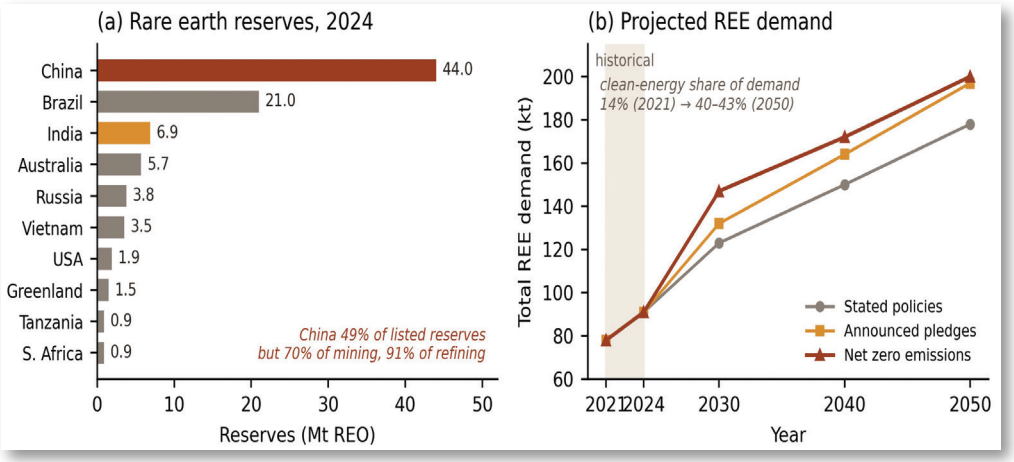


Fig. 1 (a) Rare earth reserves by country in 2024. China holds about 49 percent of the listed reserves but a substantially larger share of mining and refining. India holds the third-largest reserves while supplying 0.74 percent of world production. (b) Projected total REE demand under three policy scenarios. (Data as reported in the source review)

Background

REEs comprise the 15 lanthanides together with scandium and yttrium. Their chemical similarity, arising from 4f orbital occupation and the lanthanide contraction from La^{3+} (1.06 Å) to Lu^{3+} (0.85 Å), makes them easy to mine collectively but highly difficult to separate individually, which is why separation, not discovery, governs the economics of the industry. Demand is projected to rise from 78 kt in 2021 to about 172 to 200 kt by 2050, with the clean-energy share growing from 14 percent to about 40 to 43 percent (Fig. 1). The 2010 Chinese export restrictions and the 2015 closure of Mountain Pass showed how quickly the resulting fragility transmits into price volatility.

Conventional production carries a high environmental cost. Producing one tonne of rare earth oxides from ion-adsorption clay requires the removal of roughly 300 m^2 of land surface. It generates approximately 2,000 t of tailings and 1,000 t of wastewater containing heavy metals and leaching chemicals. At the same time, thorium and uranium in monazite create radiological handling obligations. These burdens, combined with permitting lead times often exceeding a decade, motivate the search for alternative feedstocks.

Methods

The study is a structured critical review rather than an experimental investigation. Sources are classified by origin into three tiers — primary (ores mined directly), secondary (industrial byproducts and residues) and tertiary (end-of-life products) — and each is assessed against common criteria: mineralogy and grade, extraction route, recovery efficiency, energy and reagent intensity, radiological risk, achievable scale and life-cycle environmental indicators. Case studies from 12 countries are tabulated, with their analytical methods, target elements and reported recoveries, enabling like-for-like comparison.

Table 1 — Techno-economic and environmental comparison of the three sources.

Parameter	Primary ores	Secondary sources	Tertiary sources
Typical grade	3-12 weight percent TREO	200-2,000 µg/g	10-30 weight percent REE
Recovery efficiency	70-90 percent	40-70 percent	60-95 percent
Energy intensity (MJ/kg REO)	400-1,200	150-600	50-250
Production cost (USD/kg REO)	20-60	15-40	10-30
CO_2 (kg CO_2/kg REO)	30-75	10-35	3-15
Water (m^3/kg REO)	0.5-2.0	0.2-0.8	0.05-0.3
Radiological risk	High (Th, U)	Low-moderate	Very low
Technology maturity	Commercial	Pilot to early commercial	Pilot to early commercial
Achievable scale	> 10-50 kt REO/y	Moderate	Few kt REO/y

Results

Primary sources. Bastnäsite ((Ce, La, Y)(CO)F), monazite ((Ce, La, Nd, Th)(PO)) and xenotime (YPO) remain the commercial backbone, with typical grades of 3 to 12 weight percent total rare earth oxides (TREO) and recoveries of 70 to 90 percent. Processing follows a long chain — comminution to smaller than 75 to 150 µm, physical beneficiation to 50 to 70 percent TREO concentrate, chemical cracking, leaching at 85 to 98 percent

efficiency, impurity removal and multistage solvent extraction with separation factors for adjacent elements of only 1.5 to 3.0, which is why hundreds of stages may be required for high-purity products (Table 1).

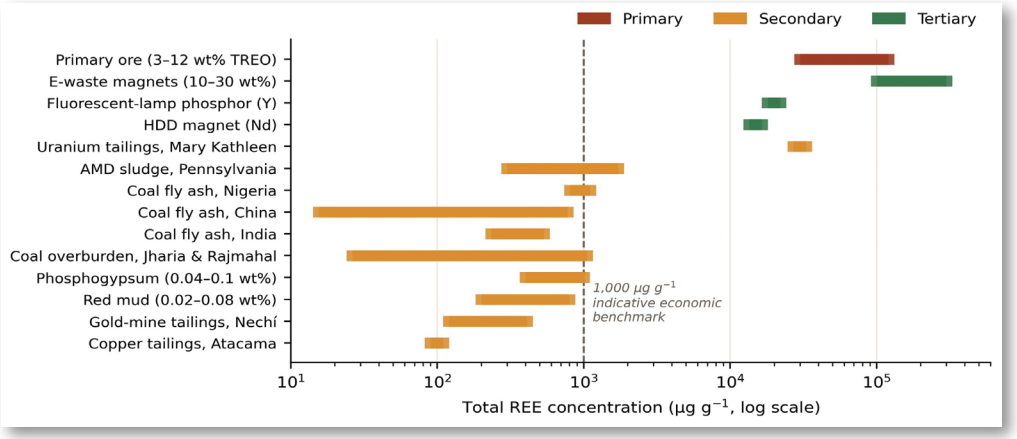


Fig. 2 Reported total REE concentrations across primary, secondary and tertiary feedstocks, on a logarithmic scale. Tertiary magnet and phosphor streams rival or exceed primary ore, whereas most secondary residues sit near or below the indicative 1,000 µg/g economic benchmark. (Compiled from values reported in the source review)

Secondary sources. Coal fly ash is the most studied, with roughly 750 Mt generated annually and REE concentrations about 30 times those of the feed coal. Reported contents range from 15.5 to 776.5 µg/g in China, 234 to 534 µg/g across eight Indian thermal plants and 806 to 1,107 µg/g in Nigeria, against an indicative benchmark of 1,000 µg/g (Fig. 2). Red mud contains 0.02 to 0.08 weight percent REEs and phosphogypsum 0.04 to 0.1 weight percent REEs. Indian overburden from the Jharia and Rajmahal basins reaches 1,051 µg/g. Recoveries of 40 to 70 percent are typical, and process innovation is active: sodium hydroxide pretreatment followed by hydrochloric acid (HCl) leaching raised fly-ash recovery to 95.5 percent, while flash Joule heating, reaching about 3,000 °C in one second, roughly doubles recovery using only 0.1 M HCl.

Tertiary sources. End-of-life products carry the highest concentrations of all. Hard-disk magnets contain around 15,000 µg/g neodymium (Nd) and fluorescent lamp phosphors around 20,000 µg/g yttrium (Y), with magnet feedstocks reaching 10 to 30 weight percent REEs. Recoveries of 60 to 95 percent are achievable, and hydrometallurgical routes deliver purities above 99 percent. Yet global e-waste exceeded 62 Mt by 2025, with only about 20 percent formally processed, and the recycling rate for REE-containing products is approximately 1 percent — the single largest untapped opportunity identified in the review.

Discussion

Table 1 resolves an apparent paradox. Tertiary sources lead on almost every indicator — highest grade, lowest energy, lowest cost, negligible radiological risk — yet cannot displace primary mining because their availability is constrained by what was manufactured a decade earlier, and their collection is fragmented. Secondary sources have the opposite profile: enormous distributed volumes but low, variable grades that raise reagent consumption per unit of metal. Primary mining, therefore, remains the only route capable of meeting bulk demand, and the alternative tiers realistically supplement it while relieving waste-disposal burdens.

The review candidly notes that recovery from secondary and tertiary sources remains in its early stages. Feedstock heterogeneity, the absence of standardized processing routes, and the resistance of REE phosphate, zircon and glassy phases to leaching all constrain commercial deployment. Nitric acid recovered as little as 1.6 percent of REEs from some U.S. coal ash samples. The economic case is often carried by coproducts rather than by the rare earths themselves — in Pennsylvanian coal waste, aluminum corecovery proved the decisive economic driver, the process being technically viable but not economically viable from REEs alone.

Conclusions

Resilience will come from diversification across all three tiers rather than the substitution of one for another. The review proposes a phased roadmap: immediate priorities (2025-2027) of streamlined permitting in Australia, Canada and Brazil with pilot investment in waste-stream recovery; a medium-term (2025-2030) target of 30 percent REE recovery from e-waste; and a long-term goal (2030-2035) of 50 percent secondary sourcing through closed-loop systems, materially reducing primary extraction by 2040. This requires standardized characterization protocols, consistent life-cycle and techno-economic assessment, and policy instruments — extended producer responsibility, in particular — capable of raising a 1 percent recycling rate by orders of magnitude. For India, large reserves, negligible production, abundant coal ash and overburden, and the National Critical Mineral Mission together create an unusually favorable setting in which to test the secondary pathway at scale. ■

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Collection in Honor of Dr. Jan D. Miller

Estimating the extent of comminution needed for optimal downstream processing performance

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Full-text paper:
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Keywords: Mineral liberation analysis, Exposure, Mineral separation

Mineral liberation, locking and exposure are directly linked to the performance of processes such as leaching and flotation. Comminution is performed prior to subsequent separation steps to increase mineral liberation and exposure that are necessary for efficient mineral separation and leaching. Correspondingly, there is an important relationship between comminution and mineral liberation, locking and exposure as well as with the associated downstream processing performance. This paper reviews important equations that can be used to calculate mineral liberation, locking and exposure, and the associated impact of comminution on these particle distribution characteristics. These equations can enable simplified predictive modeling of the effect and cost of comminution in relation to subsequent processing performance such as leaching and flotation recoveries beginning with core sample data.

Background

The relationship between host rock particles (hrp) and valuable mineral particles (vmp) plays a crucial role in the comminution process and subsequent mineral separation. Typically, host rock particles are significantly larger than the valuable mineral particles in them. During comminution, various scenarios emerge: some valuable mineral particles become fully liberated from the host matrix, others are partially exposed on the surface of the host rock particles, and some remain locked within the host rock particle. The ability to calculate the fraction of valuable mineral particles in each scenario is critical to the prediction of processing performance.

Comminution reduces the host rock particles more effectively than valuable mineral particles inside. The ability to calculate the size reduction of vmp relative to the hrp size reduction can allow for prediction of final vmp sizes for given hrp size reductions. This information can be used in combination with equations for calculating the locked, partially locked and liberated vmp material needed to determine separation performance.

Methodology

If size distributions of vmp and hrp particles are compared, on average the host rock particles are larger than

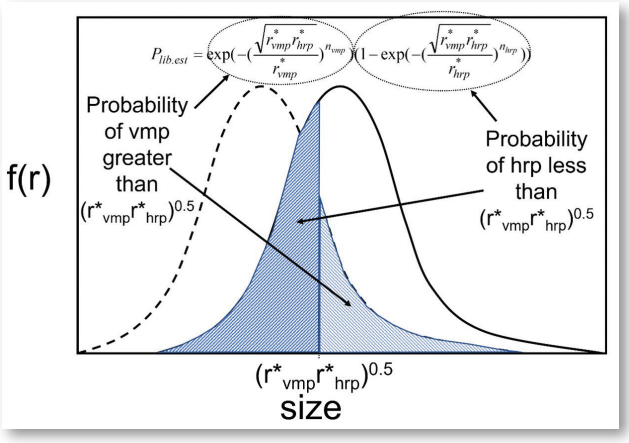


Fig. 1 Comparison of host and valuable particle size distributions and associated relationships with the characteristic size $(r_{hrp} r_{vmp})^{0.5}$ and the resulting Rosin-Rammler-based probability equation for liberated particles.

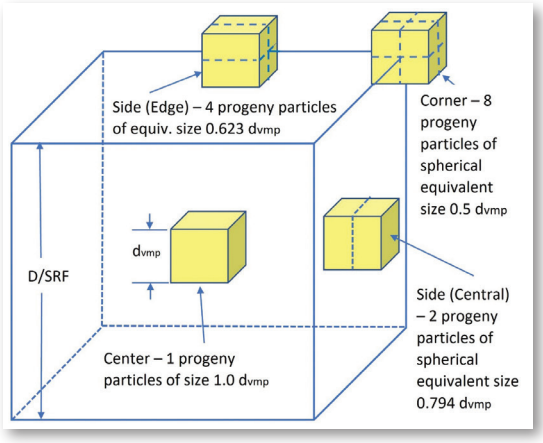


Fig. 2 Schematic diagram of a cube of host particle with valuable particles in various locations. The location of the valuable particle determines the number of progenies that would be generated if the particle was at that location before comminution.

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valuable mineral particles. However, the size distributions overlap such that some of the hrp particles are smaller than the vmp particles, and in that scenario the vmp particles are liberated. This can be illustrated in Fig. 1 with a comparative, characteristic size between the two size distribution averages, which is estimated using a geometric mean of the two particle radii $(r_{hrp}r_{vmp})^{0.5}$. Therefore, using the Rosin-Rammler distribution function, the liberated fraction can be estimated with the equation:

$$P_{lib.est} = exp\left(-\left(\frac{\sqrt{r^*_{vmp}r^*_{hrp}}}{r^*_{vmp}}\right)n_{vmp}\right)\left(1-exp\left(-\left(\frac{\sqrt{r^*_{vmp}r^*_{hrp}}}{r^*_{hrp}}\right)n_{hrp}\right)\right) \quad (1)$$

in which n_{vmp} and n_{vmp} are constants (usually between 1 and 3), r^*_{vmp} is the reference radius of valuable particles, and r^*_{hrp} is the reference radius of host particles.

The probabilities of partially locked and fully locked valuable particles can be determined using geometry and volumetric calculations. A valuable mineral particle can be located in the interior of a host rock particle, where it is fully locked or at an edge, where it is partially locked.

All valuable mineral particles of size r_{vmp} will be partially locked in a host rock particle of size r_{hrp} if the vmp center point is within r_{vmp} of the surface. Thus, the fraction of the volume of the hrp that is within the distance of the radius of the vmp from the surface is the fraction of vmp that is partially locked or exposed to the outer surface of the hrp. Mathematically, the partially locked fraction is $1 - ((r_{hrp} - r_{vmp})^3/r_{hrp}^3)$. Correspondingly, the fully locked fraction is $((r_{hrp} - r_{vmp})^3/r_{hrp}^3)$. These simple formulas can be inserted into the more complete equation that includes the liberated and nonliberated portions of the particle size distributions, leading to:

$$P_{Partially-Locked.Est} = [1 - P_{Lib.Est}]\left[1-\left(\frac{r^*_{hrp}-r^*_{vmp}}{r^*_{hrp}}\right)^3\right] \ldots \left(for \ldots r^*_{hrp} > r^*_{vmp}\right) \quad (2)$$

and

$$P_{Fully-Locked.Est} = [1 - P_{Lib.Est.}]\left[\left(\frac{r^*_{hrp}-r^*_{vmp}}{r^*_{hrp}}\right)^3\right] \ldots \left(for \ldots r^*_{hrp} > r^*_{vmp}\right) \quad (3)$$

The effect of comminution or size reduction on the size of the vmp can be estimated based on probability and geometry, as noted in Fig. 2 assuming $d_{vmp} < D/SRF$. The probabilities of the four scenarios are:

Center: $$P_{CMce} = \frac{(\frac{D}{SRF} - dvmp)^3}{(\frac{D}{SRF})^3} \quad (4)$$

Side (central): $$P_{CMsc} = 6\frac{0.5dvmp(\frac{D}{SRF} - dvmp)^2}{(\frac{D}{SRF})^3} \quad (5)$$

Table 1 — Comparison of size reduction factor (SRF) and fractions of particles that are liberated, partially locked or fully locked, and calculated and measured exposed fractions (partially locked + liberated) for an initial rhrp:rvmp of 12.5.

SRF	Liberated	Partially locked	Fully locked	Exposure calculated	Exposure measured
1	0.00718	0.219723	0.773097	0.226903	0.38
1.340096	0.013169	0.284577	0.702254	0.297746	0.44
2.078928	0.028839	0.408433	0.562728	0.437272	0.475
2.785963	0.04525	0.506666	0.448083	0.551917	0.6
3.920129	0.071901	0.627971	0.300128	0.699872	0.857
8.149667	0.160566	0.804048	0.035385	0.964615	0.925
12.15506	0.227424	0.77256	1.62E-05	0.999984	0.98

Side (edge): $$P_{CMse} = 12\frac{(0.5dvmp)^2(\frac{D}{SRF} - dvmp)}{(\frac{D}{SRF})^3} \quad (6)$$

Corner: $$P_{CMco} = 8\frac{(0.5dvmp)^3}{(\frac{D}{SRF})^3} \quad (7)$$

The final vmp size is found by multiplying the probabilities by the respective sizes and summing the total.

Results and discussion

The sum of probabilities for vmp particle distribution and vmp fracture scenarios is always one. Table 1 shows the combination of vmp particle distributions as a function of size reduction factor. Table 1 also shows the close fit between computed tomography (CT) data and calculated data using this methodology.

Conclusions

The relationships that mineral liberation and exposure have with host rock particles and valuable mineral particles in ores are discussed in the context of comminution and separation process performance. This paper presents fundamental and practical methods, along with straightforward equations, to predict the effects of size reduction on the liberation, partial locking and full locking of valuable mineral particles within ore. The proposed methods are grounded in basic statistical principles and geometric relationships, offering a simple yet effective approach to understanding and optimizing the comminution process. These same methods can be applied to other applications involving heterogeneous materials in which size reduction is important for subsequent separations. ■

References

A list of all references is available in the full paper.

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Selected Abstracts

Implementation approaches for digital transformation: Current state of the mining industry

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Full-text paper:
Mining, Metallurgy & Exploration (2025) 43:169–181, https://doi.org/10.1007/s42461-025-01347-5

Keywords: Digital transformation · Project Portfolio Management · Industry 4.0 · Smart Mine · Underground mine

The mining industry's digital transformation (DT) presents a myriad of challenges, particularly in the strategic transition toward the concept of the Smart Mine, which is characterized by digital connectivity, sustainability and real-time decision-making capabilities that enhance productivity and safety, focusing on human-centered workforce transformation. This paper seeks to evaluate the current DT approaches employed within the underground mining sector to facilitate this transformative process. To accomplish this, we conduct a comprehensive review of academic and non-academic literature on existing strategies that guide DT initiatives within the mining domain. Next, we extract successful practices and approaches from both the mining sector and the broader Industry 4.0 landscape, seeking to evaluate the implemented activities and their corresponding value using expert insights. Our findings indicate a disparity in adherence to the recommended sequence for portfolio management phases, with notable challenges in the categorization and balancing phases, which are the least utilized.

Moreover, we observe that the majority of activities suggested in the literature related to Industry 4.0 and the mining sector are employed by more than 50 percent of portfolio management experts. Despite these variances in application, most activities are perceived as valuable by industry experts, underscoring their potential contribution to the mining sector's DT journey. ■

Comprehensive utilization of iron ore tailings: A review of sustainable practices and technologies

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Full-text paper:
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Keywords: Iron tailings, High added value, Comprehensive utilization, Current status analysis

As a byproduct of iron ore mining and processing, iron ore tailings (IOT) possess stable chemical properties that severely limit their potential for reuse. Currently, many mining areas still rely on stockpiling to dispose of IOT, a practice that not only carries the risk of geological disasters but also consumes valuable land resources and pollutes the environment.

This paper systematically reviews the physicochemical properties of IOT, analyzes the environmental hazards associated with their accumulation and summarizes recent advancements in their comprehensive utilization, including the recovery of valuable elements, preparation of backfill materials, development of construction materials, synthesis of soil conditioners, and production of chemical materials such as adsorbents and catalysts. Despite these promising pathways, the transition from laboratory research to industrial application faces challenges related to economic viability, process standardization and long-term environmental safety.

Future research should focus on developing low-cost activation technologies, enhancing the long-term durability and eco-efficiency of IOT-derived products, and integrating policy-driven incentives to promote market adoption. This review aims to provide a scientific basis and strategic reference for the high-value, sustainable utilization of IOT in the context of a circular economy. ■

Critical minerals, power infrastructure and the AI energy surge:

Mining's expanding role

by Joseph R. Pere and Heather Lammers, Vice Chair and Chair, SME Government & Public Affairs Committee

The rapid expansion of artificial intelligence (AI) is reshaping U.S. electricity demand and the U.S. industrial sector in ways that directly elevate the strategic importance of domestic mining. What began as a technology story has become an energy and materials story, positioning critical minerals at the intersection of data-center growth, power-generation expansion and transmission infrastructure.

Surging demand for reliable power

After more than a decade of relatively flat electricity consumption, U.S. demand is rising sharply. Data centers, driven largely by AI workloads, currently account for roughly 4 to 6 percent of national electricity use. Multiple recent forecasts project that share could reach 9 to 15 percent by 2030 and approach 20 percent by 2035. Goldman Sachs Research estimates U.S. data-center power demand will more than double from 31 GW in 2025 to 66 GW in 2027. The U.S. Energy Information Administration and other analyses confirm that commercial-sector growth, led by data centers, is now outpacing residential demand.

Hyperscalers have been the most visible near-term catalyst. Yet, the deeper signal is broader. The country needs substantial new dispatchable generation and transmission capacity to serve both AI loads and the population's growing electricity needs. Utilities and developers are responding with an "all-of-the-above" approach to meet demand that includes natural gas, nuclear restarts and new builds, renewables and on-site generation. Transmission and distribution upgrades are equally essential and mineral intensive.

Critical minerals as the enabling layer

Every megawatt of new generation and every mile of new transmission requires copper, aluminum, steel, rare earths and a suite of other minerals. Copper alone can dominate the materials intensity of grid expansion, substations, transformers, and data-center power and cooling systems. Recent industry estimates show that power infrastructure — not just semiconductors — drives the majority of mineral demand associated with the AI build-out. Grid transmission and distribution account for a large share of that copper requirement.

Domestic mining of these materials is therefore not peripheral to the energy transition or the digital economy; it is foundational. Projects that supply copper, nickel, cobalt, lithium, coal, uranium and rare earths directly enable the generation and delivery systems that AI data centers and the broader grid require. Without expanding domestic mining and mineral production and refining, the United States remains exposed to supply-chain concentration and geopolitical risk at the precise moment demand is accelerating.

Policy and permitting context

Federal policy is changing to reflect this reality. The FAST-41 framework has been expanded to cover AI-linked infrastructure and critical-minerals projects, including copper developments that support the power-equipment supply chain. Executive actions have sought to accelerate permitting for large data-center and associated energy projects. The House has passed the bipartisan SPEED Act, which aims to streamline National Environmental Policy Act (NEPA) reviews, narrow the scope of analysis, limit certain litigation delays and improve project certainty. As of mid-2026 the measure remains pending in the Senate.

These developments build on earlier permitting-reform efforts and create both opportunity and residual uncertainty for mining. Faster, more predictable reviews for energy and mineral projects would help align supply with the materializing demand. At the same time, compliance expectations have not disappeared. Enforcement remains active, and unresolved scientific or procedural disputes continue to generate litigation risk.

Implications for miners

The data-center wave is best understood as a catalyst rather than a permanent end-state. Hyperscalers are already shifting toward third-party leasing and on-site generation strategies. The longer-term opportunity for mining lies in the sustained need for reliable, resilient power infrastructure that serves the entire economy. Companies that can deliver critical minerals with strong environmental performance, defensible data and community engagement will be well positioned to

(Continued on page 43)

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Why is winterization important?

by Sigrid Audrey-Richard, Communications Chair, Health & Safety Division

Winter is coming, and soon winterization will become the "talk of the town." Year after year, people try to plan so they are not caught unprepared when an early snowstorm comes through. Preparation is key to ensure that facilities, equipment and processes will be taken care of and ready to operate when the thermometer is below 32 °F (0 °C).

Winterization is critical for safety and production reliability. Without the necessary steps to be ready, equipment might not be available when needed. What if a pipe freezes or bursts open? What if a heating system stops functioning? What if lubricant is no longer working and the equipment stops? What if diesel becomes more like gel or wax, and clogs filters?

Winterization is not only a maintenance task but is also critical for the safe operation of equipment, proper working of utilities, prevention of injury to people, and avoiding environmental release and production losses.

To get ready, a few steps can be put in place to safely operate and maintain mines and processing plants:

- Identify critical equipment whose condition could be affected by cold temperatures.
- Schedule prewinter inspection early, at the end of the summer or beginning of fall.
- Use the preventive maintenance program to replace weather-sensitive components.
- Ensure electrical heat tracing systems are working, and steam systems are up and running.
- Change/use appropriate lubricants and ensure that diesel and gasoline are winter blended.
- Verify pipe insulation for any defect, break or failure.
- Verify, check and test heating systems prior to making them operational.
- Check and restock inventories for deicing agents for roads, walkways and stairs (such as rock salt, calcium chloride, magnesium chloride).
- Revise emergency response plans for winter-related incidents.
- Inspect all the emergency response equipment, such as eyewash stations, emergency showers and firewater systems, and check that their heating/insulation systems are functioning properly.
- Ensure that emergency response teams are trained to respond to winter safety incidents.

Safety Share **serves as a forum for the presentation and discussion of facts, ideas and opinions pertaining to the interests and technology of the Health & Safety Division. Accordingly, all material published herein is signed and reflects the individual view of the authors. It is not an official position of SME or the division. Comments by readers will be referred to that division for response. The division chair in 2026 is Amy Richins.**

Lights, camera, mining! Share your company's story at MINEXCHANGE 2027

The Society for Mining, Metallurgy & Exploration's (SME) Health & Safety (H&S) Division is inviting mining companies, contractors and industry service providers to showcase their creativity and educational efforts during a special film festival at the MINEXCHANGE 2027 SME

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Green News

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participate in both the near-term AI-driven build-out and the broader energy-market expansion that follows.

The Society for Mining, Metallurgy & Exploration's (SME) Government & Public Affairs Committee (GPAC) continues to monitor these intersecting trends — critical minerals policy, energy-infrastructure permitting and the evolving regulatory landscape — so that SME members have timely information and a voice in the discussions that shape project outcomes.

Looking ahead

The mining industry's ability to supply the materials for power generation, transmission and advanced computing will help determine whether the United States can meet rising electricity demand while maintaining energy security and environmental standards. Continued engagement by industry professionals with policymakers, regulators and the public remains essential. GPAC welcomes further dialogue on how mining can responsibly support this next phase of American energy and technology infrastructure.

(Joseph R. Pere is managing director, Gulf Services, at OMS Group LLC, and Heather Lammers, Ph.D., Q.P., is program director, Undergraduate Mining Engineering, at the Colorado School of Mines.) ■

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MPD Plenary, Luncheon, Scotch Nightcap and Student Poster Contest await you at MINEXCHANGE 2027

by Kimberly Mills, Associate Chair, Mineral & Metallurgical Processing Division Executive Committee

The Mineral & Metallurgical Processing Division (MPD) will host its annual MPD Plenary Session on the afternoon of March 1 during the MINEXCHANGE 2027 SME Annual Conference & Expo to be held in Denver, CO, Feb. 28-March 3, 2027. This session features lectures by the recipients of the prestigious Antoine M. Gaudin, Robert H. Richards and Milton E. Wadsworth awards.

The award recipients cover technical topics as well as their expertise and experience in mineral processing and extractive metallurgy from around the world. The lectures are always memorable, and something can be gleaned from each seasoned professional. It is a must-attend event for MPD members, and members of all divisions are welcome. This year's presenters will be:

- David Meadows, the Antoine M. Gaudin Award recipient for his accomplishments in furthering the engineering, technology and execution of mineral processing plant design on a global scale.
- Aidan Giblett, the Robert H. Richards Award recipient for his outstanding and sustained contributions to the advancement of comminution and grinding circuit design, and for his global leadership in translating mineral beneficiation theory into practical, high-impact operational improvements.
- Michael Moats, the Milton E. Wadsworth Award recipient for his outstanding contributions to the hydro- and electrometallurgy of nonferrous metals.

Additional MPD awards will be presented and acknowledged at the MPD Luncheon on March 3, including:

- The presentation of the Mill Gentleman of Distinction Award to Christopher A. Noble.
- Palas Kamlakar Borkar, Neha Sharma, Atharva Rane, Kwabena Boafo and Timothy Eisele will receive the Arthur F. Taggart Award for their paper "Leaching of Manganese Using Bio-solubilized Iron Reductant to Prevent Manganese Carbonate Formation," published in SME's *Mining, Metallurgy & Exploration* journal.
- The MPD Outstanding Young Engineer Award will be presented to Sumedh Gostu, whose award citation states "For contributions to hydrometallurgy and critical minerals processing, along with dedicated service to the SME MPD community."
- The Frank F. Aplan Award was not awarded this year due to a lack of nominations.

This year's invited MPD Luncheon speaker is Rick Honaker, professor in the Department of Mining Engineering and university research professor with distinction at the University of Kentucky, who will be speaking on "Securing America's Critical Materials Future Through Innovation, Collaboration, and Commercialization." As global competition for critical materials intensifies, the ability to process, purify and manufacture critical material resources domestically has become both an economic imperative and a national security priority. This presentation will highlight how industry, academia and national laboratories can leverage unprecedented federal investments to accelerate the commercialization of breakthrough processing technologies, artificial intelligence, automation and robotics. The resulting innovations have the potential to dramatically reduce costs, increase productivity, shorten deployment timelines and strengthen supply-chain resilience. Attendees will gain insight into how strategic partnerships can transform research into profitable, scalable solutions that enhance U.S. competitiveness, drive industrial growth and secure America's critical materials future.

Other MPD events scheduled for MINEXCHANGE 2027 include:

- The MPD Unit Committee Meeting on Feb. 28, which is open to all MPD members who wish to get involved in the following year's MINEXCHANGE 2028 SME Annual Conference & Expo.
- The famous Scotch Nightcap scholarship fundraising event on the night of March 2, featuring MPD Past Chair David Meadows and the Bass Metals band. Commemorative whiskey glasses and T-shirts will be available again this year.
- The MPD Student Poster Contest on the morning of March 3, preceding the MPD Luncheon.

Your participation in these events helps the MPD raise scholarship funds and encourages and supports the future engineers and scientists within the mineral processing and extractive metallurgy field. Come join us for any or all of these events during MINEXCHANGE 2027 in beautiful Denver, CO. Get involved in your division and become more engaged with your colleagues and peers. ■

Fine Grind **serves as a forum for the presentation and discussion of facts, ideas and opinions pertaining to the interests and technology of the Mineral & Metallurgical Processing Division. Accordingly, all material published herein is signed and reflects the individual view of the authors. It is not an official position of SME or the division. Comments by readers will be referred to that division for response. The division chair in 2026 is Aaron Noble.**

Letter from the SMEF President

Established in 1991, the SME Foundation (SMEF) supports education and outreach across the mining sector through tax-deductible 501(c)(3) contributions from SME members, divisions and corporate partners. The Foundation has a distinguished record of expanding public understanding of the minerals industries and providing scholarship support for the future workforce. Despite this long history of achievement, its objectives and programs are not always well understood by SME members.

The SMEF supports the mining profession through scholarships, educational programs and community engagement targeted to sustain the industry's growth and long-term vitality. Fundraising supports five core programs: student scholarships, faculty development, professional licensure resources, academic accreditation and minerals education outreach.

SMEF's educational initiatives extend well beyond scholarships. For more than a decade, the Foundation has awarded more than $1 million annually to support students and academics. Its flagship FORGE Grant Program (formerly known as the Ph.D. Fellowship and Career Development Grant Program) aims to rebuild the shrinking faculty pipeline by supporting qualified candidates pursuing tenure-track positions, thereby strengthening both mining education and the industry it serves.

SMEF also supports the PE Committee, whose mission includes maintaining and publishing the study guide and practice exam and serving more than 2,500 members through webinars and speaker bureaus. Equally important, though less visible, is SMEF's support for the ABET Committee. This committee provides evaluators who assess mining, metallurgy, geology and geological engineering programs to ensure they meet established quality standards.

The Minerals Education Coalition (MEC) Committee develops content that demonstrates the importance of mining and minerals in everyday life while showcasing careers in the industry. MEC members and local sections extend this outreach to K–12 educators by meeting with teachers and distributing educational materials at state science teacher conferences and other events for educators and the public.

For fiscal year 2027, with a budget of $1.9 million, we will continue to expand our outreach initiatives and scholarship support. The success of SMEF programs depends directly on the generous contributions of SME community members who share a passion for education and outreach. Thank you to all who contributed through personal donations or the Annual Gala and Golf Tournaments. Please visit the SMEF website for more information on programs and scholarships.

Best,

Andy Cole
SME Foundation President ■



Andy Cole

Earth Science Week focuses on critical minerals

by Rebecca Smith, Minerals Education Coalition Curriculum Coordinator

From Oct. 11-17 Earth Science Week (ESW) celebrated "Critical Minerals for a Thriving Society." The new Minerals Education Coalition's (MEC) ESW calendar activity "Critical Minerals Search" and related materials were developed in collaboration with the American Geosciences Institute (AGI). The activity is available on the Earth Science Week website, earthsciweek.org/, and MEC's ESW webpage, MineralsEducationCoalition.org/esw.

The new calendar and a free "MEC Monumental Minerals" poster are part of 5,000 ESW toolkits that can be ordered free with shipping and handling at GeoscienceStore.org/2026-earth-science-week-toolkit-critical-minerals-for-a-thriving-society/.

Go online to order this resource for teachers and students you know. ■



Third annual West Virginia golf tournament a great success

by Megan Martin, SME Foundation Manager

For the third year, mining companies from coal country gathered to raise money for the SME Foundation at The Greenbrier Resort in White Sulphur Springs, WV.

Thanks to the generous sponsors and numerous golf teams, the SME Foundation raised more than $10,000 for the FORGE Grant Program (formerly known as the Ph.D. Fellowship and Career Development Grant Program).

Guests enjoyed an evening reception on Thursday night. Then, the following morning, 86 golfers competed on the beautiful Meadows Course.

Winners

The big winner of the day was the team from Victaulic: Noah Phillips, Trea Schuller, Brian Dotson and Jordan McNamee. Also, huge congratulations to Justus Mann for making a hole-in-one.

A big thank you

Thank you to the Golf Planning Committee members Joe McQuerrey, Michael Myers, Tom Rauch and Eric Shereda. This event would not have been possible without their commitment and dedication.

Get ready for next year

We look forward to holding this event again next year and welcoming golfers to another exciting competition.

The 2026 full results can be found on the Foundation golf site at www.smefgolf.com on the photo page. ■



The winning team from Victaulic.



Safety Share

(Continued from page 43)

Annual Conference & Expo in Denver, CO.

We are looking for engaging, good-quality videos developed in-house by your people, for your people — not professionally commissioned productions.

While hosted by the H&S Division, submissions are not limited to health and safety topics. Videos may highlight employee training, operational practices, innovative technologies, environmental stewardship, leadership, lessons learned or other educational initiatives that benefit the mining industry. Videos should last no longer than 15 to 20 minutes, with shorter submissions encouraged. Selected films will be featured during an interactive conference session, giving attendees an opportunity to learn from one another and recognize the creativity, dedication and talent found throughout our industry.

You do not need a professional production crew to make an impact. We want to celebrate the great work your employees are already doing.

Interested in participating? Contact the H&S Division for submission information. ■

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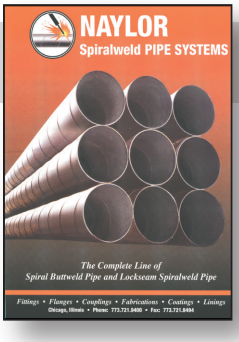
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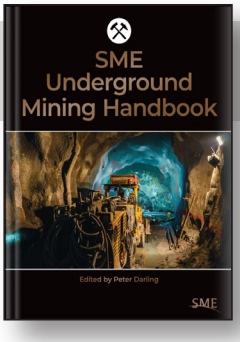
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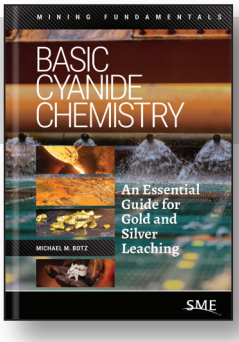
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FACULTY POSITION: INTELLIGENT MINING SYSTEMS & AUTOMATION

Department of Mining and Minerals Engineering | Virginia Tech

The Department of Mining and Minerals Engineering at Virginia Tech invites applications for an open-rank tenured or tenure-track faculty position in intelligent mining systems and automation.

We seek an innovative scholar to advance research and education at the intersection of mining engineering, automation, and intelligent systems. Areas of interest include, but are not limited to:

- Autonomous mining and intelligent machines
- Artificial intelligence and machine learning for mining applications
- Robotics, digital twins, and human-machine interaction
- Mine systems, optimization, and digitization
- Data analytics and real-time decision-making

The successful candidate will establish an independent research program, contribute to interdisciplinary collaboration, mentor undergraduate and graduate students, and teach mining engineering courses.

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Virginia Tech's Department of Mining and Minerals Engineering offers a collaborative academic environment, strong industry partnerships, and state-of-the-art research facilities in recently renovated Holden Hall, the department's longtime home. These facilities include the Autonomous Mining Arena, supporting research in intelligent mining systems and automation. The department also convenes the Built for the Mine partnership, an education- and research-focused collaboration among 12 leading mining technology companies and producers. Highly qualified and distinguished candidates may be eligible for a named professorship providing salary and operational support.

QUALIFICATIONS

Applicants must hold a PhD in Mining Engineering or a closely related field at the time of appointment and demonstrate expertise in intelligent mining systems and automation, along with a record of scholarly accomplishment or potential for scholarly impact appropriate to career stage and rank. Candidates must show the potential to develop an independent, externally supported research program and contribute effectively to interdisciplinary research, teaching, and student mentoring.

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For full position details and announcement, required application materials, and submission instructions, visit **jobs.vt.edu**. job number **538188**. Applications are accepted until the position is filled.

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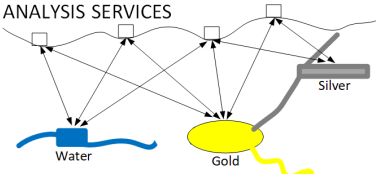
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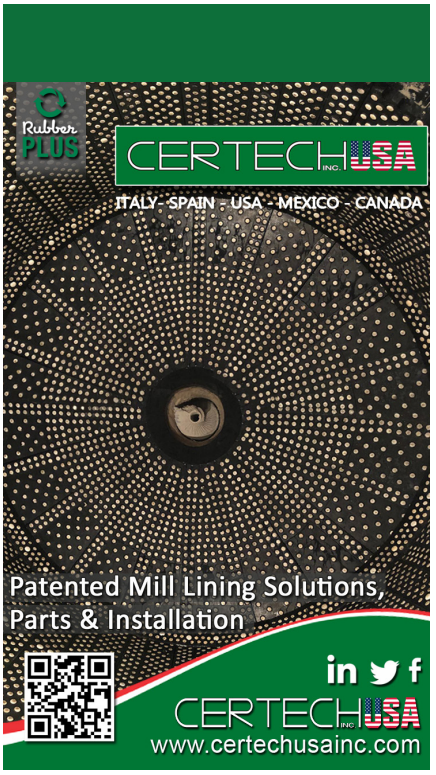
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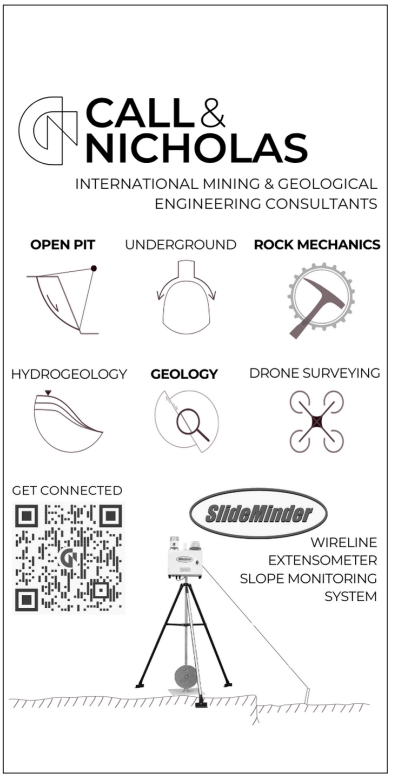
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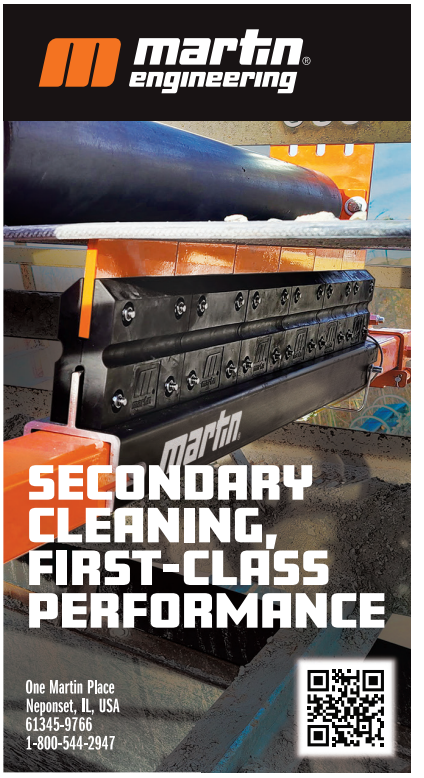
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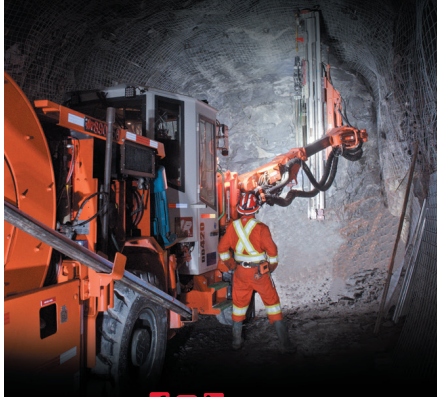
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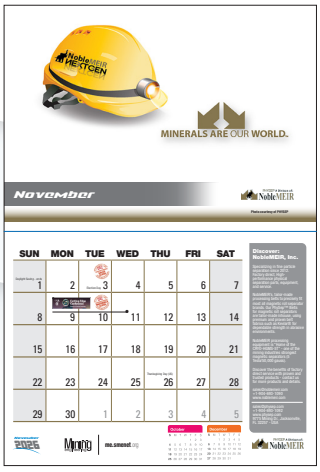
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Pipelines over projects for mineral security



William Gleason
Editor

The United States has committed billions of dollars to critical-minerals projects, but funding individual mines and processing facilities will not, by itself, secure domestic supply chains. Resilience also depends on the connections between those projects including processing and refining capacity, downstream buyers, workforce development and partnerships with allied nations.

These challenges are examined in the fourth annual *State of Critical Minerals Report*, released in September by the Payne Institute for Public Policy at Colorado School of Mines. The school also hosted its fifth annual Critical Minerals Symposium Sept. 27-28. The symposium, which has doubled in attendance since its inception, brought together representatives from government, industry, academia, nongovernmental organizations and philanthropy to examine the evolving role of government in building supply chains.

The report estimates that, since the beginning of 2025, U.S. federal agencies have made more than $7 billion in firm or conditional commitments across 62 large-scale projects, with billions more in indirect investment domestically and abroad. The scale indicates that there is a recognition of the need for coordinated investment across the value chain.

The report offers six recommendations: adopting a military prelogistics planning framework; prioritizing supply chains over individual projects; rebuilding the mining workforce; taking a regional approach to energy infrastructure investment; developing critical-minerals markets; and facilitating recovery from waste streams.

Action is already underway on some of these recommendations. For example, Colorado School of Mines (CSM) recently received more than $60 million in federal funding. Brad Handler, a researcher and director, Energy Finance Lab at the Payne Institute said the grants reflect two priorities.

"First, there is a need to support the entire mineral value chain. Second, progress will entail contributions from many engineering disciplines — from geology, mining development, processing, to advanced manufacturing — that leapfrog existing practice and allow for and respond to innovation," he said.

According to Morgan Bazilian, director of the Payne Institute and a professor of public policy at CSM, the report frames government involvement as a form of industrial policy intended to leverage U.S. strengths.

"Our policy suggestions are oriented toward military resiliency planning and support for domestic value chains, economic-based statecraft via infrastructure-led Global South engagement, commodity markets, workforce development and waste recovery," Bazilian writes.

The need to address vulnerabilities throughout the value chain is central to that approach. Investment in mining, for example, will not eliminate supply-chain risks if processing and refining remain concentrated elsewhere.

"Earlier reaction to the idea of the U.S. and allied development of critical minerals was often concentrated on the upstream, or mining the materials," Handler said. That approach, he explained, overlooked the processing and refining steps required to turn mined materials into usable products.

"If the U.S. supports some steps in a value chain, but leaves a step that is then largely provided by a foreign entity of concern such as China, then the strategic vulnerability remains not fully addressed. Thus, government must be mindful of supporting all of the discrete steps in a critical-mineral value chain," Handler added.

Supply-chain resilience also does not require every stage of production to occur in the United States. The report notes that regional partnerships can combine mineral deposits, processing capacity, infrastructure and capital to reduce vulnerabilities while drawing on the strengths of allied nations.

As Handler noted, critical-minerals development therefore requires more than funding individual projects. It requires durable value chains that can adapt to changing demand and reduce dependence on concentrated sources of supply. The ultimate test of today's investments is whether they give the United States and its allies more reliable access to the materials their economies and industries require. ■



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