December 2025
VOL. 77 NO. 12

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25

Feature Articles

Technical-paper Abstracts from *Mining, Metallurgy & Exploration*

(peer-reviewed and approved)

Invited Extended Abstracts

Selected Abstracts

SME News

Departments

Cover

Navigating the practical and financial requirements of a post-closure landscape requires foresight, judgement and assumptions. On page 20 Peter Werner explains how simple risk analysis tools and utilizing the time value of money can help bring some clarity to this end-of-mine life phase. Cover image from Shutterstock. Cover design by Ted Robertson.

SME Society for Mining, Metallurgy & Exploration

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SME Government and Public Affairs Committee
shares the voice of mining industry with lawmakers

Bill A. Hancock
2025 SME President

SME initiated work developing a new strategic plan at the 2025 SME Midyear Meeting in Denver, CO. Much data and member feedback are required to develop an effective plan that maximizes value. In the next two months many SME members will receive a survey requesting feedback, so I ask that anyone who receives an interview request or survey to please respond with your best perspectives.

The current strategic plan was completed in 2020. Normally, we evaluate and update the plan every five years but with our new executive director Melissa Russell joining SME only at the end of September, we decided to wait a year so she can be fully involved and engaged in the development and implementation of the new plan.

SME strives to be responsive to technology, member and industry changes. At times, this requires that we modify and enhance programs to maximize benefits and value. However, larger strategic considerations necessarily require periodic comprehensive assessment and consideration by the SME Board. Overarching questions need to be considered include, in my opinion: (1) how do we support the rapidly changing technology and workforce environments, (2) should/must we enhance our international efforts since that is growing organically, anyway, and (3) do we have the appropriate balance between member-centric focus versus supporting our industries, which, in other words, is an "inward-outward" consideration.

As part of the inward-outward question, SME developed the Government and Public Affairs Committee (GPAC) to provide lawmakers guidance on major issues affecting our industries. The GPAC has been doing important and impactful work since 2010 providing policymakers with our unbiased technical perspectives through white papers and testimony.

As the GPAC's work may not be well known within our membership, I asked GPAC Chair Andrea Martin and Vice Chair Heather Lammers to provide some perspectives on their work, which they provided as follows: As a 501(c)(3) organization, SME's primary mission is to support our member's careers with excellent technical resources, educational programs, networking opportunities and professional development tools. SME's outward-looking efforts include providing accurate, factual information about the mining industry to the public and, particularly, to policymakers. The GPAC is the place where that happens. GPAC is focused on U.S. law and regulations. As a professional organization, we are careful to provide education and leave lobbying to others.

Mining is heavily regulated and can be controversial; therefore, watching federal and state policy trends is important. Hot topics of workforce trends, energy infrastructure, artificial intelligence (AI), critical/rare earth minerals, academics and the environment affect us all. You may have noticed, presidential administrations can significantly influence our industry. GPAC focuses on providing facts and expertise on mining technologies and practices to government personnel and legislators, recognizing they are not in the business of mining.

(continued on page 14)

Safety Share | Many of us will be spending time decorating and preparing to celebrate with our families and friends during the holiday season. Now is a good time to remember your training from work when you undertake projects at home. When decorating your home, be sure you are safely working at heights, especially with ladders on potentially slippery surfaces. Remember that chairs are not ladders and should not be used to gain height to put up decorations. Electrical safety is another key element at home during the holiday season. Be sure that you do not overload outlets that could cause a fire. Inspect all cords, surge protectors, and outlets prior to using them, just like at work. Electricity is extremely valuable, but needs to be respected. If you are decorating with natural trees or boughs, be sure to keep them well watered and remove them if they do dry out. Tree fires are not uncommon during the holidays and can devastate your home. If you have guests coming to your home, ensure that you properly shovel and treat walkways so that they don't slip and fall. Be responsible when celebrating and watch out for others as well. Operating a vehicle under the influence can lead to disastrous consequences for individuals and families. ■

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US strikes $80 billion deal for nuclear power plants

THE U.S. government inked a partnership with the Canadian owners of Westinghouse Electric that aims to build at least $80 billion in nuclear reactors, *Reuters* reported.

It is one of the most ambitious plans in U.S. atomic energy in decades, underscoring President Donald Trump's agenda to maximize energy output, focused on oil, gas, coal and nuclear.

It also comes as growth in artificial intelligence data centers boosts U.S. power demand for the first time in two decades, straining parts of the grid.

Under the agreement with Westinghouse's owners, Canada-based Cameco and Brookfield Asset Management, the U.S. government will arrange financing and help secure permits for the Westinghouse reactors.

In return, the plan offers the U.S. government a 20 percent share of future profits after Westinghouse has paid profits of $17.5 billion to Brookfield and Cameco. The U.S. government could turn that profit into an equity stake of up to 20 percent and require an initial public offering of Westinghouse by 2029 if its value surpasses $30 billion, the companies said.

The plan was announced after Trump said in Tokyo that Japan will provide up to $332 billion to support infrastructure in the United States, including construction of Westinghouse AP1000 reactors and small modular reactors.

Japanese firms Mitsubishi Heavy Industries could be involved in building up to $100 billion of Westinghouse reactors, according to a fact sheet issued by the two countries on the trade deal.

The companies did not say when the U.S. government interest would vest, but added that the government must make a final investment decision and enter agreements to complete construction of the plants.

It remains uncertain if the deal will succeed. Building new U.S. nuclear reactors and a permanent place to deposit the waste has been difficult due to soaring costs as well as public concern about potential accidents.

The last two Westinghouse U.S. reactors built at the Vogtle site in Georgia in 2023 and 2024 were about seven years behind schedule and cost around $35 billion, more than double an original estimate of $14 billion.

Westinghouse filed for bankruptcy in 2017 due to cost overruns, and was later acquired by Brookfield. Brookfield owns 51 percent of Westinghouse, while Cameco holds the rest.

No large reactors are currently under construction in the United States.

The Trump administration in May ordered the U.S. Nuclear Regulatory Commission (NRC) to slash regulations and fast-track new licenses for reactors, seeking to shrink a multiyear process down to 18 months. The order called for 10 new large reactors under construction by 2030.

The administration also reviewed staffing levels at the independent agency, which led some critics to question whether permits would be rushed at a risk to safety.

The NRC said it would respond to a request for comment about the deal once it has returned to full operations after the government reopens. U.S. Energy Secretary Chris Wright said in a statement that Trump had promised a nuclear power renaissance "and now he is delivering."

Critics also point to the fact that radioactive waste, which remains dangerous for thousands of years, is currently kept on site at nuclear plants in cooling pools and then moved into hard casks. ■

US House report accuses China of mineral market sway

CHINA FOR decades has sought to manipulate global critical minerals prices, using its control as an economic weapon to expand its manufacturing sector and its geopolitical influence, a U.S. House of Representatives committee said, *Reuters* reported.

The allegations, contained in a 50-page report from the bipartisan U.S. House Select Committee on China and reviewed by *Reuters*, adds to a series of missives from Washington criticizing Beijing's sway in critical minerals markets.

President Donald Trump and his predecessor, Joe Biden, have in recent years sought to crimp China's dominance in the critical minerals sector.

The committee's legislative report aims to codify presidential orders into law with an array of recommendations including price controls and expanded government oversight of price reporting agencies.

The Chinese Embassy in Washington did not immediately reply to a request for comment. China has previously accused the U.S. of distorting and exaggerating Beijing's rare earths export controls and of stirring up panic over the issue.

"China has a loaded gun pointed at our economy, and we must act quickly," said Congressman John Moolenaar, a Michigan Republican and chair of the committee.

A chemist by training who previously worked at Dow Chemical, Moolenaar added that Beijing's practices had "caused American job losses, driven American miners out of business, and jeopardized national security."

The report, compiled by committee staff, was also endorsed by the ranking Democrat, Congressman Raja Krishnamoorthi of Illinois.

It alleges that China's role as the world's largest processor of many critical minerals has made it nearly impossible for the United States and allies to determine the true price of certain metals, including rare earths.

The report also suggests that the London Metal Exchange, where many minerals are traded, is susceptible to influence from Beijing, as it is owned by the Hong Kong Exchanges and Clearing. ■

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Arkansas aims to become US lithium hub, **overcoming Chinese competition, tech challenges**

ARKANSAS FACES stiff Chinese competition, sagging market prices and technological challenges as it vies to become the hub for U.S. lithium production, obstacles that state officials and industry executives said are surmountable, *Reuters* reported.

The southern state sits atop the Smackover, an underground geological formation stretching from Florida to Texas filled with salty brines containing more than 5 Mt (5.5 million st) of lithium, according to the U.S. Geological Survey.

That is enough lithium to make millions of electric-vehicle batteries and other devices if the metal can be filtered using direct lithium extraction (DLE), something that has never before been done on a commercial scale.

Beyond technical challenges, Arkansas must contend with a lithium price drop of more than 80 percent in the past 18 months, according to Benchmark Mineral Intelligence, a fall fueled by oversupply from Chinese rivals.

"What we're all trying to do is make Arkansas as competitive as it possibly can be," Patrick Howarth, who runs Exxon Mobil's lithium business, told attendees at the Arkansas Lithium Innovation Summit in Little Rock, AR.

Exxon, which has delayed by at least a year its lithium production plans to 2028, Standard Lithium and Chevron are among the companies rushing to prove DLE can work in Arkansas despite low prices.

Arkansas is betting its workforce's industrial expertise, electricity rates among the lowest in the United States, and a permissive regulatory scheme will help it become the country's lithium hub.

The only lithium mine is the United States is in Nevada, operated by Albemarle.

"We spend a lot of time persuading people outside of Arkansas that this opportunity is real, that it can be low cost in terms of production, that it can become a credible supply of lithium chemicals for North America for decades to come," said Andy Robinson, president of Standard Lithium, which is developing an Arkansas DLE project with Equinor.

Roughly 860 people attended the summit, an increase of 15 percent from a similar event held last year.

Arkansas Governor Sarah Huckabee Sanders said in an interview she is confident DLE can succeed.

"Big companies like that don't put hundreds of millions of dollars into things if they don't feel like they see a path forward," said Sanders, who was press secretary for President Donald Trump during his first term and elected as governor in 2022.

The governor said she does not believe the state's lithium industry needs government to guarantee a minimum price for its product — something Trump officials have discussed for critical minerals.

Sanders added she does not think it is a disconnect that she wants Arkansas to be a major lithium producer but does not own an electric vehicle.

"I don't own rockets, but it's still something we're really good at manufacturing," Sanders said, referring to the state's rocket industry. "I don't think you have to own a product to be able to make it in your state, to be able to sell it and to create an environment where those businesses can really do well." ■

Newswatch contents

China halts ban on exports of **three metals to US but controls remain**

CHINA HAS suspended a ban on exports of gallium, germanium and antimony to the United States, its commerce ministry said, although the three metals remain subject to broader export controls requiring shippers to first get licenses from Beijing, *Reuters* reported.

China restricted exports of the three metals between August 2023 and September 2024 before singling out the United States for an outright ban last December in response to new curbs imposed on its chip sector by Washington.

The ban caused shortages among U.S. users, and some importers resorted to workarounds like routing shipments through third countries to get their hands on the materials used in products including semiconductors, fiber-optic cables, ammunition and flame retardants.

The ban's suspension marks the latest relaxation of China's mineral export control regime following the recent meeting between U.S. President Donald Trump and Chinese President Xi Jinping in South Korea.

The suspension will last until Nov. 27, 2026, China's commerce ministry said in a statement.

However, the decision to suspend the ban did not revoke the earlier decisions to add the three metals to the dual-use export control list, so exporters will still need licenses from Beijing for foreign sales. ■

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Ten minerals added to 2025 critical minerals list;

New list to include copper, metallurgical coal, silver and more

THE U.S. Geological Survey (USGS) has added 10 minerals to the critical minerals list, including copper, metallurgical coal, uranium, boron, lead, phosphate, potash, rhenium, silicon and silver.

As required by the Energy Act of 2020, USGS used an updated methodology to quantify the risks associated with potential supply-chain disruptions and recommend mineral commodities for inclusion on the updated 2025 Draft List of Critical Minerals.

The updated methodology uses an economic model that the USGS developed to estimate the potential effects of foreign trade disruptions of mineral commodities on the U.S. economy. The analysis also provides a prioritization based on the results. The economic model has several advantages over previous assessments, including the ability to directly compare the results against other economic risks and the costs of initiatives aimed at reducing the risks.

The critical minerals list guides federal investments and permitting decisions and helps shape the government's broader minerals strategy.

Reuters reported that the Trump administration is expanding the list amid efforts to boost domestic mining and cut reliance on imports, particularly from economic rival China.

The list serves as a blueprint for Washington's push to secure supplies of materials needed for defense, manufacturing and clean energy technologies. It determines which projects qualify for federal incentives, informs national stockpiling and research priorities, and signals to private investors where the government sees long-term strategic value.

Officials and industry leaders say strengthening domestic production could help insulate the United States from potential supply shocks or export restrictions imposed by competitors like China, which dominates the global refining of many critical minerals.

Doug Burgum, the interior secretary, said the expanded list "provides a clear, data-driven road map to reduce our dependence on foreign adversaries, expand domestic production and unleash American innovation."

The new list also includes uranium, which is enriched to fuel nuclear reactors, as well as boron, lead, phosphate, potash, rhenium, silicon and silver. Potash and phosphate are used as fertilizers to grow crops around the world. ■

US Department of Energy announces $355 million of funding opportunities to expand critical mineral production

THE U.S. DEPARTMENT of Energy (DOE) announced $355 million for two notices of funding opportunities (NOFOs) issued by its Office of Fossil Energy to expand domestic production of critical materials essential for advancing U.S. energy production, manufacturing, transportation and national defense.

The first NOFO provides up to $275 million for American industrial facilities capable of producing valuable minerals from existing industrial and coal byproducts. The second provides up to $80 million to establish Mine of the Future proving grounds for real-world testing of next-generation mining technologies.

The DOE announced in August its intent to invest $1 billion to advance and scale mining, processing and manufacturing technologies, delivering on President Donald Trump's executive orders, Unleashing American Energy and Immediate Measures to Increase American Mineral Production. These actions will secure America's critical materials supply chains, increase domestic mineral production, reduce reliance on foreign sources and strengthen U.S. energy independence.

"The Mine of the Future—Proving Ground Initiative will be among the DOE's first major investments into mining technology research and development in almost four decades," said U.S. Department of Energy Assistant Secretary of the Office of Fossil Energy Kyle Haustveit.

The Office of Fossil Energy announced up to $275 million under the Mines & Metals Capacity Expansion NOFO to address the potential for America's industries to recover valuable critical materials by piloting promising future separation and recovery technologies directly at industrial sites. It includes two focus areas for the design, construction and operation of large pilot-scale facilities to produce critical materials: coal-based feedstocks — advancing and accelerating demonstration of critical material production using coal-based resources as feedstocks; and industrial byproducts and wastes — open to all U.S. industry sectors that produce market-ready materials where industrial byproducts and/or wastes can be a source of crucially needed critical materials.

Projects selected under this initiative will also create opportunities for hands-on workforce training to prepare the next generation of American miners and engineers to operate advanced mining systems safely and efficiently. ■

US, Abu Dhabi governments to invest $1.8 billion with Orion into critical minerals mining and refining projects

THE U.S. and Abu Dhabi governments will invest $1.8 billion into mining and refining projects across the globe with private equity fund Orion Resource Partners to bolster Western access to lithium, rare earths and other critical minerals, *Reuters* reported.

The investment plan comes as market leader China crimps access to critical minerals even as demand jumps globally across the economy, forcing manufacturers and others to jostle for fresh supply.

The U.S. International Development Finance Corp. (DFC), which is controlled by Washington, along with Orion and the Abu Dhabi sovereign wealth fund ADQ, have contributed $1.8 billion — $600 million each — to the newly formed Orion Critical Mineral Consortium.

The consortium, which hopes to grow to $5 billion with funds from others across the globe, aims to quickly get minerals supply to market and plans to avoid exploration-stage projects.

"What we're focused on is projects that are in production or can be put into production in the very near term to get material back to the U.S. and allied nations," said Frank Fannon, the consortium's managing partner who served as U.S. Assistant Secretary of State for Energy Resources during President Donald Trump's first term.

For other potential investors, Fannon said Orion would seek those with a "shared value and shared understanding" of the need to boost Western access to critical minerals.

Orion's announcement comes two days after private equity firm Appian Capital Advisory and the International Finance Corporation launched their own $1 billion fund to invest in minerals projects in Africa and Latin America.

Orion plans to "go where the rocks are" and invest in mines across the globe as well as the processing facilities needed to turn metals into the building blocks for batteries and other equipment, Fannon said.

"We are absolutely committed to funding the supply chain to the extent necessary to secure end-stage product for customers and consumers," said Oskar Lewnowski, Orion's founder and chief executive officer.

Orion will focus its investments on minerals considered critical by the United States, Canada, the European Union and Australia, as well as copper and uranium, both executives said.

The DFC, which also holds a stake in mining firm TechMet, will be involved in investment decisions and that involvement should help reduce any project's geopolitical risk, the executives said. ■

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SME Society for Mining, Metallurgy & Exploration

Coeur announces acquisition of New Gold to create a new, all North American senior precious metals producer

COEUR MINING Inc. announced it has signed a deal to buy New Gold Inc. and New Gold's two gold mines in Canada in an all-stock deal valued at about $7 billion.

New Gold shareholders will receive 0.4959 shares of Coeur common stock for each New Gold common share. The exchange ratio implies consideration of $8.51 per New Gold common share, based on the closing price of Coeur shares of common stock on the New York Stock Exchange.

This represents a 16 percent premium to the Oct. 31, 2025 closing price of New Gold on the NYSE American. In the aggregate, this implies a total equity value of approximately $7 billion based on New Gold's common shares outstanding and a pro forma combined equity market capitalization of approximately $20 billion.

The agreement will create a leading all North American-based precious metals producer with an approximately $20 billion market capitalization.

It brings together seven high-quality operations producing approximately 1.25 million gold equivalent ounces in 2026, including 20 million ounces of silver and 900,000 ounces of gold. More than 80 percent of its revenue will be generated from the United States and Canada.

The combined company is expected to generate approximately $3 billion of EBITDA and approximately $2 billion of free cash flow in 2026 at significantly lower overall costs and higher margins, representing a material increase to Coeur's expected 2025 full-year EBITDA and free cash flow of approximately $1 billion and $550 million, respectively.

This strong free cash flow profile is expected to lead to a net cash position at closing and a rapidly growing cash balance, creating a clear path to a potential investment-grade credit rating and to higher levels of stockholder returns.

This strong financial position is expected to accelerate investment in multiple high-return organic growth opportunities including New Afton's K-Zone, brownfield exploration at Rainy River and across all of Coeur's portfolio in the United States, Mexico and Canada.

The transaction is accretive on all of Coeur's key per-share metrics, including net asset value, operating cash flow and free cash flow, positioning the combined company for a potential share price re-rating.

The combined company will be among the top 10 largest precious metals companies and top five largest silver producers globally, with silver representing 30 percent of total metals reserves. This enhanced scale is expected to provide investors with significantly enhanced daily trading liquidity of more than $380 million with the potential for inclusion in key major U.S. indexes.

Upon closing, several members of the New Gold management team are expected to join Coeur to create a stronger and more resilient organization. Additionally, current New Gold president, chief executive officer and director, Patrick Godin, and one other current New Gold director will join Coeur's board of directors upon closing of the transaction.

"This transaction provides clear and compelling benefits for New Gold and Coeur shareholders by bringing together two companies with similar cultures to create a stronger, more resilient and larger-scale precious metals mining company," said Mitchell J. Krebs, Coeur's chairman, president and chief executive officer. ■

President's Page: A busy time for SME's GPAC

(continued from page 4)

GPAC was formed in 2009, with work beginning in 2010, to watch the goings-on in government and the courts and to look for opportunities to provide informed mining facts. SME members from all divisions and backgrounds participate and, in fact, they are needed. GPAC leverages the expertise of SME members on all mining-related topics. GPAC is supported by Deb Struhsacker, mining and public lands policy consultant. Struhsacker has worked in mining and policy affairs for decades. She has testified on Capitol Hill repeatedly and is a font of knowledge on mining policy and regulatory issues.

GPAC produces technical information and intellect in a variety of ways, all available on the SME website at https://www.smenet.org/what-we-do/technical-briefings. Browse the four white papers at the top. SME provided recent comments on the U.S. Geological Survey 2025 Draft List of Critical Minerals. We have targeted papers on U.S. energy policy, federal permitting, and a 2024 concept paper on why the U.S. needs a National Materials and Minerals Council. This last paper was the result of a roundtable discussion of mining technical and policy experts that SME hosted in 2024. SME assembled mining experts, researchers and academics with government officials to brainstorm strategies to elevate the U.S. mining industry to meet our nation's future needs. Concepts and ideas from this paper can be seen in the Trump administration's executive orders on mining and energy and the redirection of the Departments of Interior and Energy, and Environmental Protection Agency.

Further down the webpage are technical briefing papers with basic information on a variety of mining topics in concise, easy-to-read formats. GPAC meets monthly and has been doing its best to keep up with the current activities (shall we say, pandemonium) of U.S. regulatory affairs. Interested? Contact current chair Andrea Martin, incoming chair Heather Lammers or SME liaison Bill Gleason, and join us.

Deep Enough! ■

Barrick hikes dividend, shifts focus to North America
as gold prices bolster profit and offset decline in production

BARRICK MINING raised its dividend and expanded its share buyback program after reporting an adjusted quarterly profit that beat estimates, as stronger gold prices helped offset a decline in production, *Reuters* reported.

The Canadian miner's interim chief executive officer Mark Hill told *Reuters* that its focus in the future will be "firmly on North America … because it is our next growth area and it is the next growth in gold as well, so that is what we are focused on going forward."

The miner jointly owns Nevada Gold Mines with Newmont and is also looking to develop the Fourmile gold mine in Nevada.

Barrick, the third-largest gold miner by production, has had a volatile year, marked by the loss of control of its gold mine in Mali, which led to a $1 billion write-off of the asset, and the exit of Mark Bristow as its chief executive officer.

The Barrick board's search committee, led by independent director Brett Harvey, is working to find a new president and chief executive officer, the company said in a statement.

In Mali, four of Barrick's employees are in jail over a dispute with the company over the country's new mining tax code.

Hill said his main focus is to get those employees out of jail, adding that the company has to change some of the ways it is approaching the issue. Barrick also filed for arbitration against Mali, though the recent hearings over the company's request for an urgent hearing over the dispute were rejected by the World Bank's dispute tribunal. "We agree that arbitration, while an option, is probably not a preferred option and is not going to resolve (the problem of) the people who are incarcerated in the short term," Hill said.

Barrick has been locked in a long-running standoff with Mali's military-led government since it was forced to suspend operations in mid-January. That move followed the government's decision to block Barrick's exports for two months, detain some of its executives and seize three tons of bullion.

Gold prices, which are sensitive to geopolitical and financial uncertainty, averaged $3,574.95/oz in the third quarter, more than 16 percent higher than the preceding quarter and 43 percent above the levels seen a year earlier. Prices of the precious metal were buoyed by safe-haven demand as uncertainty over U.S. President Donald Trump's tariff plans and geopolitical tensions stoked inflation concerns. ■

Resolution Copper completes deepening
and rehabilitation of historic No.9 shaft

RESOLUTION COPPER has reached a major milestone with the completion of its multiyear, $200 million rehabilitation and deepening of the historic No. 9 shaft, a critical step in paving the way for one of the nation's most important new sources of copper and critical minerals.

Originally constructed in 1971 by the Magma Copper Co. in Oak Flat and operated as a production shaft until the mid-1990s, the refurbished and deepened shaft now extends to a final depth of 6,898 ft underground, nearly five Empire State Buildings tall, and measures 22 ft in diameter. The completed No. 9 shaft is now the second deepest single-lift mine shaft in the United States, behind only Resolution Copper's No. 10 shaft at 6,943 ft.

Rehabilitated and deepened from 4,800 ft to over 6,800 ft, the No. 9 shaft now connects to the No. 10 shaft, serving as ventilation and access for future underground development. Together, the network of underground mine workings form the backbone of the project's next phase of underground development, creating the foundation for future copper production that will strengthen the U.S. supply of this critical mineral.

"Completing the No. 9 shaft is a huge milestone and a testament to the dedication and expertise of our underground team and contracting partners," said Vicky Peacey, president and general manager of Resolution Copper.

"This achievement underscores what's possible when American miners, homegrown talent from local communities, including the Superior, Miami, Globe, San Carlos Apache Tribe, Hayden, Kearny and Winkleman, come together to do the job safely. While ongoing litigation continues to stall development, we are ready to advance this important copper project, enabling thousands of high-paying jobs, billions in economic development for rural Arizona and access to a domestic supply of copper essential to American security and modern infrastructure. The sooner the litigation delays stop, the sooner this project can move forward, and the sooner Arizona and the nation will benefit," she added.

The recent shaft-sinking project also achieved two years without a single medical injury or lost-time incident, underscoring Resolution Copper's strong commitment to safety. Over the course of the work, crews drilled nearly 14, 500 ft, poured more than 560 cu yd of concrete, and installed nearly 140 yd of shotcrete.

"This accomplishment reflects years of planning, discipline and teamwork between our people and partners," said Rob Tobin, operations and maintenance manager at Resolution Copper. "Achieving this safely for more than two years without a recordable injury shows the professionalism and dedication of everyone who worked underground to bring No. 9 back to life in a modern way." ■

Dig baby, dig!

Get going and move your mine ahead as fast as possible

by Douglas Silver

The dismantling of the U.S. Bureau of Mines in 1996 heralded in an era of the federal government ignoring miners. We were considered a pariah to the world, needlessly disturbing the Earth in quest of personal wealth. This attitude changed under the Biden administration, when they recognized that the eco-transition away from fossil fuels required certain critical minerals. They invested more than $600 million into grants and loans in 2024. The current administration has turbocharged this effort and as of November, $4.4 billion has been committed to our cause. A truly stunning number! Three executive orders and one legislative act (OBBBA) underpin this effort. Every day seems to involve an announcement of another company getting federal attention.

These overdue changes are closely aligned with America's desire to reduce its dependence on competitor nations, especially China. They are designed to reduce permitting time and the regulations that stifle construction while encouraging rapid mine and technology developments. The successful execution of these strategies should make America (1) less dependent on other nations for commodities, especially those with national security implications, (2) more productive through the creation of additional jobs and tax revenues and (3) serve as a pathway to lifting the middle-class citizens.

Most of the monies come from various Department of Defense (DOD) programs, but there is also representation from the Department of Energy, the U.S. Treasury and Congress.

Thirty-eight companies, representing 22 commodities and 19 states are on the Fixing America's Surface Transportation Act (FAST-41) list for expedited permitting. This program does not include funding, it only addresses permitting.

In addition, 21 companies (Table 1), representing 12 commodities (antimony, bismuth. cobalt, copper, gold, graphite, lithium, nickel, rare earths, silver, tungsten and zinc) have been the selected to receive $4.358 billion. Seven states (Alaska, California, Idaho, Louisiana, Michigan, Nebraska and Nevada) receive $4.193 billion. Nevada is the clear winner ($2,276.20 million). Greenland received $120 million (and is still not for sale) and Canada obtained more than $45.55 million. Thirteen of these companies are Canadian, four are American, three are Australian and one is British (based on their primary stock-exchange listings).

Under the Biden administration, a disproportionate amount of grants went to universities investigating possible extraction technologies, such as pulling rare earths out of coal. The current administration plans to spend $1.5 billion to add rare earth processing circuits at mines as well as developing separation and magnet manufacturing plants. These efforts are principally focused on California, Texas, Michigan and Quebec.

What is fascinating is how these funds are being delivered. Many are in the form of grants and loans, but the U.S. government is also taking equity positions in four companies. It swapped a 5 percent equity position in Lithium Americas (Thacker Pass lithium mine) in exchange for allowing the company to draw down $435 million and defer $182 million of debt service over the first five years of the loan. The DOD acquired $400 million (15 percent) of MP Materials (Mountain Pass Rare Earths) preferred shares in exchange for a 10-year offtake with a floor price of $110/kg NdPr. All magnets produced go to the DOD. Finally, the government invested $35.6 million buying equity positions in Trilogy Metals and South32, the owners of the Ambler polymetallic project in Alaska, and are fast-tracking road construction efforts.

On Oct. 20, 2025, the United States and Australia committed to each investing $1 billion over six months into rare earth mining and processing projects as joint ventures, sole projects in Australia and joint projects in the United States, Australia and Japan. In exchange, the United States committed to selling Australia Aukus nuclear-powered submarines by 2032. The total deal is valued at $8.5 billion and includes the Pentagon building a gallium refinery in Western Australia.

Also in October, Orion Resource Partners launched the Orion Critical Mineral Consortium with the U.S. International Development Finance Corp. (DFC) and Abu Dhabi sovereign-wealth fund with $1.8 billion committed capital and a target raise of $5 billion. These funds will be used to invest in and develop near-term producing critical mineral assets.

Appian Capital Advisory announced a $1 billion partnership with the International Finance Corp. (IFC) to accelerate the responsible development of critical minerals, metals and mining related projects in emerging markets. The IFC will anchor the fund with $100 million and the fund will invest in equity, credit and royalties and be managed by Appian.

In October JPMorgan Chase announced the formation of a $1.5 trillion "Security and Resiliency Initiative," which plans to execute a 10-year plan to facilitate, finance and invest in industries critical to national economic security and resiliency. This will include many different industries, but $10 billion is purportedly earmarked for the critical minerals industry.

Most of the North American public mineral companies are Canadian. In August, the Canadian government created the Major Projects Office,

an office designed to simplify and accelerate federal decision-making. It is akin to FAST-41. To date, five companies (Canadian Nickel, Foran Mining, Newmont Corp., Northcliffe Resources and Nouveau Monde Graphite) are being fast-tracked.

These numbers are impressive but not without concerns. One concern relates to how companies are selected. Are these decisions based on technical merit or political influence? A second concern is whether the rubber will hit the road? Even if the funds were spent tomorrow, it takes years to construct a mine. There will also, no doubt, be a few less-than-ethical enterprises trying to get in on the action. Their failures will cause setbacks for the rest of us. The current administration also has a habit of taking credit for deals yet to close. It will be interesting to see if these funds actually get dispersed in a timely manner. But the largest concern is what happens if the Democrats take the Presidency in 2028? Will they pull back or terminate some or all of these efforts? So, to those of you who snag a piece of this action, DO NOT DAWDLE! Get going and move your mine ahead as fast as possible. Once the land has been disturbed, it is much harder to rescind permissions. So… Dig Baby! Dig! ■

Editor's note: The opinions expressed here are those of the author and do not necessiarly reflect the views of SME or *Mining Engineering*.

Table 1

Companies receiving U.S. federal funds for mining.

Company name	Proposed funding (up to US$ M)	Property name	Commodity	Location
Graphite One Inc.	$574.70	Graphite Creek	Graphite	Alaska, USA
Novo Minerals Limited	$45	Estelle	Sb	Alaska, USA
South32	$17.85	Ambler	Cu, Zn, Ag, Au	Alaska, USA
Trilogy Metals	$17.85	Ambler	Cu, Zn, Ag, Au	Alaska, USA
MP Materials	$444.60	Mt Pass	REE	California, USA
Locksley Resources	$191	Mojave	Sb	California, USA
American Tungsten	$25.50	IMA	W	Idaho, USA
Perpetua Resources	$80+	Stibnite	Sb	Idaho, USA
Ucore Rare Metals	$22.40		REE	Louisiana, USA
Highland Copper Corp	$250.0	Copperwood	Cu	Michigan, USA
Talon Metals	$2.47	Tamarack	Ni	Michigan, USA
U.S. Antimony	$245	Multiple	Sb	Multiple locations
NioCorp	$10	Elk Creek	REE	Nebraska, USA
Golden Metal Resources	$6.20	Pilot Mountain	W	Nevada, USA
Lithium Americans	$2,260+	Thacker Pass	Lithium	Nevada, USA
Northcliffe Resources	$15	Sisson	W	New Brunswick, Canada
Fortune Minerals	$6.40	Nico	Co-Au-Bi-Cu	NWT, Canada
Lomiko Metals	$8.35	La Loutre	Graphite	Quebec, Canada
Volta Metals	N/A	Lavergne – Springer	REE	Quebec, Canada
Fireweed Metals	$15.80	Mactung	W	Yukon, Canada
Critical Mineral Corp.	$120	Tanbreez	REE	Greenland
Total	**$4.358.12**			

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The party's over, now what?

by Peter Werner

Technological advances in mine equipment and milling processes have enabled mining companies to exploit ever lower grades of ore. The result has been larger disturbances, greater volumes of waste, a complex web of infrastructure, and an overall trend toward mega projects that can extend over several square kilometers. This explosive growth in a mining operation's disturbance footprint provokes an obvious question: What is it going to cost to reclaim all of this? At face value, this can be an enormous financial liability for a company, but since the timing of reclamation may be years in the future for many operations, these costs can be heavily discounted, thereby limiting the burden on the corporate balance sheet. Nonetheless, mining companies are eager to remove these liabilities as quickly as possible; conversely, regulators want assurance reclamation will, in fact, occur. How might one bridge these competing interests? Navigating the practical and financial requirements of a post-closure landscape requires foresight, judgement and assumptions; however, companies that do not adequately plan for these future expenditures when there is no offsetting income stream will likely face some difficult decisions. Simple risk analysis tools and utilizing the time value of money can help bring some clarity to this end-of-mine life phase.

Photo courtesy of Montana Department of Environmental Quality

Landusky Mine in Montana: five years after reclamation.

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Asset retirement obligations

Moody's Ratings published in 2024 a review of asset retirement obligations (AROs) for 24 of the largest listings in its metals and mining sector (Moody's Ratings, 2024). Some of the results should be reason for alarm. One of the more remarkable findings was the increase in ARO obligations compared to long-term debt. The total outstanding reclamation obligations for the companies surveyed are the equivalent of 42 percent of their combined long-term debt. Moody's estimated compounded annual growth in AROs since 2018 at 9.7 percent and rising, and if current trends continue, AROs could eclipse long-term debt within 10 years. For one company, its combined outstanding AROs represented more than 50 percent of its most recent annual revenue. The growing significance of a company's AROs in combination with servicing long-term debt, ties up capital that otherwise could be used for the exploration and development of new properties, putting a company at risk from nonincome-producing assets.

Some companies are taking steps to reduce this liability by reclaiming parts of their operations during active mine life, but the contribution to the bottom line is often minimal, especially for operations with an openpit or multiple active waste rock dumps or a tailings impoundment, all of which may be needed right to the end of mine life. Alternatively, through discounting these future financial obligations or offloading expiring properties, companies are able to avoid a balance sheet awash in red ink and maintain a favorable credit rating. Despite these maneuvers, ever-increasing AROs point to a future day of reckoning for somebody, whether it is a company that cannot meet its ARO obligations or the regulator who inherits an environmental liability.

How long is long term?

It is not uncommon for a mine plan to include language that states post-closure monitoring and maintenance will continue

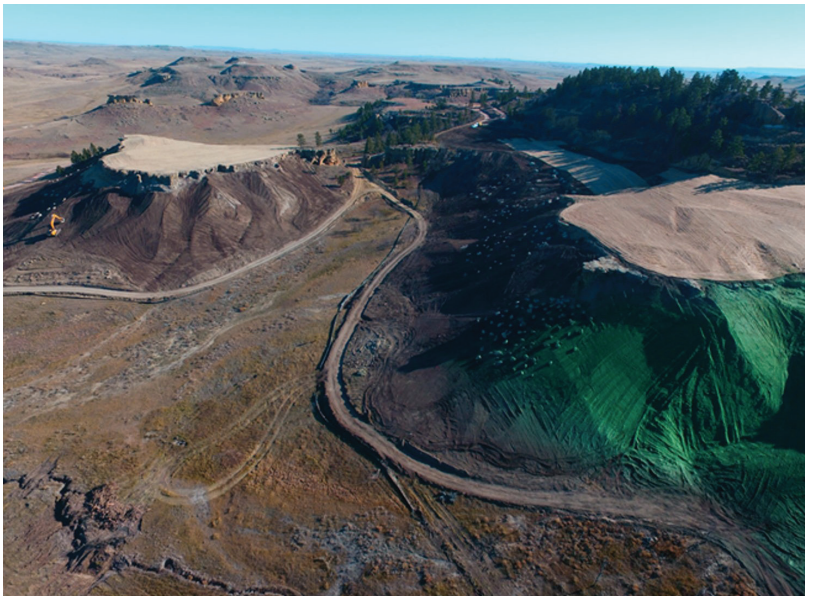
for some finite length of time — say, 30 years — after which the company may apply for bond release. This approach begs the question: What is so different about year 31 and beyond that makes monitoring and maintenance unnecessary? Assigning an arbitrary benchmark for when a mining company has fulfilled its reclamation obligations suggests: (1) a site will achieve a state of perpetual environmental equilibrium, and (2) one can predict when this will occur. We know neither of these to be true. Moreover, we fail to fully appreciate reclaimed mine features are simply artificial landforms that will change and evolve over time just as their natural counterparts do.

In the last few years, there has been growing recognition by nongovernmental organizations (NGOs) and industry organizations that some mine facilities may require long-term care and maintenance (Australian National Committee on Large Dams (ANCOLD), 2012; International Council on Mining and Metals (ICMM), 2019; Mining Association of Canada (MAC), 2019). This acknowledgment is primarily addressing the long-term risks posed by closed tailings facilities, but certainly could be applied to most any reclaimed mine facility. While recognizing some closed mine facilities may pose long-term risks or may require long-term monitoring, what appears to be missing is an answer to the question: How long is "long term"? This lack of a working definition underscores the regulator's dilemma: How do you calculate financial assurance if you do not know how long to apply costs? The federal mining regulations do not address this conundrum, and current guidelines struggle to provide a precise definition (ICMM, 2019; MAC, 2019). Without a common understanding of what long term means, it is difficult to address mine closure in a meaningful way.

A start to defining long term in the context of mine reclamation could include addressing the following three questions:

1. How should one think of long-term care and maintenance?
2. What should be included in long-term care and maintenance?

Photos courtesy of U.S. Department of Agriculture



Riley Pass Uranium Mine Complex in South Dakota: landform reclamation in progress (top) and completed (bottom).

3. Why is long-term care and maintenance important?

The answer to how one should think about long-term care and maintenance (LTCM) requires accepting that it should be viewed in terms of geologic time and not simply in engineering time. Consider the time a mine will be in a closed state will be far, far longer than it ever was in operation.

Mining creates landforms, whether they be waste dumps, tailings impoundments or some other constructed mine feature. These, however, are artificial landforms, different from those that have evolved through natural processes; yet, both types will continue to change in shape and size in response to climatic and environmental forces. The most recognizable landforms on a mine site are tailings impoundments, waste dumps and openpits. Certainly, these have the potential to pose significant risk to human health, safety and the environment, but many other lesser landforms also inhabit the mining landscape: diversion ditches, portals, sediment ponds and roads, to name a few. While a mine is in operation, these facilities are maintained as part of the normal mining cycle, as part of regularly scheduled maintenance, or in response to some system failure. After closure, when the regulator has determined the operator has met the requirements of the closure plan and the intent of the regulations have been satisfied, the operator's bond may be released and the permit retired. At this point there is no longer a designated responsible party to maintain these facilities, and they become part of the surrounding landscape where they are subject to the same natural forces and processes that have driven geomorphological change for millennia. Indeed, regulators and NGOs have recognized that some reclaimed mine facilities — specifically, tailings dams — may need care and maintenance exceeding 1,000 years (International Commission on Large Dams (ICOLD), 2013). As mine closure guidelines (ANCOLD, 2012; ICOLD, 2013) extend the time frame for post-reclamation care and maintenance, companies should begin preparing for a much longer site presence and financial commitment at their closed properties.

What should be included in LTCM requires thinking beyond water treatment. While a significant feature of any post-closure regimen where it may be required, water treatment is not necessarily the only system that requires long-term oversight. Reclaimed mine facilities and their components can be highly engineered with very narrow construction and operating tolerances. Water balance covers, underdrains and seepage collection systems, pipeline valves, couplers and gauges, electronic monitoring arrays, drain filters, passive treatment systems and dewatering devices, are commonly found as part of reclaimed mine facilities. Some systems include synthetic or reactive materials like geomembranes or metals that may degrade over time, while natural processes such as settlement and slope creep can compromise buried components. Inclusion of these elements in the reclamation design implies they are necessary for that facility's proper function whether during operations or in post-closure. To assume these systems will function as designed indefinitely is misguided.

The answer to why LTCM is important can be reduced to simple economics: It can be really expensive.

Photo courtesy of U.S. Department of Agriculture

Beal Mountain Mine in Montana: leach pad cover maintenance after 10 years.

Risk-based closure

While many mining risk analysis exercises concentrate on the operations phase, applying it to the post-closure environment can highlight potentially vulnerable facilities and reclamation components that may not otherwise be flagged during operations.

Reclaimed mine sites can be a complex of integrated systems where each component may have a specific function in support of another dependent system. An underdrain must work to prevent the buildup of a phreatic surface in an embankment to ensure stability is not compromised; a diversion ditch must function to prevent stormwater from eroding a reclamation cover and exposing harmful materials, or an electronic monitoring array needs to remain operational to capture incremental slope movement that may lead to more consequential stability problems.

A common theme in the analyses from the Mount Polley (2015), Fundão (2016) and Brumadinho (2019) tailings dam failures was that multiple, interdependent system breakdowns and conditions led to eventual dam collapse. Warning signs of system performance irregularities at these sites were evident, that if addressed, may have averted a complete system failure.

To further illustrate the point about long-term integrity, after a tailings facility is closed it still must function as a stable repository for tailings; however, the operating requirements applied during mining to ensure a safe facility may be less relevant after closure. The risk drivers present during operations (such as water holding capacity, liquefaction potential, seepage) may no longer be as critical to facility stability, replaced by closure-related concerns such as cap integrity, underdrain performance or stormwater routing. While likely different, the potential failure modes and consequences from a tailings facility's nonperformance after closure still exist in some form, and it may continue to be a threat to human health and the environment. To dismiss the importance of tailings impoundment integrity based on a facility coming to the end of its operating life is ill advised, as this phase will be replaced by a state of functional life that can extend in perpetuity.

The U.S. Forest Service recently conducted a risk assessment of a mine facility on National Forest System lands using the failure modes and effects analysis (FMEA) methodology. Mine features included a tailings storage facility, waste rock dumps, mine portals and shafts, a water treatment facility, mill and administrative buildings and related mine infrastructure. The exercise focused strictly on the post-closure time frame and did not limit the analysis period to a specific future end date. The outcome of the FMEA (unpublished) yielded interesting results. The exercise identified that the risk drivers were not the extreme events such as the probable maximum flood or maximum credible earthquake; rather, they were the smaller, chronic events like seasonal storms that impacted ancillary structures and facilities such as diversion ditches, or it was the failure of engineered systems such as underdrains and electronic monitoring stations that posed the greatest risks over time.

The FMEA showed recurrent natural processes (such as wildfire, storm runoff, vegetation succession, slope creep, freeze-thaw cycling) were the principal drivers behind eventual reclamation failure over an extended time horizon. This is due to the incremental degradation of individual component performance leading to more acute nonperformance and eventual system-wide breakdown. Not surprisingly, simple periodic care and maintenance such as cleaning diversion ditches, repairing rills and gullies, and replacing electronic monitoring systems can reduce risk levels and help avert eventual widespread facility failure.

The FMEA participants concluded that the natural processes that drove risk would always be present and would slowly degrade the reclaimed facilities over time. The only solution to maintaining system performance was a commitment to site care and maintenance — well, forever.

Cost considerations

Water treatment is often the most expensive ongoing post-closure activity at a reclaimed mine site and can easily cost millions of dollars

per year, but even relatively simple, low-cost care and maintenance activities, such as site inspections, data retrieval, cleaning diversion ditches or minor site regrading, can run tens of thousands of dollars per year depending on site conditions. Often a third party is retained to oversee the annual care and maintenance work, adding an additional layer of cost. So, even without a water treatment component, a site may require tens to hundreds of thousands of dollars in annual care and maintenance to ensure reclaimed facilities remain stable and function as intended during the post-closure period.

Financing such annual costs when they occur would likely be unsustainable for any length of time. Alternatively, taking advantage of the time value of money to create a trust account to finance the recurring out-year cost requirements can ensure funding will be available for ongoing future care and maintenance. When faced with an open-ended time frame, an interest-bearing account is likely the most cost-effective means to fund LTCM.

A simple example can illustrate the effectiveness of this concept. Assume an annual care and maintenance requirement of $50,000 and a discount rate of 3 percent. Running the calculation to a future date when the present value of the out-year annual expenditure drops below $1 yields a net present value (NPV) of $1.7 million. The point in time when this occurs is approximately 400 years in the future and is effectively the same as running the calculation as a perpetual fund calculation. Conversely, if one simply pays $50,000 per year and adjusts for inflation over this same time period, the total cash outflow would be $6.6 billion. Increase the annual care and maintenance to $500,000 and the NPV is $17.5 million, while the nondiscounted approach yields $322.7 billion. A one-time payment of $17.5 million is certainly a manageable sum for most mining companies to eliminate what otherwise would be a chronic drag on the balance sheet.

Assumptions about inflation, appropriate discount rates, annual cost requirements and unexpected site developments present challenges when forecasting far into the future. Using NPV is an imperfect tool precisely because of these uncertainties, but the alternative is to assume, wrongly, care and maintenance requirements will be short lived, and risk a crushing future financial burden.

The financial benefits of using a trust fund for a company should be evident, and it provides the regulator with more confidence than counting on a company's year in, year out financial wherewithal to fulfill its reclamation obligations. Some jurisdictions have developed additional incentives for companies to fund LTCM trusts. The Canadian province of Saskatchewan has developed a program where a company can establish a LTCM fund and relinquish the site to the management of the regulatory authority (Saskatchewan, 2009), an attractive proposition for a company wanting to remove this liability altogether from its balance sheet.

Closing remarks

In summary, what appears at times to be a company's singular focus on developing and operating a mine overlooks the significant financial liability a mining operation presents on the back end, a time when there is limited positive cash flow to offset reclamation costs. There is no expiration date on reclamation integrity, and mining companies should recognize their post-closure care and maintenance obligations may last far longer than they have currently planned for and, in some instances, may be a forever proposition. As the Moody's report highlighted, the AROs of mining companies are becoming an ever-increasing liability and could significantly handicap a company's financial viability. Finding a means to lighten this financial burden while ensuring a company's commitment to reclamation should be of interest to all parties. Funding future reclamation obligations in advance using trust funds is one approach that could provide a measure of relief. ■

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Management in the mining industry is not business as usual

by William Gleason, Editor

The mining industry is a unique space. It is one in which geologists and chemists can intersect with computer and data science professionals daily. The industry requires expertise in not just mining and metallurgical engineering, but also electrical, mechanical, environmental and more. It requires expertise in worker health and safety, behavioral science, finance and economics, as well as human resources management. The locations of mining operations are often in remote corners, and for underground activities, they are unlike anything else in the world.

The industry presents those who join it a wealth of opportunities, but often struggles to overcome incorrect perceptions of safety, labor and environmental standards, making it difficult to recruit and retain employees at a time of increased demand for mined materials.

Workforce management in mining

Global demand for mined materials, particularly critical minerals, is increasing along with the rise of artificial-intelligence (AI) data centers and a global energy transition away from traditional fuel sources. An uncertain geopolitical climate has increased trade tensions between the United States, China and Russia, which in turn has increased demand in the United States for secure supply chains of minerals for national defense. The U.S. government has increased funding and support for the mining industry, providing much-needed financial and legislative support to the industry. And private investors like JPMorgan Chase have followed with an influx of money into the industry. Despite this support, the industry is still struggling to find and retain its workforce.

According to data from the U.S. Bureau of Labor Statistics, the average miner is now over 45 years old, and fewer than one in 10 mining professionals are under 30. Meanwhile, universities have cut back on mining programs, and enrollment continues to fall. For companies operating in remote regions or across borders, the traditional pipelines that once fed technical talent are running dry. Automation of machines and operations will change the way work is done, making some tasks safer and more efficient, but AI and machine learning are far from being able to replace the mining workforce.

The workforce recruitment and retention challenges combined with the technical and operational challenges of the mining industry present unique challenges for the management of the mining industry. *Mining Engineering* spoke with representatives from three mining companies about these challenges — Hecla Mining, South32's Hermosa Mine and Quintana Resources — to get their insights into the state of workforce management in the mining industry.

Hecla Mining was established in 1891 and is the oldest silver company listed on the New York Stock Exchange. It is the largest U.S. and Canadian silver producer and a leading critical minerals producer in the United States. Its Lucky Friday Mine in Idaho has been in production for more than 80 years and is one of the top seven primary silver mines in the world. Sara Pickens, manager of talent and benefits at Hecla Mining Co. brings 25 years of experience in human resources, including eight in the mining industry. She has spent her career exploring what makes workplaces work, focusing on the intersection where the employee experience meets organizational strategy. Matt Blattman is vice president of technical services at Hecla Mining Co., based in Coeur d'Alene, ID. He leads a corporate technical team supporting Hecla's four operating mines and advanced greenfield and brownfield projects. Blattman specializes in mine planning, strategic optimization and automated design tools.

Photo courtesy of Hecla Mining

Many of Hecla's operations such as its Lucky Friday Mine in Idaho have been part of the local community for generations, offering lifetime careers to residents.

Quintana Resources is a metals and mining investment holding company with headquarters in Houston, TX that owns and operates mines globally on a selective basis, and provides flexible capital to producing or near-term producing mines in the global metals and mining industry. Xavier Ochoa, chief operating officer of Quintana, is a mining engineer with close to 30 years of broad professional, multidisciplinary experience in the precious metals and copper industries. Ochoa holds a B.Sc. in mining engineering from the University of Arizona, as well as various professional certifications. He is the chair of SME's Industry Workforce Strategic Committee.

South32 is a global mining and metals company, creating value by producing commodities that are used in many aspects of modern life. Its operations, development options and exploration programs are diversified by commodity and geography. Its Hermosa zinc and manganese project in Patagonia, AZ is a brownfield project that has the potential to be a globally significant producer of metals critical to a low-carbon future. Hermosa is being designed as South32's first "next-generation mine," using automation and technology to minimize the impact on the environment and be in line with South32's goal of achieving net-zero operational carbon emissions by 2050. Skylie Estep is a seasoned human resources leader, with more than 15 years of experience in the mining industry. As South32's director of human resources for the Americas, she plays a pivotal role in talent strategy, organizational development and workforce development supporting exploration and development projects.

These three companies represent a wide range of the U.S. mining industry. Hecla is a well-established company with deep roots in Idaho, South32 is paving its future in Arizona, and while the companies have different business models, some of their challenges are similar.

Recruitment and retention — where do the workers come from, and how to keep them?

When it comes to employee recruitment and retention, Estep noted South32 is challenged with teaching the community about the benefits

of a career in the industry that is much maligned. "Mining hasn't been a popular career choice for recent generations in the United States, and the human resources pipeline is dwindling," Estep said. "It is a question of numbers, especially as the industry starts to grow again, and there's no surprise when we say we need more bodies, more people entering the mining workforce across the country."

Hecla is at the other end of the spectrum with some of its operations being cornerstones of the communities in which they operate. Many of Hecla's operations such as the Lucky Friday Mine in Idaho have been part of the local community for generations, offering lifetime careers to residents, but these operations are also seeing a growing number of employees reach retirement age. Hecla faces many of the same challenges as one of the newest operations in the United States.

"Like many in our sector, we face a storm of workforce challenges: increasingly remote operations, an aging workforce and shifting employee expectations. A fundamental obstacle is the declining visibility of mining careers," Pickens and Blattman wrote. "With fewer university programs and lower enrollment, we face a growing awareness gap. Compounding this is the misconception that mining only needs engineers and geologists, when modern operations also rely on environmental scientists, chemists, data analysts, IT professionals, civil engineers and project managers, many of whom don't yet see mining as a viable career path."

Quintana faces a more nuanced struggle: keeping trained people in the face of intense local competition.

At its U.S. operations and in Mexico, the company experiences both extremes of the labor market. In its Texas corporate offices, access to talent is plentiful while at its mines, trained specialists are scarce. "At our corporate office, we have ample availability to attract talent of all ranges of experience," said Ochoa. "Retention is straightforward as it's leveraged by wages, cost of living, and comfort in our environment. Most of our retention problems lie with mining technical specialties that are in high demand."

Those challenges multiply at the mine level. "Finding workers comes down to location," Ochoa added. "People want shorter commutes and access to urban amenities. Retention becomes difficult when new operations nearby start up — we are often the closest source of trained staff."

At many of Hecla's operations, Pickens said retention is critical and the company offers a number of work-life balance opportunities to employees such as robust career development, cross-disciplinary mobility and meaningful advancement opportunities.

Photo courtesy of South32

South32 is focused on building a workforce from the local community for its Hermosa project in Patagonia, AZ and will be hiring 300 direct employees in the next 18 months.

"While long-lived operations, some with more than 40- to 80-year histories, offer job security rare in today's economy we also offer continuous training, professional certifications, and initiatives like Safety 365 to reinforce our investment in employees' growth and well-being," Pickens and Blattman wrote. "The key is creating an environment where people build careers, not just hold jobs."

As a new site that is not yet in full production, South32 is still focused on building a workforce from the local community, which has not had active mining for more than 70 years. "Our challenge is explaining the possibilities to the community. Communicating opportunities and getting everyone ready for what's to come. We will be hiring 300 direct employees in the next 18 months as we prepare for operations," said Estep. "In terms of retention, one thing we offer is the ability to develop a project from the ground up. We are approaching Hermosa's development and operation with creativity, out-of-the-box thinking and entrepreneurial spirit. To do this, we need the experience and expertise of miners who want to develop the next generation of miners. Those that bring their learnings, want to build a teaching, hands-on growth culture, leverage technology to support safer and cleaner operations and believe in minimizing environmental impacts while maximizing shared value for communities."

Creating a pipeline

Education partnerships have become one of the most effective tools for building a sustainable

Photo courtesy of South32

The Hermosa project is being designed as South32's first "next-generation mine," using automation and technology to minimize environmental impact.

workforce pipeline.

Hecla has taken an active role in this space. "We are proud of the strong relationships we've built with our educational partners," said Pickens. "A standout example is our partnership with Alaska's Mining and Petroleum Training Service (MAPTS) at Greens Creek, where we've sponsored 23 participants — all of whom graduated with job offers." Hecla also contributes to scholarships, curriculum development and internship programs that often lead directly to full-time positions.

South32 has pursued similar partnerships through formal memoranda of understanding with both the University of Arizona and the Santa Cruz County Provisional Community College District. "Our first collaboration is the county's first electrician certificate program," said Estep. "We're providing full scholarships for 16 students and investing more than $440,000 in the program. This will serve as a blueprint for future skilled trades training in the region."

Quintana is taking a more localized approach, offering short-term shadow work for high school students and co-op employment for college students. "We support local colleges and universities through applied research and lab work," the company explained. "If students take on mining degrees, we give them co-op priority when the time comes."

A changing workforce

Every industry and profession is learning to adapt to the emergence of artificial intelligence. For the mining industry, Hecla and South32 are embracing the rapidly coming changes.

South32 sits at the leading edge. Hermosa is being built to integrate automation and remote operation from day one. "A common misconception is that AI will replace employees, but that's simply not the case," said Estep. "AI is an enabler for better performance — it's 'augmented intelligence.' Our workforce will learn new skills and talents to leverage AI. It's not fewer employees — it's different skill sets. Because Hermosa is under construction, we don't need to retrofit. We can build digitalization into every role profile from the start."

Hecla's approach to digital transformation focuses on upskilling and mentorship. "We pair experienced operators with digital natives to create two-way mentorship," the company said. "By involving employees in technology selection, we ensure efficiency gains translate into safer, more rewarding work — not job loss."

"AI and automation are transforming mining into a technology-driven industry, though not as radically as headlines might suggest," Blattman said. "These tools enhance human decision-making rather than replace it." Predictive maintenance, machine learning for ore recovery, and automated drilling all rely on human oversight. "The shift isn't about fewer jobs but different ones. Operators become system managers; data collectors become analysts," Blattman added.

Ochoa said Quintana is at an earlier stage of this transition. "So far, AI hasn't had any effect on our operations. In the corporate office, we are using it for document drafting and summarizing, though accuracy remains a concern. Some professionals are starting to self-impose the need to learn about AI applications, but it's not yet a pressing issue."

The road ahead

There are no clear or easy solutions to the workforce challenges. The Mining Industry Human Resources Council projects that more than 79,000 mining workers will need to be hired across North America by 2030 just to maintain current production levels. At the same time, the global energy transition will push demand for critical minerals to record highs.

In that context, the strategies emerging today — early education, local employment, digital upskilling and holistic safety — are not just responses to immediate shortages. They represent the foundation of a new social contract between mining companies, their workers and their communities.

Mining's next generation will be more diverse, data literate and community rooted than any before it. For companies willing to invest in people as deeply as they invest in technology, the payoff will be a workforce ready not just to operate the mines of the future — but to define them. ■

Mining's next frontier:
Perspectives and transformations

by Sandra Nowosad, Sakshi Hazuria Anderson, Angela Binder, Simit Raval and Oscar Jaime Restrepo Baena

As the mining industry faces times of change, new challenges arise to ensure raw material supply for future generations. Different scenarios are currently shaping the way we mine and teach mining engineering. Led by an increasing demand for raw materials, net-zero requirements for improving long-term operation performance, technological advancements such as automation and digitalization, safety improvements, environmental considerations and a need for social acceptance, mining is pursuing to change and adapt to these requirements at a faster pace.

Such changing times raise new concerns, one of the most relevant is the lower number of students interested or enrolling in mining engineering and related fields, leaving mining engineering as one of the less preferred career options for students. Nonetheless, it is essential to continue addressing and supplying the skill sets that are suited to the contemporary and future mining industry. To this end, globally, academia is currently undergoing several initiatives such as curricula updates and adaptation, upskilling, improving teaching practices and techniques, including e-learning techniques, enhancing industry-academia and inter-university collaboration, and much more.

In countries like Australia, where mining plays a crucial role in the economy, the need for curriculum updates is more pressing than ever. As the mining industry evolves with new technologies and sustainable practices, there is a growing demand for a workforce skilled in these modern approaches. Recognizing this necessity, universities such as the University of New South Wales and Curtin University have taken significant steps to revamp their educational programs. By updating their academic offerings, both universities aim to equip graduates with the necessary skills to drive innovation and sustainability in mining, supporting Australia's development as a leader in this critical sector.

Moreover, the selection of topics that drive curricula update and the focus of the research institutions in mining engineering must extend beyond mere technological and technical aspects to include social and ethical dimensions. In this context, the Universidad Nacional de Colombia, in association with the Colorado School of Mines, has introduced the topic of humanitarian engineering (HE) in 2020. HE is a sociotechnical approach that focuses on developing engineering solutions that promote the sustainable development of communities addressing their basic needs and aiming to improve their quality of life (Menéndez-Aguado et al., 2023; Smith et al., 2023). By focusing on sustainable development, community engagement and equitable resource distribution, HE helps the industry build positive relationships with stakeholders, reduce conflicts and foster social license to operate. As the mining industry seeks sustainable and socially responsible practices, future engineers require training in this area to understand the broader impacts of their work, fostering a mindset that prioritizes community well-being and environmental stewardship alongside technical proficiency.

However, developing skills toward humanitarian engineering and sustainable mining among new generations of mining professionals remains a complex task. Integrating the necessary content to prepare future engineers for the multifaceted demands of the industry into a single study program poses significant challenges. To address these complexities, modern educational approaches such as the ones integrated in the mining engineering programs at Clausthal University of Technology can be leveraged to enhance both teaching and learning experiences (Binder, 2024b; Bothe-Fiekert et al., 2023; Nowosad et al., 2024). Innovative teaching methods, such as blended-learning, project-based learning, case studies, scenario simulations and interdisciplinary collaborations, can help bridge gaps by fostering critical thinking, creativity and empathy among students. By embracing modern pedagogical strategies, institutions can better equip future engineers to navigate the evolving landscape of the mining industry responsibly and effectively.

Emerging trends in mining engineering education

The COVID-19 pandemic served as a catalyst for accelerated digitalization across various sectors, including mining, boosting industries to adopt technological solutions at an

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unprecedented pace. In response to disruptions caused by restrictions and safety measurements, the mining sector embraced digital tools and automation to ensure operational continuity while prioritizing the health and safety of workers. Furthermore, while contemporary mining faces a rising demand for both primary and secondary extraction of raw materials, specially driven by the need for critical minerals to achieve a just energy transition, this demand exists in tension with environmental and social concerns. Modern mining operations aim to adopt cleaner technologies and embrace more responsible practices, striving to find a balance where the pursuit of critical minerals coexists harmoniously with environmental, social and governance stewardship.

However, despite these efforts, accessing resources and bringing mines into operation has become increasingly challenging. According to a report by S&P Global, it now takes approximately 18 years for mines to progress from the initial discovery phase to begin operations (Manaldo, 2024). This extended timeline is influenced by a variety of factors, including regulatory complexities, environmental considerations, and the need for substantial technological and financial resources. At the same time, geological orebodies are increasing in complexity and depth. Mining companies are compelled to explore deeper deposits and assess extraction based on more sustainable processes, often leading to a shift from surface mining to more complex underground operations. This trend is reflected in an analysis of more than 1,000 mining projects globally, which shows that about 150 of these projects are transitioning, or have already transitioned, from surface to underground operations (Nowosad and Langefeld, 2023). This shift brings multiple technical challenges, including ensuring productivity and safety in operations, managing ventilation and dealing with issues related to seismicity, ground control and geomechanics. Additionally, there is a critical need for innovation in areas such as tailings management, advanced extractive technologies and efficient mine closure processes. Moreover, the industry's future relies on integrating automation, electrification and digitalization into mining practices, which also necessitates embracing new business models. These complexities highlight the urgent need to engage a younger, more agile and environmentally conscious workforce capable of navigating the technical and strategic challenges that lie ahead.

Addressing these future perspectives in mining engineering education involves anticipating and integrating the skills and knowledge that the next generation of professionals require to navigate an evolving mining industry. One of the primary challenges lies in balancing the traditional core aspects of mining engineering with emerging areas such as sustainability, digital technologies and social responsibility. Educators play a crucial role in this process, acting as both guides and innovators. They need to be adaptable, resilient and committed to lifelong learning. By prioritizing mentorship, collaboration and continuous learning, educational institutions can prepare students not only to address current industry challenges but also to anticipate and innovate for future ones. Engaging with industry partners and leveraging international networks like the Society of Mining Professors (SOMP) can provide valuable resources and insights, ensuring that the next generation of engineers is well equipped to lead the mining sector toward a sustainable and technologically advanced future. By bringing together global experts, SOMP facilitates the sharing of diverse insights and resources, fostering a collaborative environment that helps academics involved with mining engineering education to improve their programs. This global network helps break down academic silos, ensuring that educational strategies are well rounded and incorporating international best practices. One of its significant contributions was the development of the SOMP "Mines of the Future" white paper. This report outlines strategic insights and recommendations for addressing future challenges in mining and reflects the organization's commitment toward a sustainable future. Since the white paper was published in 2019, the world has seen a changing environment; however, the principles and the vision for future mines based on five main topics — operational efficiency, novel mining systems, sustainable mining practices, education, and research — instead of becoming obsolete are today more valid and relevant than ever (Saydam et al., 2019).

Acknowledging the need to address these challenges and benefiting from the active participation of academic representatives, SOMP developed different activities. Specifically, in the last three years, different workshops have taken place with the objective of identifying emerging topics in mining engineering education and discussing the competencies and the profile of the mining engineer of the future. These efforts led to the identification of the top five emerging topics that have gained relevance in the period 2022-2024 (Fig. 1). In 2022, the top emerging topics included automation,

artificial intelligence, entrepreneurship, diversity and digitalization, reflecting a push toward technological advancement and inclusivity. In 2023, the focus shifted to sustainability, innovation, systems thinking, intergenerational equity and communication, highlighting the importance of sustainable practices and holistic approaches. Meanwhile, in 2024, the emphasis was placed on artificial intelligence, mine closure, sustainable mining, leadership and zero-entry mining, indicating a strong orientation toward responsible management, leadership development, and the integration of cutting-edge technologies in mining operations. This evolving landscape of topics underscores the dynamic nature of the mining industry and highlights the multifaceted skill set required for future mining engineers. As the industry evolves, it is clear that a comprehensive approach, integrating technological innovation with sustainable and ethical practices, will be crucial.

In 2023, a workshop was conducted to pinpoint the technical and interpersonal skills needed to drive transformation in the mining industry. During this workshop, discussions highlighted five key technical skills: environmental awareness, comprehensive technical expertise in mining, programming, project management, and smart data and big data management. On the interpersonal front, the top competencies identified were communication, leadership, social awareness, emotional intelligence and community engagement. These insights supported a joint description of the mining engineer of the future. This professional is envisioned as a driven individual and a competent engineer with curiosity and creativity who applies general technical mining skills in a globalized world, who fully understands the mineral value chain and its relevance for modern life, and who can work in a multidisciplinary team environment with the major goal of enhancing and driving the sustainable extraction of raw materials for future generations.

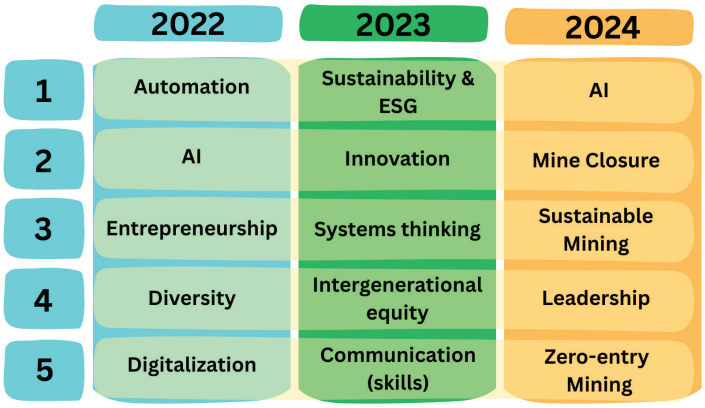
Moreover, these insights have enabled the identification of four streams that are redefining mining engineering education: artificial intelligence, sustainability and ESG, future technologies and generational shifts.

Artificial intelligence. The integration of artificial intelligence (AI) — namely, generative AI — emerges as a key focus, transforming student engagement and content delivery, yet this enthusiasm is often tempered by the need for rigorous analysis and ethical considerations. In higher education, the use of AI can support the development of collaborative content and projects; however, its use by students and academics brings its own set of concerns, particularly around academic integrity and possible impact on the learning process. This paradigm has led to higher institutions having different perspectives toward the use and implementation of AI. Depending on the accessibility to technological infrastructure and resources, some institutions embrace the integration of AI in teaching and learning, as well as into their administrative processes. Conversely, other institutions approach AI adoption with a more cautious perspective. Developing student facilities with AI must include an understanding not only of the underlying data structure and data management practices, but also specific applicability and limitations of AI. For instance, gathering, synthesis and analysis of geological data and how it can be leveraged by AI-guided mineral exploration (BHP, 2024). Algorithms developed on specifically formatted data designed for use in this application will "learn" over time through refinement and human inputs. This refinement process is critical to improving the accuracy and usability of the tool. This implies a continuing need to interact with the autonomously generated data to ensure the conclusions drawn are appropriate. While introducing students to the potential offered by AI, academics also have to train them on the limitations of the technology. Critical evaluation skills have to go hand in hand with the use of these technologies to ensure outputs correctly reflect and interpret the underlying data, and students learn to quantify and qualify the conclusions they draw from these tools.

Generative AI (gen-AI) is one of the most diverse tools in the AI arsenal. It presents an ongoing challenge for academics as they work to find the optimal balance between educating students on the current and future applications of AI and the threat it presents to academic integrity. Mining engineering curricula have been adapted in recent years to include

Figure 1

Top five emerging topics in mining engineering education.



industry application of gen-AI in areas such as mine planning, operational optimization, scheduling maintenance, slope stability and failure prediction models, and mine automation. Well-defined policies on the appropriate use of gen-AI have simultaneously been developed to ensure students are aware of the permissibility of the use and limits of these technologies. Curtin University's position on gen-AI use by students in academic submissions starts from the point of nonpermissibility. Permissions required for use of and specific uses of AI tools like ChatGPT, Microsoft Copilot and Gemini are well understood by students. Other software like Quilbot and Grammarly are often viewed as facilitating tools, and the changes they suggest to the composition of assessments, while also indicating nonoriginal student work, are often not seen as violating AI use rules. In any case, explicit unit coordinator approval and source attribution, often in the form of a declaration of the use of gen-AI, is required. An unappropriated use can lead to cases of academic misconduct lodged against students and depending on the severity of the offence, can present significant penalties for them. Students and academics must stay on top of this evolving landscape and stay informed about recent developments in both the technology and its appropriate use so that they adequately prepare students for the workforce.

Furthermore, concerns about cost, infrastructure and the readiness of both faculty and students to adapt to such technological changes contribute to a more hesitant stance. Meanwhile, the industry perspective is often driven by the immediate potential for AI to enhance efficiency, safety and profitability in mining operations. Moreover, considering the increasing demand on technological literacy required and the accelerated adoption from the side of the industry, the partial or improper development and implementation of AI skills in teaching and learning could exacerbate inequalities and an educational divide.

Sustainability and ESG. Sustainability and environmental, social and governance (ESG) considerations take center stage, reflecting the industry's shift toward responsible and ethical resource management. This involves integrating broader concepts such as HE, circular economy, sustainable mining and ESG stewardship into the curriculum (Rua et al., 2020; Hutwalker et al., 2021; Restrepo Baena, 2024). The first prioritizes community well-being and socioeconomic impacts, encouraging students to consider how mining operations affect local communities and to design projects that foster positive social outcomes. Similarly, the principles of sustainable mining emphasize the reduction of environmental footprints, enhancing resource efficiency and ensuring long-term environmental balance. Furthermore, integrating this along with fostering ESG stewardship in mining engineering education prepares engineers to handle challenges such as the impacts of climate change, resource scarcity and social equity, ensuring they can make informed decisions that align with global sustainability goals.

Future technologies. The advancement of future technologies represents the third stream, highlighting the need for innovation in extraction methods and the adoption of cutting-edge technology such as digitalization and automation to enhance efficiency and safety at the workplace. As these technologies become more integral to mining, they require the development of a multifaceted skill set that integrates technical expertise with a deep understanding of advanced systems and data analytics, and mining engineering education must evolve to include comprehensive training on these technologies. To achieve this, stronger industry-academia collaboration is required. This collaboration can enable educational institutions to facilitate practical learning experiences that will prepare students for technologically advanced mining environments. Moreover, the adoption of future technologies in mining demands not only technical acumen but also skills in communication, problem-solving and systems thinking. Engineers must be adept at working in multidisciplinary teams, where they can leverage diverse perspectives to innovate and solve complex challenges. As the industry continues to advance, equipping future engineers with these comprehensive skills will be crucial, positioning them to lead the way in implementing safe and efficient mining practices that leverage the full potential of automation and digital technologies.

Generational shift. Lastly, addressing generational shifts becomes essential, as education must adapt to the evolving expectations and values of a new workforce eager to contribute to sustainable and technologically advanced mining practices. Today's learners, often characterized by their digital nativity and propensity for rapid information consumption, require innovative delivery methods that resonate with their learning preferences. They anticipate interactive and adaptable learning experiences that go beyond traditional lectures and textbooks.

Instead, there is a need for dynamic, multimedia-rich content that leverages technology in the classroom. This adjustment of teaching methods and materials particularly considers the shortening of attention spans and aims for greater effectiveness. A proven way to respond to individuality and diversity is to design more agile methods that shift from traditional frontal instruction to blended and flipped classrooms. Students can engage with (digital) learning material at their own pace, while classroom in-person time can be focused to develop problem-solving and collaborative learning. Furthermore, acknowledging the generational differences between students and educators presents not only a challenge but also an opportunity for mutual benefit by embracing this generational shift. Recognizing that students bring diverse values, perspectives and skills to the table enhances the educational experience for everyone involved. Engaging with these varied viewpoints enriches the learning environment and fosters a culture of inclusivity and innovation, ultimately benefiting both students and educators.

Regional approaches and initiatives

The four identified streams — artificial intelligence, sustainability and ESG, future technologies, and generational shifts — are vital for shaping the future of mining engineering education. Recognizing and defining these streams is only the beginning; driving action towards their integration is essential to support the transformation of mining. This section highlights the regional initiatives and proactive steps taken by four universities represented by the authors in pursuing the integration of these streams into their educational frameworks: Australia, Colombia and Germany. Through these initiatives the universities are not only adapting their mining engineering programs to be more aligned with current and future industry needs but are also paving the way for innovative practices that inspire global standards, ensuring their students become adaptable and forward-thinking leaders in the mining sector.

Australia. Australia is not only a mining powerhouse but also a global leader in mining education, hosting two universities ranked among the world's top five for mineral and mining engineering in the QS World University Ranking 2025. Institutions such as the University of New South Wales (UNSW, ranked second), Curtin University (ranked third) are internationally recognized for pioneering research and education. Specially, Curtin University's Western Australian School of Mines (WASM) is constantly adapting its curriculum in response to rapid changes integrating emerging technologies, sustainability and ESG expectations, as well as contemporary student perspectives and expectations. Unlike other mining schools, student enrolments at WASM have followed an upward trend since 2020 in both undergraduate and graduate programs. Regarding the identified emerging topics, AI, sustainability and emerging technologies are addressed throughout the wide variety of units and embedded across both programs. Students undertaking final-year research projects already engage with themes such as advanced algorithms, AI, mine surveying, earth observation, machine learning, advanced rock mechanics, automation and electrification. Moreover, the undergraduate degree offers the "Mine Automation and New Technologies" unit. Leveraging the campus location in Kalgoorlie and proximity to mining operations, this unit has, over its last three editions, achieved a high percentage of industry participation enabling students to learn directly from the innovators, developers and technology integrators. Industry engagement is further enhanced for all students during strategically planned "Work Integrated Learning" weeks in each semester, featuring specialized workshops, site visits, software training or expert presentations on campus. Modern pedagogical approaches are also widely implemented, including flipped classrooms, project-based learning, real-world applications, capstone projects and blended learning. To better address student perspectives, in 2025, WASM conducted separated student feedback sessions with mining engineering students and industry advisors. The student sessions provided a safe and open venue to share feedback on content delivery, unit content and structure to the academic team. These initiatives demonstrate WASM's commitment to continuous improvement and excellence, as well as alignment with the evolving needs of both students and the mining industry. By continually refining its curriculum and engaging with industry, WASM ensures that graduates are equipped with relevant, future-focused skills. This approach reinforces Australia's position as a global leader in mining engineering education and innovation.

Furthermore, UNSW has worked in recent years to integrates all emerging topics into its curriculum. A new set of stream learning outcomes has been developed to clearly define the capabilities and attributes expected of graduates, emerging technologies are now emphasized across all topic areas in their

curriculum, reinforcing the importance of innovation and digital literacy. At the same time, the program maintains and expands its strong focus on safety, risk management, social responsibility and sustainability. Furthermore, geology content has been expanded in the first and second years, increasing the unit load and deepening students' understanding of mine site geology and its integration with mine planning and operations. To further support specialization in modern and sustainable mining practices, four new electives have been introduced, including technology management in mining; data analytics and automated technologies for minerals and energy resources; space resources engineering; and sustainable tailings management.

These curriculum developments and improvements collectively ensure that graduates from Australian universities are equipped to lead in a sector shaped by technological advancement and sustainability stewardship.

Colombia. The Mining and Metallurgy Engineering (MME) program of the School of Mines at the Universidad Nacional de Colombia is proactively integrating AI into its curriculum and research efforts to prepare students for the technological demands of the mining industry. The program emphasizes the use of AI-driven tools for data analysis, predictive modeling and process optimization, particularly in areas such as resource estimation and operational safety. The integration of Future Technologies is driven by partnerships with leading companies like Epiroc and Stracon through industry-led academic initiatives such as Cátedras Empresariales. Faculty members collaborate with the industry partners to develop real-world applications of AI, while also addressing concerns about ethical implementation and the digital divide. These collaborations provide students with hands-on experience in applying AI tools for automation, operational efficiency and safety in mining projects across Colombia. Furthermore, workshops and courses on machine learning and big data equip students with the skills to navigate a rapidly digitalizing mining sector.

Sustainability and ESG are central to the program's philosophy, reflecting the global demand for socially responsible and environmentally conscious mining practices. The program integrates circular economy and HE principles to ensure that students understand the sociotechnical dimensions of mining, particularly in engaging with communities and addressing equitable resource distribution (Restrepo Baena, 2024). In this framework, practical coursework is conducted in collaboration with Virginia Tech, the Colorado School of Mines and Universidad de Chile as well as joint projects that are focused on reducing environmental footprints, improving resource efficiency and fostering sustainable mine closure practices. Furthermore, other initiatives conducted in relation to HE has involved extensive collaboration with other international institutions such as the Colorado School of Mines, the Massachusetts Institute of Technology's D-Lab and Southern Methodist University. These initiatives have focused efforts on empowering artisanal and small-scale mining communities in Colombia, with particular emphasis on supporting female miners (Gibson et al., 2022; Restrepo Baena and Velilla, 2021; Schwartz et al., 2021; Tarra-Almario and Restrepo, 2021; Veiga et al., 2022). Students are trained to work alongside these communities, codeveloping sustainable mining practices that prioritize community well-being, equitable resource distribution and environmental protection. Through these projects, the program not only enhances the students' sociotechnical skills but also fosters a mindset of inclusivity and ethical responsibility essential for the future of mining engineering. These efforts aim to prepare engineers who prioritize both technical excellence and the well-being of communities impacted by mining.

Recognizing the rapid generational shift and the importance of future technologies, the program adopts innovative teaching methods to resonate with the learning preferences of today's students. It incorporates flipped classrooms, project-based learning and interdisciplinary collaborations, allowing students to engage with content interactively. Furthermore, the MME program at the Colorado School of Mines actively partners with industry to expose students to cutting-edge technologies such as automation, electrification and digitalization in mining operations. These strategies not only bridge generational gaps but also prepare students to lead the industry in implementing sustainable and technologically advanced practices.

Germany. As a representative example of the situation in Germany, without the claim to completeness or generalizability, the circumstances relating to the four identified trends are described in relation to the mining engineering program at Clausthal University of Technology (CUT).

In the context of AI, two main areas to be addressed in the mining engineering program emerge: the integration of AI as a future technology in mining, and the use of AI as a tool for everyday tasks. To prepare students

effectively, it is essential to expand their skill sets in this direction along with a reflective approach to AI utilization. One successful initiative integrated at CUT is the "ChatGPT and Brain Hand-in-Hand" workshop, co-developed and conducted by the Mining Institute, the Language Center and the Writing Workshop of CUT. This workshop encourages students to engage thoughtfully with AI technologies and enhances their research and writing capabilities. The guidelines on academic writing introduced in this workshop incorporate AI as a tool and promote a reflective use empowering students to expand their capabilities (Binder, 2024a). In this field, the university offers various AI services, especially in the field of large language models (LLMs), to ensure equal access for students and educators. These services are continuously evaluated and expanded to meet the needs of a modern academic community. Additionally, different literature management tools are currently being tested, with plans for university-wide licensing. To provide an overview of AI's potential, a digital event series was conducted during the summer term of 2024, showcasing the available AI services, research possibilities, AI-based course design, and support for the writing process. This initiative aims to familiarize educators and students with the multifaceted possibilities of AI, promoting its thoughtful and productive application in education and research. Educators from the field of mining actively supported these initiatives, cocreated pilot activities and frequently contributed their perspectives to the board of service providers.

At CUT, extensive efforts have been undertaken to integrate sustainability and ESG principles into the mining engineering curriculum based on a hybrid approach that differentiates four key integration possibilities (Binder et al., 2018; Hutwalker et al., 2021). The university's overarching theme of circular economy has also been integrated and is part of various aspects of the program. Special events focusing on sustainable mining practices and responsible mining operations are organized, emphasizing a competency-based approach. Significant attention is placed on developing communication skills tailored to diverse target audiences, ensuring that students can effectively engage with various stakeholders in the mining sector as in the case of the "sustainable mining" unit. Furthermore, one notable initiative is the implementation of the "Blue Mining" approach, which is applied specifically in the underground mining department (Nowosad et al., 2023). This strategy equips students with a holistic model for sustainable mining practices, preparing them to address contemporary challenges while promoting environmentally and socially responsible methods in the field. Other notable initiatives were the integration of the "mine closure" and "underground water management and treatment" elective units as part of the ME master's program (Bothe-Fiekert et al., 2023). Through these efforts, CUT is committed to fostering a forward-thinking educational environment that prioritizes sustainability and ESG considerations in mining.

Incorporating a competency-based approach, CUT emphasizes principles over individual techniques within its curriculum related to future technologies. The goal is to help students develop a systemic understanding that enables them to engage with evolving technologies and their integration into the mining industry (Binder, 2024b). At a technical level, the "IoT and Digitalization for the Circular Economy" module exemplifies this integration, alongside the incorporation of real-world applications within various sessions (Nowosad, 2024). Another area of relevance and development is mine automation. Educational institutions play a critical role in preparing the future workforce for success in an increasingly automated mining industry. To do this effectively, curricula must adapt to include subjects such as data science, systems engineering and automation technologies, equipping students with the necessary multiple skills required to work with and manage autonomous systems. Additionally, student research projects and theses often focus on emerging technologies and sustainable matters, further emphasizing their importance in contemporary education. Moreover, both units feature continuous industry engagement through guest lectures and case studies. Fostering partnerships with industry stakeholders is essential, ensuring that the next generation of mining experts is ready to meet the demands of a rapidly evolving sector. Through these strategic educational initiatives, CUT aims to cultivate a workforce that is adept at navigating and leveraging future technologies in mining in a sustainable way.

CUT currently experiences a significant generational diversity among its students and faculty. While Ph.D. students and postdoctoral researchers may be only one generation apart from the students, the gap is much larger in traditional mining and processing disciplines, with five professors approaching retirement. This creates a pronounced generational divide, reflecting a higher potential for conflicts as well as opportunities to learn. Moreover, the diversity within student cohorts extends due to different

educational pathways, encompassing a range of experiences, learning preferences, obligations and values. To address these differences and embrace this diversity, CUT has implemented various initiatives that blend individual self-learning phases with project-based learning, alongside traditional teaching methods.

However, structured measures specifically targeting generational differences have not yet been established and are not a focus area of the university's diversity strategy. Nevertheless, efforts such as the workshop during the SOMP's 33rd Annual General Meeting on the "Clash of Generation" have contributed to raising awareness of these issues.

Outlook

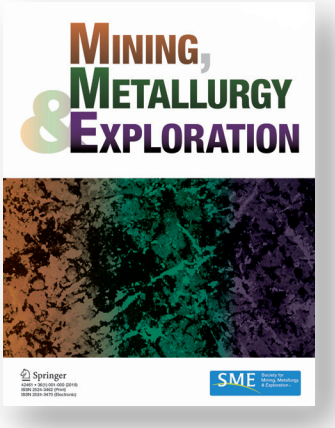
The future of mining engineering education is shaped by integrating sustainability, advanced technologies and acknowledging generational shifts into the academic programs. A focus on sustainability and ESG fosters the development of socially responsible and environmentally conscious mining practices. Initiatives in humanitarian engineering emphasize equitable resource distribution and community well-being, equipping students to address the sociotechnical challenges of the industry. Advancements in future technologies, including AI, automation and digitalization, are transforming mining operations. By partnering with industry leaders, universities prepare students with the skills necessary to navigate these changes, emphasizing interdisciplinary collaboration, data analytics and systems thinking. Furthermore, the ongoing generational shift demands modern ways of teaching and innovative teaching approaches, such as flipped classrooms and project-based learning, which cater to diverse learning preferences and values. Universities like Curtin University, UNSW, Universidad Nacional de Colombia and Clausthal University of Technology exemplify these efforts. In Australia, the integration of modern technologies and industry engagement maintain mining engineering curricula up to date, while a spirit of continuous improvement drives the development and continuous modernization of mining engineering units preparing students for a competitive career in mining. In Colombia, partnerships with industry and global institutions drive hands-on AI and sustainability projects, while in Germany, initiatives like the "Blue Mining" approach and workshops on AI usage highlight a commitment to responsible resource management.

Collaboration, especially through networks like the SOMP, plays a crucial role in driving these transformations, uniting academia, industry and global stakeholders to achieve the necessary systemic changes. As these trends converge, mining education is poised to produce forward-thinking engineers equipped to lead sustainable, technologically advanced and socially equitable mining practices, setting global benchmarks for the industry. *(References available from the authors.)* ■

Acknowledgments

The authors would like to express our sincere gratitude to all the members of the Education Committee of the Society of Mining Professors (SOMP) for their invaluable contributions, dedication and leadership in advancing the field of mining engineering education. Special thanks go to all SOMP members who actively participated in the workshops over the past three years. Their insights, expertise, and collaborative spirit have been instrumental in identifying and framing the key future trends for mining engineering education presented in this work. *(The 2026 SOMP Annual General Meeting will be held in Blacksburg, VA, USA, hosted by current president Emily Sarver of Virginia Tech.)*

Extended abstracts from the SME journal Mining, Metallurgy & Exploration



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Invited Extended Abstracts

Mine planning optimization under circular reference loop characteristics: A workflow combining grid search and mixed integer programming

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Full-text paper:
Mining, Metallurgy & Exploration (2025) 42:2903–2922, https://doi.org/10.1007/s42461-025-01346-6

Keywords: Openpit mine planning, Grid search, Mixed integer programming, Economies of scale, Capacity planning, Block sequencing

Mine planning traditionally involves three critical subproblems that are typically solved sequentially: capacity planning (selecting maximum possible production rates), cut-off grade selection (deciding material destinations), and block sequencing (determining extraction order). However, these decisions are fundamentally interdependent, creating circular reference loops where each decision influences the others. This interdependency means that combining individually optimal solutions cannot guarantee overall optimization, yet current approaches fail to address these relationships adequately. This study presents a comprehensive workflow that simultaneously optimizes these three interdependent subproblems using mixed integer programming (MIP) combined with grid search methodology. The approach leverages cost-capacity relationships derived from the historical data of similar mining projects to develop empirical models representing economies of scale (EoS) effects on mining costs, processing costs, capital recovery and metal recovery parameters.

Background and methods

The historic data of selected mining projects were extracted from their NI 43-101 reports, which provide standardized technical documentation. The selection of six NI 43-101 projects as reference cases was based on multiple operational characteristics to ensure comparability and reliability of the derived cost functions. The selection criteria included geographical region (specifically, Canadian operations), commodity type (gold), mining method (openpit operations), deposit characteristics, regulatory environment and operational scale. These criteria were designed to minimize variations in external factors that could confound the cost-capacity relationships, such as different regulatory

frameworks, labor market conditions and infrastructure availability.

Based on the cost and metal recovery functions derived from the historical data, a mine planning model was then developed to optimize block sequencing and material destination decisions for given operational capacities. While the original intention was to develop a model that could concurrently optimize all three subproblems — block sequencing, capacity planning and cut-off grade selection — the inherent interdependencies among these variables create complex nonlinear relationships, resulting in a nonlinear programming problem that would be computationally intensive to solve.

To address this complexity, a two-stage approach was adopted. In the first stage, the model assumes predetermined mining and processing capacities, allowing for the simultaneous optimization of block sequencing and cut-off grade decisions within these capacity constraints. A systematic grid search method efficiently explores the solution space to determine optimal capacity configurations, while MIP optimizes block sequencing and material destinations for each capacity scenario.

The grid search method evaluates various capacity configurations to identify the option that yields the highest net present value (NPV). Each capacity configuration is evaluated through the optimization model, allowing for a comprehensive comparison of potential operational scenarios. The systematic nature of the grid search ensures that a wide range of capacity combinations is considered, while the simultaneous optimization of block sequencing and destination selection for each configuration ensures that the evaluation accurately reflects the operational potential of each scenario. This methodological framework mitigates computational complexity while ensuring the identification of optimal operational parameters through a structured evaluation process, effectively balancing computational efficiency with optimization accuracy. The grid search represents a systematic approach to optimization by dividing a search area into equally sized grids and evaluating each grid point to find the optimal solution. This methodology consists of three main steps: (1) defining an appropriate search area within the grid space, (2) calculating objective values for each selected grid point and (3) identifying the optimal grid point based on the computed objective values.

Using the operational data collected from the NI 43-101 reports of the six mining projects, published between 2018 and 2023, regression analyses were performed to establish cost and recovery functions, as illustrated in Fig. 1a-d.

These empirically derived functions formed the foundation for the subsequent optimization process. The functions capture the relationships between operational scale and various cost components, as well as the impact of capacity on metal recovery rates. The block sequencing model was then solved through the application of a grid search method, requiring 33 distinct iterations to identify the optimal combination of capacity configuration, block sequencing and material destination decisions. Each iteration represented a unique combination of mining and processing capacities, systematically exploring the solution space to find the configuration that maximizes project value. The optimization process was executed using AMPL submitted to the IBM ILOG CPLEX solver.

The grid search optimization process began with a systematic division of the capacity configuration search area into equal grids. The initial phase of optimization involved the selection of four distinct values for both mining and processing capacities, with these values chosen based on the reserve characteristics.

Discussion

For mining operations, the selected capacities ranged from 4.5 to 60 Mtpa, with specific values of 4.5, 23, 41.5 and 60 Mtpa. Similarly, the mineral processing capacities were selected to range from 2.5 to 30 Mtpa, with specific values of approximately 2.5, 11.7, 20.9 and 30 Mtpa. These capacity ranges were chosen to explore a wide spectrum of operational scales while maintaining practical feasibility. The case study successfully identified an optimal configuration of 20.79 Mtpa mining capacity and 15 Mtpa processing capacity. The results reveal that processing capacity has a more significant impact on project value than mining capacity, highlighting the critical importance of balanced capacity planning for both mining and mineral processing operations. This integrated optimization approach provides mining operators with a more robust decision-making framework that properly accounts for the complex interdependencies of operational parameters, leading to improved project economics compared to traditional sequential optimization methods.

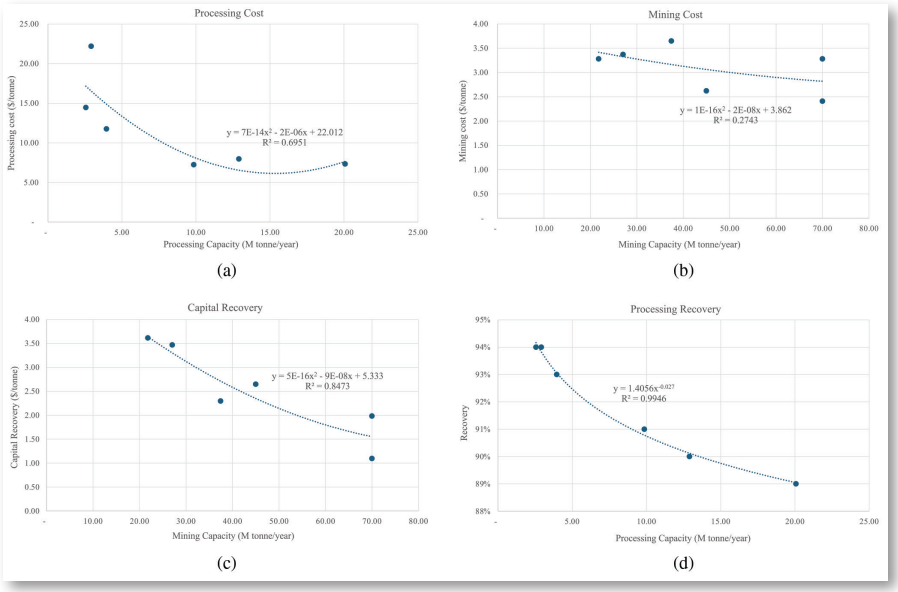

Fig. 1 (a) Processing capacity: processing cost data set and fitted function. (b) Mining capacity: mining cost data set and fitted function. (c) Mining capacity: capital recovery data set and fitted function. (d) Processing capacity: metal recovery data set and fitted function.

Conclusion

Mine planning shows circular reference loop characteristics that require solving subproblems concurrently. This research takes a step toward a concurrent solution despite computational limitations. The results highlight the critical importance of balanced capacity planning between mining and mineral processing operations. Rather than maximizing individual capacities in isolation, the optimal solution emerges from a careful balance between mining and mineral processing capacities.

The analysis shows that changing mineral processing capacity has a greater impact on the project value, though any adjustments of mineral processing capacity must be accompanied by corresponding changes in mining capacity to maintain operational efficiency.

Future research can present several promising directions to extend the framework of this study. First, future research should incorporate stochastic optimization techniques that explicitly account for uncertainties in commodity prices, discount rates and geological parameters, as the interaction effects between these uncertainties may lead to significantly different optimal capacity configurations than those identified through deterministic approaches. ■

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

Collection on Extraction of Critical Materials and Battery Metals

Enhanced flotation of various Au-Cu-Ag ores using zinc/arsenic/pyrite/lead depressants and Eriez column/StackCell high-intensity technologies

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Full-text paper:

Mining, Metallurgy & Exploration (2025) 42:2583–2633, https://doi.org/10.1007/s42461-025-01260-x

Keywords: Gold, Copper, Silver, Depressants, Column flotation, StackCell high-intensity flotation

The increasing challenges in floating copper (Cu), gold (Au) and silver (Ag) ores are driven by factors such as rapidly growing demand, the complex mineralogy of modern deposits, and declining ore reserves and ore grades. Low-grade porphyry ores require fine or ultrafine grinding to achieve adequate mineral liberation. Extremely fine Cu, Au and Ag mineral particles (smaller than 10 µm) may be physically encapsulated within sulfide minerals like pyrite or arsenopyrite. However, fine and ultrafine particles (smaller than 20 µm) have low collision efficiency with bubbles, resulting in a loss of valuable minerals to the tailings. Porphyry Cu, Au and Ag ores can contain undesirable penalty elements like arsenic (As), zinc (Zn) and lead (Pb), which are difficult to reject. Selective flotation is required using different reagents and pH conditions for each mineral. This paper investigates the improved flotation performance of five low-grade Cu, Au and Ag ores using Eriez column/StackCell high-intensity technologies and various reagents to minimize final concentrate contents of sphalerite (ZnS), arsenopyrite (FeAsS) and galena (PbS) before incurring a penalty.

Introduction

Eriez column/StackCell high-intensity technologies can improve the flotation of fine and ultrafine particles by generating extremely small bubbles (picobubbles or nanobubbles) that overcome the typical challenges associated with floating tiny materials. The very fine bubbles preferentially nucleate directly onto the surface of hydrophobic (water-repelling) particles. This "bubble frosting" increases the overall hydrophobicity of the particle, making it easier to attach to conventional-sized bubbles. This synergistic effect drastically improves the probability of successful particle-bubble collisions. These benefits include higher recovery rates, better selectivity and lower reagent costs compared to conventional flotation methods.

Figure 1 depicts the key features of the Eriez StackCell. The high-turbulence contacting chamber is isolated from a quiescent separation chamber, which allows for independent optimization of the particle collection and froth recovery processes. The StackCell achieves between 75 and 85 percent reduction in flotation residence time requirement by increasing the flotation rate constant of minerals through introduction of air and particles directly into the multistage rotor-stator mechanism within the contacting chamber. This mechanism has an extremely high specific energy input that is converted to turbulent kinetic energy through the rotor blade design and generates between four and five times higher turbulent dissipation rates as compared to conventional flotation machines. As a result, recovery of fine particles and slow floating minerals is increased, and flotation volumetric requirement is reduced. The StackCell has been successfully applied to a wide range of mineral flotation applications, including rougher and cleaner applications (rougher, rougher scavenger, cleaner, cleaner scavenger) for base and precious metals, as well as fine flotation applications for industrial minerals and coal.

This paper presents the flotation results of five different ores with various Cu, Au and Ag grades and As, Zn and Pb contents, using various activators, collectors and depressants.

Methodology

Five Troilus gold ore samples — J-Zone (3 t), SW zone (3 t) with high zinc content, 87-zone (3 t) with high arsenic, zinc and lead contents, and X22-1~2 zone (3 t) with low copper and high arsenic contents — were used to investigate flotation performance with the Eriez flotation column (or StackCell) technologies.

Bench-scale mechanical cell flotation tests were conducted to identify the most optimal flotation feed particle size, circuit configuration and reagent scheme.

Following identification of the most optimal rougher-scavenger flotation feed grind size, the sample was bulk milled to the appropriate P_{80} size, followed by rougher-scavenger column flotation in series. Bench-scale flotation kinetics, release and steady-state column flotation testing were utilized to scale up an industrial rougher-scavenger flotation circuit consisting of Eriez StackCells.

Succeeding primary column flotation optimization and bulk rougher-scavenger treatment of each zone sample, secondary grinding studies were conducted on the rougher-scavenger concentrate to determine grinding times necessary to achieve P_{80} grind sizes of 40 and 20 µm. Cleaner flotation testing was then performed using an Eriez automated multistage column (Fig. 2) flotation circuit.

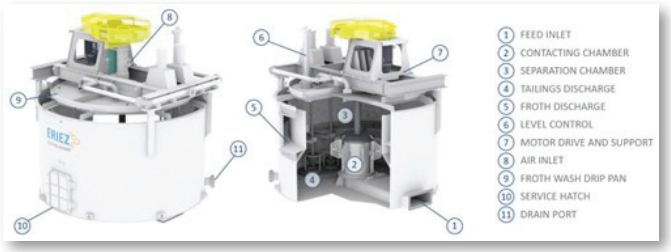

Fig. 1 Illustration of the Eriez StackCell.

Fig. 2 Each zone of the three-stage cleaner column flotation.

Results

Collectors KAX 51 and SPRI 206 were effective to float the five ore samples tested. The addition of 200-400-g/t sodium sulfite (Na_2SO_3) pyrite depressant in the cleaner stages could effectively depress pyrite, especially for the SW zone ore, with the highest Fe (pyrite) content among the five zone samples investigated; 50 g/t of $ZnSO_4{\cdot}H_2O$ depressant selectively depressed zinc sulfide minerals, such as sphalerite; 70 g/t $(C_3H_3NaO_2)n$ depressant reduced concentrate lead content, especially for the X22-2 zone ore, with the highest lead content.

In the column/StackCell flotation of five ores with various Au, Cu, Ag, Zn, As and Pb contents, the rougher-scavenger-cleaner circuit Cu, Au and Ag flotation recoveries were approximately 90.4 to 95.8 percent at the concentrate copper grade of 13.6 to 17.4 percent and feed copper grade of 0.024 to 0.070 percent; 87.5 to 95.1 percent at the concentrate gold grade of 65.6 to 214.7 g/t and feed gold grade of 0.32 to 0.62 g/t, and 80.7 to 91.8 percent at the concentrate silver grade of 62.6 to 279.7 g/t and the feed silver grade of 0.26 to 1.12 g/t, respectively. The benefits of the Eriez column/StackCell flotation technologies include high flotation selectivity and increased recovery due to unique hydrodynamic designs.

Conclusions

Enhanced flotation results were achieved for five Troilus ore zones using the Eriez column cell and StackCell (simulated) high-intensity flotation technologies as compared to conventional mechanical flotation. In the treatment of fine material using conventional flotation, recovery losses are attributed to poor bubble/particle collision rates. As a result of the use of cavitation-tube sparged column flotation or high-intensity bubble-particle mixing in an air-supersaturated slurry via StackCell, vastly improved product recoveries were realized, compared to a conventional cell. Additionally, the employment of countercurrent wash water and a deep froth phase yielded optimal concentrate grades. Although the StackCell is designed specifically to expedite flotation rate, its use of wash water and ability to maintain a deep froth bed offer improved product grades, like column flotation cells. ■

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Collection on Sustainable Development in the Minerals Industry

In the nexus of the coal mining industry and transition to sustainability: A comprehensive bibliometric analysis

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Full-text paper:
Mining, Metallurgy & Exploration (2025) 42:2699–2716, https://doi.org/10.1007/s42461-025-01301-5

Keywords: Energy transition, Coal, Lignite, Decarbonization, Bibliometric analysis, R-Bibliometrix, Biblioshiny, Sustainable transition, Coal mining industry

This paper presents a review of research papers concerning the coal mining industry and its transition to sustainability (CMITS). The methodology involves a bibliometric analysis using the Scopus database and the Bibliometrix R-tool, applied to a dataframe spanning 33 years (1990 to 2023), by categorizing the CMITS into 12 categories. Conclusions were derived for the temporal evolution of scientific production, keyword analysis, authors' collaboration, and contributions by country, and were visualized through R-biblioshiny.

Background

The tendency of coal mining industries to incorporate their activities into the context of sustainability has increased steadily in recent years, driven by worldwide efforts to transition to a new energy-mix model that targets minimizing environmental impact. Achieving sustainability in the mining industry requires a series of transformative steps, ranging from extraction methods to the use of mining equipment, fostering a coevolution between industries and communities. This transition is a significant and complex challenge, attracting research interest from diverse fields, including social science, renewable energy, economics, political science, humanities and public policy. Consequently, the respective literature on this topic has expanded considerably over time. When conventional literature reviews become insufficient for managing the vast and rapidly growing body of research on a specific issue, bibliometric analysis is often employed.

Although bibliometrics is not a novel methodology — its origin dates back to the 1950s — it remains a crucial tool for organizing the overwhelming volume of academic literature and the multifaceted and multidisciplinary nature of the subject. This paper presents the temporal evolution of the research publications concerning the CMITS, aiming to (1) identify the predominant topics in scholarly publications regarding the coal mining industry's transition to sustainability, (2) identify the organizations and countries that contributed the most to research on the coal mining industry's transition to sustainability, (3) identify the knowledge gaps that exist in the current literature on the transition from coal mining to sustainability and (4) identify the potential directions for future research in the field.

Methods

The methodology was designed and developed by first discretizing the 12 research categories, as the coal mining industry and its transition to sustainability constitute complex and multiparametric aspects with a wide variety of research issues to be investigated. The research categories are: (1) mining operations (MINOPS), (2) environmental engineering (ENVENG), (3) socioeconomic aspects (SOECON), (4) sustainability and circular economy (SUSTCE), (5) transition strategies evaluation (TRASEV), (6) technological and natural hazards (TENAH), (7) policy and regulatory aspects (POLREG), (8) technology, education and innovation (TEDINN), (9) stakeholders engagement and consultation (STAKEC), (10) financial and investment (FININV), (11) mining planning and project management (MPRMNGT) and (12) transformation engineering (TRSENG). The main search of the articles per category was employed with the

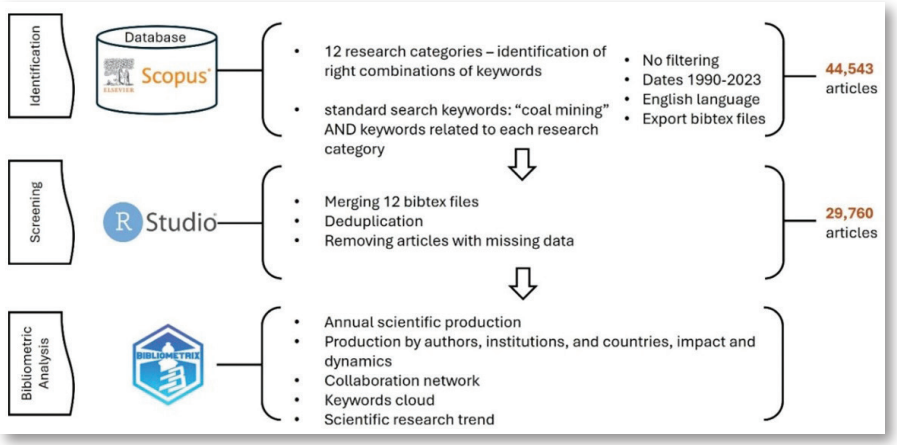

Fig. 1 Methodological workflow.

defined keywords. The steps involved screening the data (merging, deduplicating, and removing missing data) in the RStudio environment, while the primary bibliometric analysis was conducted using the R-Bibliometrix tool. Figure 1 presents the methodological workflow.

Results and discussion

As shown in Fig. 2, the distribution of the 29,760 articles exhibits an exponential-like behavior, indicating a growing interest over the last four years. Between 2019 and 2023, 12,260 articles were published, accounting for 42 percent of the total publications over the 33 years.

Figure 3 presents the increasing trend of published papers for each research category between 1990 and 2023, divided into seven five-year periods. The number of publications in the 1990 to 2004 period was under 1,000 for each research category, and the observed fluctuations were very mild. Since 2005, the number of published documents has increased rapidly, reaching a peak in 2023, across all research categories, although with varying development rates per category. As shown in Fig. 3, the categories ENVENG and MINOPS exhibit higher publication rates in all phases, followed by the TEDINN, STAKEC and MPRMNGT categories. The ENVENG category produced an average of 104 articles annually during the first period, while during the seventh period, the average annual production increased 12-fold to 1,283 articles per year.

Figure 4 presents a quantitative visualization of the 50 most-used words in scientific articles from all 12 research categories.

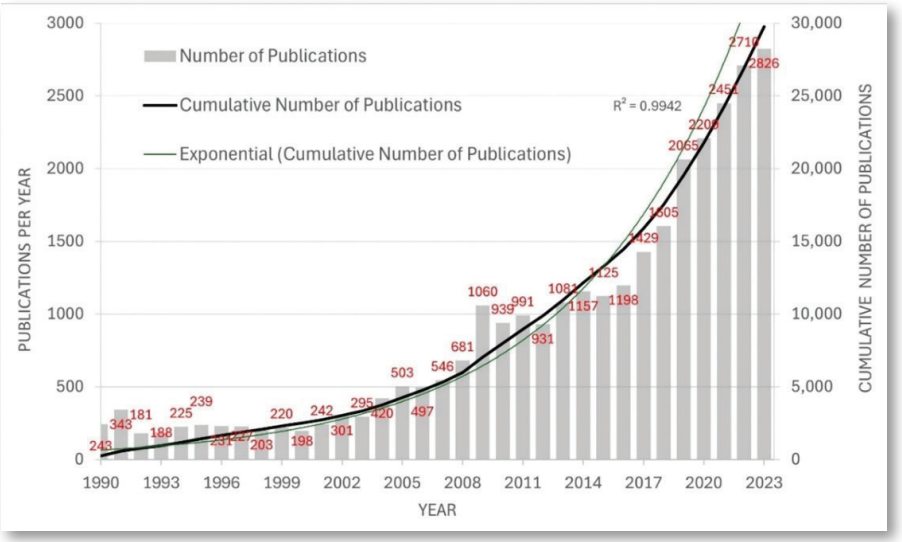

Fig. 2 Total number of relevant papers published each year (all the research categories were encountered), and mean total citation rates per year on CMITS from 1990 to 2023.

Conclusions

The main conclusions of the present study are:

1. The most frequently discussed topics are ENVENG, SUSTCE, TENAH, SOECON and POLREG.
2. China is the leading contributor, producing more than 55 percent of the global publications, followed by the United States, India, Poland and Australia. China is the world's major coal mining producer, so it is often incorporated as a case study in many articles' titles.
3. The most frequent words/phrases that emerged in more than 1,000 published articles are groundwater, risk assessment, environmental monitoring, human,

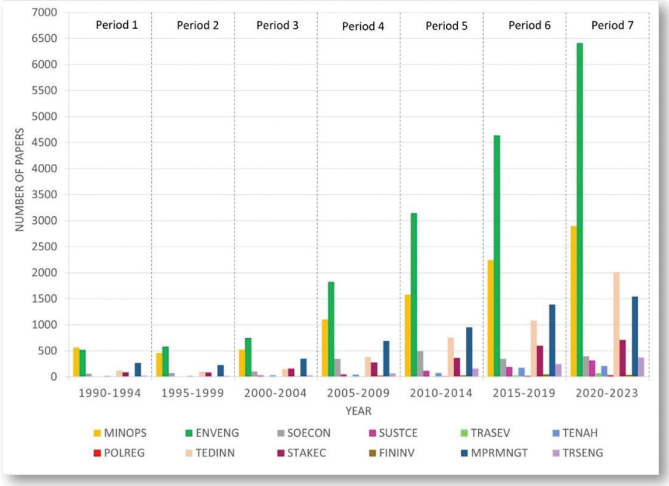

Fig. 3 Evolution of the number of published papers per five-year interval from 1990 to 2023 by research category.

Fig. 4 Tree map depicting the frequency of keywords plus terms in all categories.

water quality, subsidence, methane, rocks, aquifers, rock mechanics, coal seam, environmental impact and sustainable development.

4. Some knowledge gaps identified through the bibliometric analysis pertain to underexplored research areas. Specifically, transition strategies evaluation (TRASEV) and policy and regulatory aspects (POLREG) exhibit less research, indicating insufficient attention to strategic frameworks and legislative analyses for sustainable transitions.
5. Countries such as India, Indonesia, South Africa, Vietnam, Pakistan, Mongolia, Bangladesh and Colombia face challenges in balancing development needs with sustainability goals, limited access to advanced technologies, and vulnerability to socioeconomic disruptions during transitions to cleaner energy sources. ■

References

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

Prevalence and predictors of stress, anxiety and depression-related symptoms among mining workers in Ontario, Canada

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Full-text paper:
Mining, Metallurgy & Exploration (2025) 42:2045–2068, https://doi.org/10.1007/s42461-025-01285-2

Keywords: Occupational health, Mental health, Mining, Male-dominated industry, Well-being

The impact of mental illness on workplaces is well established, and the increased risk that poor mental health presents is cause for concern, notably, in workplaces where injuries can lead to serious harm or death, such as is often the case in male-dominated industrial settings. Although these consequences are well documented, research specific to mining industry workers remains negligible. Findings are nonetheless compelling, as they seem to reflect higher rates of mental health-related symptoms among mining workers. Further research is needed to better understand and improve the mental health and well-being of mining workers and mitigate these risks.

Background

Workers in male-dominated industries have been found to be at greater risk for mood and anxiety disorders, and the limited existing literature depicts higher rates of mental illness among mining workers specifically. Determining the prevalence of various mental health problems and identifying factors that contribute to poor mental health in this workforce is therefore crucial. In Canada, specifically, research on this topic remains especially limited despite the mining industry's importance as a major employer of Canadians and a significant contributor to the economy.

As part of a larger project that seeks to better understand the mental health and well-being of workers employed by an international mining company in Ontario, Canada, the aims of this study were twofold. The first objective was to determine the prevalence of stress, anxiety and depression symptoms among these workers. The second objective was to identify demographic, psychosocial and health-related factors and work-related factors associated with stress, anxiety and depression symptoms for this workforce.

Methods

A total of 2,224 mining workers across 25 worksites at one company in Ontario, Canada completed a self-reported survey. The perceived stress scale (PSS), the Beck anxiety inventory (BAI) and the Beck depression inventory II (BDI-II) were used to determine the prevalence of stress, anxiety and depression symptoms, respectively. In addition,

the survey instrument included demographic questions, as well as assessments of psychosocial and health-related factors associated with stress, anxiety and depression, such as relationships, burnout, substance use and various aspects of the work environment and conditions, to name a few.

Results and discussion

The prevalence of depression symptoms (12.5 percent) and anxiety (5.9 percent) in this sample were found to be higher than in the working-age Canadian population, and multiple regression analyses revealed many shared predictors for stress, anxiety and depression symptoms. The demographic, psychosocial and health-related predictors can be classified into four main categories: (1) individual characteristics, (2) interpersonal relationships, (3) lifestyle and (4) the overlap between physical and mental health. Work-related predictors were also grouped into four categories: (1) work schedule and demands, (2) effort-reward imbalance, and recognition and reward, (3) job insecurity and job satisfaction and (4) the physical and psychological work environment. A comprehensive overview of all categories of predictors is presented in Fig. 1.

Age was found to be a significant predictor of stress, anxiety and depression, which is unsurprising because mental health problems are typically higher in younger adults, peak in the working-age population, and decrease in the latter stages of one's career. Moreover, these findings were consistent with other mining worker mental health and well-being studies.

Gender differences were also expected, because many mood and anxiety disorders have a higher prevalence among women. In our study population, more women than men had scores reflective of anxiety and depression. However, average scores were higher for male workers than for female workers. The combination of a smaller female population within a workforce of predominantly male workers who have already been found to have a higher predisposition for mental health problems could explain why the differences between prevalence rates are on the lower end of the typical ratios between women and men. Additional individual characteristics that were found to be significant predictors include level of education and income, which are known to be important determinants of mental health.

Our analyses also revealed that support from superiors and colleagues, as well as relationship satisfaction had a protective effect for mental health. Marital status was also found to be an important predictor for stress, anxiety and depression, with higher symptom prevalence among workers identifying as separated, which is consistent with findings elsewhere in the mining-specific mental health literature.

It is well established that lifestyle choices affect health. In our study, alcohol consumption was a significant predictor of stress, while drug use significantly predicted anxiety. This is consistent with other mining-specific research findings. The literature also suggests that elevated drug and alcohol use is a more widespread problem in mining in general. Although prevalence of problematic alcohol and drug consumption was not the focus of this paper, it was assessed as part of this study, and findings are consistent with this hypothesis.

Having experienced a work-related injury or having been diagnosed with a physical health problem during the last year and taking medication for a physical health problem also negatively impacted worker mental health in our study population. Although physical and mental health are interrelated, they continue to be treated as separate entities. Seeking to improve the mental health of workers requires acknowledging that their physical health is a contributing factor to their mental health and overall well-being, and vice versa.

In addition to these health-related and psychosocial factors, several work-related factors impacted worker mental health. Notably, work-life balance was found to be conducive to better mental health, and an imbalance between effort and reward affected mental health negatively. Noteworthy in this context is that there are numerous labor groups (for example, staff, multiple unions) within this organization, therefore incentive programs vary tremendously. As a result, while some workers' mental health may be impacted negatively by their overcommitment to receive incentive pay, for instance, others may be feeling inadequately rewarded due to the absence of any such incentive pay program.

Issues of job security and job satisfaction were also detrimental to worker well-being, which is also consistent with the literature. Finally, the hazardous nature of mining was associated with higher stress and anxiety among workers, and issues of discrimination, bullying and harassment were detrimental to worker wellbeing, whereas an organizational culture fostering civility and respect were conducive to better mental health outcomes.

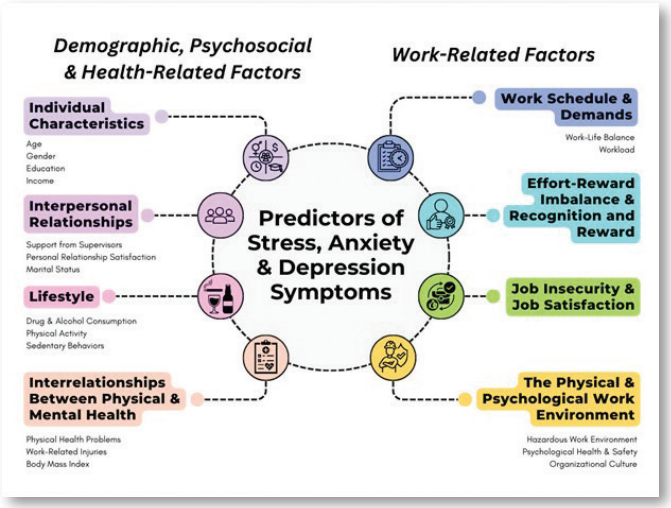

Fig. 1 A comprehensive overview of all categories of predictors.

Conclusion

Our study findings illustrate the importance of recognizing the multidimensionality of health. Mental health problems are undoubtedly the result of a number of interrelated factors, which include mental, physical and social components in addition to demographic and workplace-specific factors. To improve the mental health and well-being of mining workers, each of these factors must be considered. ■

References

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

Selected Abstracts

Tunnel overbreak prediction: An integrated approach using 3D photogrammetry and machine learning

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Full-text paper:
Mining, Metallurgy & Exploration (2025) 42:1441–1457, https://doi.org/10.1007/s42461-025-01278-1

Keywords: Overbreak, PCA, MRMR, GAN, Machine learning

In civil and mining engineering applications, predicting overbreak is crucial to optimize excavation processes and ensure safety. This study presents a comprehensive exploration of overbreak prediction-based 3D photogrammetry utilizing advanced analytical methods such as principal component analysis (PCA), maximum relevance minimum redundancy (mRMR) and machine learning (ML) regression models, enhanced by generative adversarial networks (GAN) for data augmentation. First, correlations and multicollinearity among geological and operational variables were investigated. Ten geological parameters from tunnel face mapping were analyzed to reveal the causative factor of the blasting mechanism between the rock mass's complex geological parameters and overbreak. Initially, PCA and mRMR facilitated feature extraction and selection, revealing significant variables influencing overbreak. After the reduction of the dimensionality of the input parameter, the research compares the result of the target and comparative models. Moreover, to address the limited availability of tunnel observations for machine learning, the original 210 data sets of input and target parameters were expanded to 1,000 data sets using the GAN method. Subsequently, ML regression models, enriched by GAN-augmented data sets, were employed to unravel the impacts of the selected features on overbreak prediction. Augmenting the data set fivefold via GANs markedly improved ML regression model efficacy, especially for the artificial neural network (ANN) model, which exhibited a substantial R2 increase from 29 to 96.4 percent and a 68 percent reduction in MSE to 0.402E–3 when compared to the original data set. This robust methodology underscores the relevance of comprehensive feature analysis and data augmentation in improving overbreak prediction in excavation projects, thereby contributing substantively to tunnel excavation. ■

Oval ducts in mining ventilation systems: Optimization of the operation costs and increase of clearance in mine roadways

Javier Menéndez[1,2], Jesús M. Fernández-Oro[3,*], Mónica Galdo[3], Laura Álvarez[2], Cipriano López[4], Antonio Bernardo-Sánchez[2] and María B. Díaz Aguado[5]

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Full-text paper:
Mining, Metallurgy & Exploration (2025) 42:557–570, https://doi.org/10.1007/s42461-025-01206-3

Keywords: Auxiliary ventilation, Oval ducts, Mining, Ventilation costs, Operation costs

To optimize the clearance in mine roadways and reduce operation costs, new oval ducts can be used in auxiliary ventilation systems instead of conventional circular ducts. In this work, an experimental study was conducted to investigate the performance of conventional circular ducts compared to two types of oval ducts with equivalent cross-sectional area. The laboratory tests were conducted on a test bench under various operating conditions using a 45-kW axial fan with speed control and flexible ducts 20 m in length and a cross-section of 0.78 m^2. Additionally, a mining development with a cross-sectional area of 15.57 m^2 in a deep mine was selected as a case study to analyze the increase in clearance and the optimization of the operation costs. A novel analytical model was developed based on the results of the experimental analysis. Variable friction coefficients along the ducts and different duct qualities were considered to determine the air leakage as well as the fan power requirements in the case of leaky ducts. The results obtained show an increase in pressure loss in the oval ducts, resulting in greater energy consumption for the ventilation system. However, a reduction in excavation costs of 6.4 percent can be achieved when the height of the mining developments is reduced using oval ducts. Finally, the results indicate that the use of oval ducts allows reducing operating costs and improving the efficiency of mining operations. ■

The miracle of cyanide

by Jim Arnold, P.E., NAE

Let's have some fun with a quick thought experiment. It is 1870 and you are the mill superintendent at a successful gold mine. The general manager walks into your office and says, "Ezekiel, (lots of people were named Ezekiel back then) I have a project for you. Our stamp mills and sluices have made us a lot of money, but the lab tells me that we are missing lots of fine gold locked with the gangue and free gold that is just too fine to collect by gravity. I want you to come up with some sort of chemical that will help us get it … you know, something to dissolve and collect that gold we are missing."

It is a good idea, but the general manager is a mining engineer, and he doesn't understand how difficult this is going to be. But you get to work. To start, you make a wish list of the traits that you would like this chemical to have. Once you have a list of desirable traits you can then search for a chemical that best fits the criteria. Yes, it is unlikely that anything will perfectly fit all criteria, but let us give it a shot.

1. It must dissolve gold: Ouch. Right off the bat you run into trouble. The very reason gold is valuable is because very little reacts with it. The gold of the pharaohs is just as bright and shiny as it was 3,000 years ago. How are you going to find a chemical that is so very reactive that it will dissolve gold?
2. It must not dissolve rock: Double ouch. Now the difficulty of your quest hits home. If your wonder chemical is so very reactive that it will dissolve gold, isn't it a bit ridiculous to expect it to not react with rock? To boot, you want your chemical to not react with just about any rock: silicate, carbonate, sulfide, oxide, and so on. You are already thinking this just isn't going to work, but you carry on.
3. You want it to be cheap: Any chemical that meets the first two criteria is a very special substance, isn't it? How can you expect that to be cheap? But, hey, it is your wish list, so it goes on the list.
4. It must dissolve in water: It is going to be much handier to work with this chemical if it is water soluble. Everything is wet, anyway, once it leaves the sluices, so let us not require our wonder chemical to be oil or alcohol based.
5. It works in very low concentrations: No, you don't want just 10 percent or even 1 percent. You want this stuff to do its job in parts-per-million concentrations. Your criteria get more ridiculous by the minute.
6. And while we are at it, it needs to dissolve at ambient temperatures: It gets cold here at the mine. We cannot be waiting a week for this stuff to go into solution. Also, we are dealing with way too

(Continued on page 50)

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SME News Contents

Last chance to qualify
for the SMEF VIP Access Conference Pass

by Lorie Laessig, SME Foundation Specialist

Join the 50 proud donors of the SME Foundation (SMEF) and earn a special VIP Access Conference Pass for the MINEXCHANGE 2026 SME Annual Conference & Expo in Salt Lake City, UT. By contributing $1,000 or more to any SMEF program during the 2025 calendar year, you will receive an exclusive badge recognizing your commitment to advancing the mining industry.

Time is running out. All donations must be received by Dec. 31, 2025, to be eligible for this benefit. Make your contribution online at www.smefoundation.org, or mail it to the SME Foundation, 12999 E. Adam Aircraft Circle, Englewood, CO 80112. ■

Mining for the perfect Christmas

by Russell J. Sheets, P.E., SME RM

If you had not noticed the stores beginning to put out various Christmas and holiday decorations for sale — in August — we are rapidly approaching the season of gift giving. The countdown to Black Friday, Cyber Monday and, ultimately, Christmas Eve is on. Whether you plan to do your shopping in the next several weeks or on Dec. 24, you may be wondering, "What presents will I get for my kids, or spouse, or parents, or friends?" Or you need new decorations to festivize your home or office, and wonder what decor is appropriate this year.

Well, you are in luck. We have produced some ideas for decorations and presents that not only will be on someone's wish list this Christmas but also require support and products from the mining industry.

As we get ready for the season of gift giving, take a minute to reflect that holiday decorations and presents require support and products from the mining industry.

Decorations and lights

To set the ambiance, and get you and those around you in the Christmas spirit, let us talk about decorating. First, a big tree — one that The Old Man would gladly bargain for — from which to hang ornaments and lights. Now, I know you are thinking that trees are grown, not mined. However, odds are that tree came from a tree farm, where in addition to sunlight and water it received fertilizer, which contains the product of mineable sulfur, phosphates and potash.

Now on to the lights — bright, twinkly LED lights. My preference is for colored versus clear, which results in a split household, but either string has copper wire. Connections and adapters may contain bauxite, nickel and zinc, among other minerals, and silica and soda ash are needed for the glass. Then, there are the semiconductor chips — gallium, indium, phosphates again, selenium and many more give us a bright, decorated tree.

Finally, the ornaments, which provide so many opportunities, depending on your preference and decoration style. A star upon your tree could very well contain aluminum, silver or copper metals. If you are out of ribbon to hang those ornaments, then a hook of some type of metal or metal alloy secures those ornaments on a branch. The ornaments of glass (silica), any metal or even homemade ornaments that your kids made from clay. Do you see where this is taking us?

We are losing shopping time, so I better move on to potential gift ideas.

Gifts for any occasion

The easy gift that would not exist without mining: jewelry — rings, necklaces, bracelets, earrings, pendants and watches — made with precious metals and gemstones. The options and combinations are never-ending, and they might get you out of any situation, like discussing whether color lights or white lights are better.

OK, OK, on to something that is a bit more practical and fun. How many of your giftees have electronics on their wish lists? Walkmans, boomboxes and Gameboys were popular gifts some years ago, and these could be solid go-to gifts for those who like retro gear. More than likely, they are looking to listen to music and play video games off the modern-day, multipurpose Walkman/Gameboy equivalent — smartphones. The electrical components, connections and semiconductors can contain nickel, copper, silver, gold and gallium. Several rare earth elements are needed to support that liquid crystal display with vibrant colors with a glass screen over the top. They need batteries to charge and power. Lithium-ion batteries are common, and they use spodumene (cathodes) and graphite (anodes).

Televisions, computers, tablets and video-game systems include a similar list of minerals, and then some.

OK, the individual that you are searching for has been really good this year. We will go out on a limb and say they may be in line for a new automobile … let us say we are looking for a hybrid car. What could be in those

(Continued on page 48)

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Showcase your support: Sponsor the 2026 IM&A Division Luncheon

by Himesh Patel, R&D Engineer, FLSmidth Inc. and Secretary-Treasurer, IM&A Division

Demonstrate your company's commitment to the industrial minerals and aggregates community by sponsoring the premier Industrial Minerals & Aggregates (IM&A) Division Luncheon to be held Feb. 24 during the MINEXCHANGE 2026 SME Annual Conference & Expo in Salt Lake City, UT. Your sponsorship provides exceptional visibility while directly funding student scholarships. Two impactful opportunities are available:

Title sponsorship: $6,000

- VIP table for 10 guests.
- Logo placement in all promotional materials.
- Opportunity to distribute promotional items.
- Verbal recognition and company bio during the event.
- Connector-level conference benefits.

Supporting sponsorship: $3,000

- Three complimentary luncheon tickets.
- Logo inclusion in all promotions.
- Verbal and slide recognition.
- Automator-level conference benefits.

To secure a sponsorship, contact Emma Salditt, SME Partnership Development Manager, at sponsorships@smenet.org or 303-948-4224 and mention "Industrial Minerals & Aggregates Division Sponsorship."

Speaker opportunity

We are also seeking a dynamic speaker for the luncheon program. This is an excellent opportunity to share insights with industry leaders. Interested speakers should submit a proposed topic and bio for consideration to Gaurav Soni, IM&A Division Chair, at gaurav.soni@flsmidth.com or Himesh Patel, IM&A Division Secretary-Treasurer at himeshpatel.ism@gmail.com.

Act now, and secure your role in this key industry event and support the next generation of talent. ■

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Rock in the Box

(Continued from page 47)

car batteries: cadmium, cobalt, lead, lithium, nickel and lanthanum. The wiring and circuitry connected to those batteries have us looking at tungsten, copper, platinum and gold again. How about the frame and structure? Bauxite (aluminum), iron ore (steel), manganese and molybdenum (steel alloys).

The problem with this Christmas guide is that it is being shared with all of you who already are "in the know" as to how mining provides so much around us. Everything from the decorations to the presents we are likely to share with loved ones would not exist if the rest of the year we did not show up to our day jobs. The items above are a mere sliver of everything around us that is created and manufactured from mineable resources. When you gather with family and friends over the holiday season, particularly those who may not understand or be exposed to the positive impacts of mining, take the time to share. Maybe make it a New Year's resolution for 2026 to do some STEM outreach in your community.

If you need some prepared information on mining and mineral uses, check out the SME Foundation's Minerals Education Coalition (MEC) website at www.mineralseducationcoalition.org for presentations, classroom activities, fact sheets and information appropriate for all ages. The MEC is where I found all the information for this month's Rock in the Box article (and so much more).

Now for the bonus Christmas gift: coal — not just for naughty children anymore. Your friends might be geologists who are missing a coal specimen in their rock and mineral collections, they will appreciate the gesture. You should also be able to pass it off to loved ones as an "immature diamond."

To all of you — however you and your family celebrate the holiday season — have a Happy Hanukkah, a Merry Yule, a Happy Kwanzaa, a Merry Christmas and a Happy New Year in 2026.

(For more information on how to get involved in the Mining & Exploration (M&E) Division, email Russell Sheets at rsheets@barr.com. Sheets has been an SME member since 2005 and Registered Member since 2014. He currently serves as the Assistant Vice Chair for Program Planning for the M&E Division and sits on SME's Professional Engineer (PE) Committee.) ■

A wrap-up of the 2025 PCMIA-SME
Pittsburgh Section Short Presentation Contest

by Cengiz Kaydim, graduate research assistant, West Virginia University

We are thrilled to announce the results of the 2025 Pittsburgh Coal Mining Institute of America (PCMIA) and SME Pittsburgh Section Short Presentation Contest. This year's competition showcased exceptional research talent from students across The Pennsylvania State University (Penn State), West Virginia University, University of Kentucky and Virginia Tech, making it our most competitive event to date.

Our sincere appreciation goes to our panel of judges — Joe Sbaffoni, Michael J. Brnich and Sena Cicek — whose expertise and careful evaluation ensured a fair and rigorous assessment of all presentations. We also extend special recognition to Mary Delrosso for her outstanding work in coordinating this year's contest.

After a competitive first round of eliminations, seven students advanced to the live presentation session, where they delivered compelling research presentations and skillfully addressed questions from the jury panel. Congratulations to the 2025 top three winners — (1) Triveni Gangadari of Penn State, (2) Kaveh Asgari of West Virginia University and (3) Daykin Schnell of University of Kentucky. The quality of research presented this year was remarkable, reflecting the innovative work being conducted across our regional universities in advancing coal mining technology, safety and sustainability.

Mark your calendars — submissions for the 2026 contest will open in early September.

The PCMIA and SME Pittsburgh Section are proud to jointly sponsor this annual contest, which recognizes outstanding research conducted at select regional universities. The contest provides students with a valuable platform to present their work to industry professionals and compete for monetary prizes based on presentation quality and research merit as evaluated by an expert judging panel.

For questions or more information, contact Mary Delrosso at mary412d@comcast.net.

We look forward to welcoming new talent and groundbreaking research in 2026.

First place: Selective separation of rare earth elements into groups using ion exchange resins and complexing agents, by Triveni Gangadari, Mohammad Rezaee and Sarma V. Pisupati.

Rare earth elements (REEs) are vital for clean energy, electronics and defense technologies, yet the United States remains heavily reliant on imports to meet demand. Given the limited availability of primary REE resources, exploration of secondary sources is necessary. One such source includes acid mine drainage (AMD), a major environmental challenge that is considered a viable secondary source of REEs. In this study, we present a solid-phase extraction (SPE) approach using ion exchange resins in a fixed-bed column to achieve group-wise separation of light and heavy rare earth fractions (LREEs and HREEs) from a mixed REE concentrate obtained through AMD treatment. The mixed REE concentrate solution was subjected to adsorption using strong cation exchange and chelating resins, followed by elution with complexing agents such as IDA, NTA, DTPA and EDTA. These complexing agents are known to exhibit differences in complexation stability between LREEs and HREEs, with one agent showing strong selectivity, enabling efficient group separation. Operating parameters such as pH, complexant concentration, flow rate and elution strategy were systematically optimized. Chelating resins outperformed sulfonic acid-based resins. The maximum adsorption capacity was 37.9 mg/g. Desorption modeling indicated film diffusion limited behavior (K_f = 0.00001 1/s) for LREEs. A maximum separation efficiency up to 90 percent was obtained for HREEs over LREEs. Adsorption followed the Langmuir isotherm, and both increasing pH or complexant concentration reduced selectivity. The resins also demonstrated good reusability over multiple adsorption-desorption cycles. This work highlights resin-based SPE as an environmentally friendly and scalable pathway for REE group separation.


Triveni Gangadari

Triveni Gangadari is a Ph.D. student in energy and mineral engineering at Penn State, specializing in hydrometallurgical processes for sustainable recovery of critical minerals from secondary resources such as red mud and AMD. Her research advances selective separation of REEs and scandium, contributing to resource security and the clean energy transition. She earned her B.Tech. in chemical engineering from Osmania University, India, graduating at the top of her class. Gangadari's work has earned multiple awards, including first place in the MPD Student Poster Contest at the MINEXCHANGE 2025 SME Annual Conference & Expo. An active member of SME, Graduate Women in Science (GWIS) and Association for India's Development (AID), she combines research, industry experience and outreach to promote sustainability and innovation in mineral processing.

Second place: Assessment of angular grinding media on copper sulfide ore grinding and flotation, by Kaveh Asgari.

This study investigated the influence of novel angular grinding media on the comminution and flotation performance of chalcopyrite ore. Comparative grinding tests were conducted using both conventional spherical media and angular media under identical conditions. Test

(continued on page 50)

Fine Grind

(Continued from page 46)

much water to heat it.

7. It needs to be easy to acquire: Yes, although this amazing chemical is nearly impossible to imagine, you want it to be made in quantity by multiple suppliers. We do not want any supply-chain issues.
8. It is not offensive to use: It would be nice if the stuff doesn't stink up the mill, explode, burn the eyes or skin, and is not carcinogenic.
9. It goes away on its own: Now your wish list has crossed over from the ridiculous to the insane. Nobody wants a forever chemical and neither do you. You want just the oxygen from the air to kill it. You want sunlight to kill it. You want rainwater to kill it. It needs to be hearty enough to dissolve gold yet fragile enough to nearly self-destruct.
10. It needs to be nontoxic: It needs to be friendly to plant and animal life.

You realize that your wish list is completely crazy, and you frankly doubt if you can find anything that will meet just the first two criteria. Much work to do …

The miracle substance

A few years after you make your list, cyanidation is developed. It is crude in the early stages but after years of refinement it becomes the worldwide staple for gold processing.

What is most remarkable is that it pretty much meets all of your 1870 criteria except the last one. It does a great job of dissolving gold in very low concentrations and pretty much leaves everything else alone. It is very cheap as reagents go, and easy to work with if you are careful. It is used in many industries, so the supply is stable. Yes, it has an odor, but there are much worse milling chemicals. It does die on its own but with a little help it is destroyed very quickly to very low concentrations. The last criterion is a miss, and it is a big miss. Cyanide, although a fertilizer to plant life, is highly toxic. Yet it is manageable. You have to look pretty hard to find instances of cyanide deaths in the mining industry.

I often think that we do not appreciate just what a perfect storm of amazing traits cyanide brings to our industry. For 150 years we have been trying to find a better replacement, but cyanide is still the gold standard (ha, see what I did there?). Your wish list from 1870 was so ridiculous that it was nearly futile to pursue. Yet here we are. Cyanide is truly a miracle substance.

(The article above was recently shared among the Nevada MPD Golden Opportunities community and reprinted here with the author's permission. Jim Wickens, editor of Golden Opportunities, thought a wider audience might enjoy it. Wickens further commented that Arnold makes great points regarding the efficacy of cyanide versus other lixiviants. From a pure technical perspective, cyanide is simply far superior; there just isn't anything that comes close. From a health, safety and environment (HSE) perspective, none of the other options come without significant risk, and in some cases, offer arguably worse outcomes. So then, why have we wasted so much effort trying to find an alternative? Why haven't engineers and scientists stood up and explained the advantages and realities surrounding HSE more clearly? Well, unfortunately, it would seem that the nonoperations side of our industry is more concerned with appeasing false narrative and chasing easy government grant money than doing what is actually best.) ■

PCMIA-SME

(Continued from page 49)

results revealed that the angular media produced a product with an 80 percent passing size (P_{80}) that was approximately 16 percent finer than a spherical media product after 10 min of grinding. To achieve a target product size of 150 µm, angular media required 2 min less grinding time, leading to a 22 percent reduction in energy consumption. Additionally, a 10 percent decrease in the generation of ultrafine particles (smaller than 37 µm) was realized with angular media, which positively impacts froth flotation recovery. Over a range of grinding times, the angular media consistently outperformed spherical media in terms of energy efficiency, fineness of product and ultrafine minimization. This superior performance is attributed to the unique geometry of the angular media, which enhances impact efficiency and lifting behavior inside the mill, particularly at lower mill speeds. Flotation tests further confirmed the advantages of angular media with 7 to 8 percent higher chalcopyrite recovery and 1 to 2 percent improved concentrate grade across both coarse and fine grind sizes. Shape analysis of ground particles showed that angular media products exhibited higher angularity and lower sphericity, characteristics that favor particle-bubble attachment and flotation efficiency. These findings suggest that the use of angular media can significantly improve both grinding efficiency and downstream flotation performance.

Kaveh Asgari

Kaveh Asgari is a Ph.D. student in mining engineering at West Virginia University, specializing in comminution

(continued on page 52)

Winter months and holiday season bring safety challenges to mines

by Matthew Main, Communications Chair, H&S Division Executive Committee

As we move into the winter months and approach the holiday season, it is critical to recognize the unique challenges this time of year brings to mining operations. Cold weather, shorter daylight hours and increased distractions can significantly impact safety performance. Leaders have added responsibility to ensure that their teams recognize these challenges and engage with miners while managing their own personal safety.

Slips, trips and falls

Winter conditions introduce hazards such as snow, ice and freezing temperatures. These can affect both surface and underground operations. Slips, trips and falls, ice accumulation on walkways, stairs and equipment platforms are risks that everyone has a responsibility to manage. Effective workplace exams, job risk assessments and equipment pre-operational inspections are key to identifying winter hazards. However, recognition is one thing, and minimizing risk takes deliberate effort. When leaders celebrate those that take the time to shovel snow, apply ice melt and sometimes put up barricade tape as a gift to their coworkers, it increases the likelihood that employees will continue mitigating these winter hazards. Another thing that will make mitigation more likely is to strategically stage materials where miners will have easy access. Putting shovels and ice melt near walkways make it more likely they will be used. Easy access to quality footwear and traction devices will also help reduce the risk of injury from a slip and fall.

Reduced visibility

Reduced visibility is another persistent risk through the winter months. Snowstorms and more dark hours can make operations difficult in the mining environment. It is important that areas where miners work during dark hours have good lighting. Through workplace exams and proper correction, miners will be better equipped to spot and mitigate hazards. Provide miners with headlamps as a backup for areas that may have poor lighting. When visibility is reduced while operating equipment in a snowstorm, having good windshield wipers cannot be understated. Mine operators should proactively replace wiper blades before the winter starts. Leaders should follow up to ensure that miners are completely clearing snow and ice from window surfaces before moving. This is a practice we should all adopt, whether on or off the mine site. I often see vehicles driving around town with just a small area cleared of snow and ice.

Cold stress

Cold stress is another factor that can increase the risk of injury to miners. Mine operators need to provide heated areas for breaks. For some miners, the only heated areas nearby are vehicles, so it is important that heating systems in vehicles are serviced before the temperatures plummet. We should encourage miners to layer their clothing to maintain proper body temperature during work activities. Employees who get overheated while working could begin sweating and then in cold environments become colder with wet clothes. We can train miners to recognize the symptoms of cold stress and to look out for their coworkers. Operators should consider providing miners with hand and body warmers to use if it gets really cold. We should remind miners to stay hydrated. People often fail to drink enough fluids during colder temperatures, but it is important that miners remain hydrated during work activities.

Vehicles, equipment and roads

When it comes to vehicles and equipment, the cold weather can impact equipment performance and road conditions. Batteries, tires and hydraulic systems are all vulnerable in freezing temperatures. Proper preventive maintenance and quality preshift inspections are effective to make sure that our vehicles and equipment will perform well throughout the winter. Snowstorms can impact visibility during the storm, but the impacts to road conditions can last long after the flakes stop falling. Mine operators should have prepared plans for winter road maintenance in place with the necessary materials staged. Applying traction material to roadways after plowing helps mitigate slippery conditions. Operators should also consider installing tire chains on equipment in areas where roads will be snowpacked for extended periods. Every driver or operator needs to understand the road conditions and reduce speeds. Stopping vehicles and equipment in slippery conditions will take longer, and evasive maneuvers to avoid hazards can cause a loss of control. Reducing speed and planning different driving actions will help miners keep control of their equipment.

Emergency plans

Winter weather can often cause impacts to power, heating fuels and communications. Mines should

(continued on page 52)

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PCMIA-SME

(Continued from page 50)

and flotation of sulfide and rare earth ores. His research focuses on developing energy-efficient grinding methods and integrating advanced characterization and modeling techniques for process optimization. Asgari has published more than 40 peer-reviewed papers, contributed to a book chapter and is the inventor of a registered patent in mineral processing. He has presented award-winning research at major international conferences such as MINEXCHANGE SME, where he received recognition for his innovative work on energy reduction in grinding systems.

His industrial experience spans copper extraction, flotation optimization and rare earth recovery, and he has worked with research and industrial teams across multiple countries, gaining a global perspective on sustainable mineral processing. Asgari actively collaborates with both academia and industry to bridge scientific research with practical mineral processing applications, aiming to advance next-generation, low-energy and sustainable technologies for the mining industry.

Third place: Full-scale and small-scale modeling and testing of underground methane explosions, by Daykin Schnell, Josh Calnan and Zach Agioutantis.

Accidental methane explosions are of concern in underground coal mines in the United States. Significant work has gone into reducing the risk associated with methane explosions and helping to ensure the safety of the underground coal miner.

However, the potential for accidental methane explosions still exists. Many studies have been conducted to better understand how methane explosions impact underground mining environments and to determine what steps can be taken to protect miners. Current research includes modeling methane explosions from field testing and past mine incidents. Additionally, predictive models have been developed that can effectively estimate the effects of potential methane explosions. Work is currently ongoing to develop, test and validate multiple computational fluid dynamic (CFD) models for estimating air overpressures from methane explosions in underground mining environments. Full-scale CFD models have been validated against field test data from National Institute for Occupation Safety and Health (NIOSH) testing at the Lake Lynn Experimental Mine. An additional 1/10 small-scale CFD model has been developed concurrently with a 1/10 small-scale physical mine network to establish procedures for full-scale methane explosion impacts through small-scale field testing.

Daykin Schnell

Daykin Schnell is currently a graduate research assistant at the University of Kentucky as a mining engineering Ph.D. candidate. His current research with the University of Kentucky focuses on ground vibrations and other impacts from blasting. He has a B.S. in mining engineering, a M.S. in explosives engineering and 10 years of industry experience. He has worked on numerous projects involving blast optimization and improvement and blast vibration management relating to surface and underground mining in metal-nonmetal coal and construction industries. ■

Safety Share

(Continued from page 51)

develop and review emergency plans before winter fully hits. Consider what it will take to protect people, the environment and the operating assets. Prolonged exposure to cold temperatures can cause extensive damage to processing equipment.

Having cots, blankets and food stores is a good idea to look after miners if they have to stay at the site for extended periods. Having backup heaters and fuel staged to keep processing equipment warm will protect against costly repairs.

Stress and fatigue

The upcoming holiday season brings excitement but also stress and fatigue, which can affect focus and decision-making. Leaders should engage with miners often to encourage open dialogue about the stresses that may be impacting some individuals. Remind employees about available resources through the operation and the community. Be aware of these realities and help employees stay focused at work so that they can protect themselves for their families and the holiday fun. Fatigue from holiday activities and the longer dark hours is another challenge to overcome during this time of year. Talk to miners about managing their fatigue and take action when it appears that operators are struggling with fatigue; especially when operating equipment.

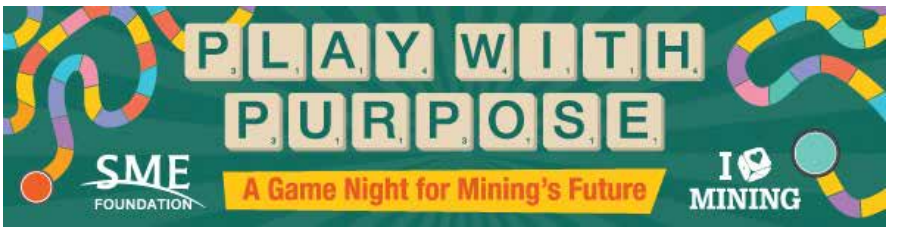
Preparation, planning and working together

Proper preparation and planning as well as working together with all miners are key to managing these additional hazards that we face this time of year. Leaders should increase field presence with miners to reinforce a visible commitment to safety and building the proper safety culture at the site.

Take time this season to show appreciation to your coworkers, employees and supervisors. Let us make a commitment to successfully navigate this exciting time of the year. ■

Play with Purpose at SMEF Gala Dinner at MINEXCHANGE 2026

by Lorie Laessig, SME Foundation Specialist



Join the SME Foundation and Play with Purpose. Celebrate with us at the SMEF Gala Dinner and Silent Auction on Feb. 22, 2026, proudly sponsored by Hexagon. This signature event will kick off the MINEXCHANGE 2026 Annual Conference & Expo in Salt Lake City, UT. Enjoy an evening filled with entertainment, games, a delicious dinner and the chance to reconnect with friends and colleagues.

Highlights include:

- Cocktail reception — sponsored by Schlam.
- Dinner wine service — sponsored by Jennmar.
- Special door prizes — sponsored by J. H. Fletcher & Co.
- After-party — sponsored by UPG.
- Awards program — recognizing major contributors and scholarship recipients.

Individual dinner tickets are $150 each, and tables of 10 are available for $3,500. Our annual SMEF events are made possible by the generous support of our corporate sponsors. Tickets and table sponsorships can be purchased online at smeannualconference.com.

Purchase a "Friend of the Foundation" ticket for $250 and receive the following benefits:

- A $100 tax-deductible donation to the SMEF.
- Reserved seating at the SMEF Gala Dinner.
- An invitation to the SMEF VIP cocktail reception.
- A special thank-you mention in *Mining Engineering* magazine.
- A listing in the gala dinner program as a Friend of the Foundation.

Following dinner, join us for a fun after-party featuring dessert, entertainment, carnival games and prizes. Business or cocktail attire is encouraged for this festive evening.

Silent-auction donations needed

The annual SMEF Silent Auction, sponsored by McCarl's Technical Services, will take place during the SMEF Gala Dinner. We are currently seeking donated items valued at $100 or more to feature in the auction. You or your organization can also make a cash donation directly to the SMEF, allowing us to purchase high-quality items at wholesale for the auction. All donors will be recognized in the April issue of the *Mining Engineering* magazine, and donations are tax deductible.

Your participation, whether through gala attendance, table sponsorship, auction donation or bidding, help raise vital funds for the education and outreach programs supported by the SMEF.

We look forward to seeing you in February. ■

SMEF awarded grant to support educational resources for teachers

by Rebecca Smith, MEC Curriculum Coordinator

The Minerals Education Coalition (MEC) has received a big boost from a $18,000 grant from the Gimme Foundation. The grant money allows the MEC to send educational materials such as SME mining-careers handbooks, coloring and activity books, everyday-uses posters, monuments posters and/or periodic-table posters to SME Sections and Chapters to distribute to teachers at the National Science Teaching Association annual conferences, state-level science teacher conferences, career days, science festivals and SME teacher workshops.

The Gimme Foundation was established in 2007 to primarily support and promote the mining industry, supporting the mining industry through scholarships and assisting in the recruitment of mining engineering students. It promotes the mining industry by assisting various organizations to educate the public on the importance of mining to society. The foundation's objectives are to help educate the public regarding mining's overall contributions to society as it exists today, as well as the importance of mining to provide the minerals needed for both basic and advanced products. It is hoped that these educational efforts will improve the public's perception of mining.

The MEC is very grateful for this grant from the Gimme Foundation. Since receiving the grant, a rich set of resources were given to teachers at events this fall in Minnesota, Utah, California, Colorado, New Mexico, Arizona, North Carolina and Kentucky.

If your section is interested in receiving MEC educational materials for an event you are attending, contact the MEC. ■

CLASSIFIEDS

University of Kentucky®

The Department of Mining Engineering at the University of Kentucky invites nominations and applications for a tenure-track (tenure-eligible) faculty position at the rank of assistant professor. This will be a joint appointment between the Department of Mining Engineering and the Department of Chemical and Materials Engineering. Candidates for the position must hold a Ph.D. degree in Extractive Metallurgy, Metallurgy, or a closely related field, and must be committed to excellence in the areas of teaching, research, and service. In addition to these qualities, preference will be given to candidates who have experience in the mining industry.

The University of Kentucky, located in the heart of Kentucky's scenic Bluegrass region, is home to more than 38,000 students and over 26,000 employees. As a land-grant university for the commonwealth, the mission of the University of Kentucky is to provide excellent education, conduct outstanding research, and perform service in an academic environment in a manner that ensures the professional success of our students, meets the needs of our constituents, and responds to the technological challenges of the commonwealth.

The Department of Mining Engineering is one of the larger mineral-related programs in North America. The department consists of seven faculty members who have diverse specialties that cover a wide range of subjects in the mining engineering discipline.

Responsibilities of the successful applicant will include teaching and student advising at both the undergraduate and graduate levels. The selected candidate will also be expected to develop a sustainable research program that attracts external research funding and addresses the needs of the mining industry. The position is open to all the specialty areas of mining and geological engineering, including contemporary issues in mining, such as reclamation, health and safety, and mine operations.

Applicants should submit the following: 1) a cover letter, 2) a curriculum vitae, 3) a research statement (upload as specific request 1), and 4) a teaching philosophy (upload as specific request 2).

Applications submitted by January 31st, 2026, will receive full consideration. However, the position will remain open until filled.

To apply, go to https://ukjobs.uky.edu/ and click on Search Jobs and enter requisition #FE04695 or use this link.

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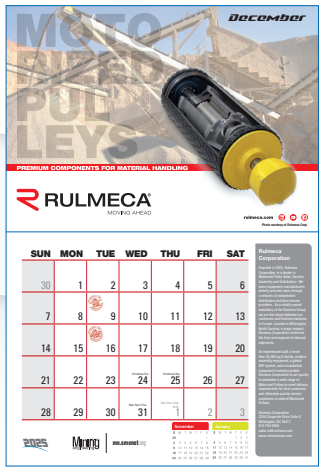

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MOVING AHEAD

Artificial intelligence can help reshape the industry

William Gleason
Editor

The U.S. Department of Energy (DOE) on Nov. 15 issued a press release outlining plans for two notices of funding opportunities to the tune of $355 million to expand domestic production of critical minerals and materials (page 11).

The funding opportunities are issued by DOE's Office of Fossil Energy to expand domestic production of critical materials essential for advancing U.S. energy production, manufacturing, transportation and national defense. The first funding opportunity provides up to $275 million for American industrial facilities capable of producing valuable minerals from existing industrial and coal byproducts. The second provides up to $80 million to establish "Mine of the Future" proving grounds for real-world testing of next-generation mining technologies.

"The Mine of the Future — Proving Ground initiative will be among the DOE's first major investments into mining technology research and development in almost four decades," U.S. DOE Assistant Secretary of the Office of Fossil Energy Kyle Haustveit said in a press release. "This effort will help establish the United States as the world's leading producer and processor of non-fuel minerals — creating economic prosperity in fossil energy communities across the country while strengthening critical mineral supply chains for the United States and its allies."

Of the many media releases that reach my inbox each day, the bit about research funding caught my eye. Funding for technology and research, in my opinion, will be desperately needed for the industry in the coming years, especially in the absence of the mining division of the National Institute for Occupational Safety and Health (NIOSH). You might recall that back in April hundreds of scientists, researchers and support staff at NIOSH received reduction in force notices. While some branches of NIOSH have been reinstated, others, like the mining division have not been fully reinstated. NIOSH was the only federal agency engaged in research and technical development to advance miner safety and health.

Specific research and development areas of interest for the DOE include comminution and rock mechanics, extraction, automation and robotics, and data and sensing. One focus area will be artificial intelligence (AI) and machine learning, including algorithms to optimize equipment efficiency, resource extraction and processing, and the development of autonomous vehicles.

Two days after the release from DOE, on Nov. 17 South32, which is building its own mine of the future at the Hermosa Project in Arizona announced significant AI advancement with plans to work with Emerson on a multimillion-dollar automation project that will deploy integrated remote operations systems for South32's first "next-generation mine," enabling the production of critical minerals while minimizing environmental impact.

"The Hermosa project represents the kind of forward-looking investment that drives both economic growth and energy security," said Ram Krishnan, chief operating officer of Emerson.

Advances in AI have the potential to reshape the mining industry. Applied correctly, AI could make the industry more efficient and sustainable. And it could help provide solutions for one of the industry's most daunting challenges — how to recruit and retain a qualified workforce.

Starting on page 25 of this issue, representatives from South32, Hecla and Quintana Resources share their thoughts about the workforce challenges including how AI is reshaping the industry.

AI has immense potential for the mining industry to become safer and more productive, but it is far from a quick solution to the workforce issue.

"A common misconception is that AI will replace employees but that's simply not the case," Skylie Estep, South32 director of human resources for the Americas told me in response to questions for the business management feature in this issue. "AI is an enabler for better performance. It's 'augmented intelligence' and our workforce will learn new skills and talents to be able to leverage AI. It's not less employees, it's different skill sets and capabilities, and we're here for it."

■■■

Investment in the mining industry, workforce issues, AI and machine learning, and every other topic important to the mining industry will be part of the MINEXCHANGE 2026 SME Annual Conference & Expo, to take place in Salt Lake City, UT, Feb. 22-25. Registration for the conference is now open. You can secure your spot and pick your hotel by visiting https://me.smenet.org/registration-for-minexchange-2026-sme-annual-conference-now-open/. ■

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Tunneling & Underground Construction

OFFICIAL PUBLICATION OF UCA

Volume 19 NO. 4 // December 2025

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Special Editorial Supplement from the publisher of Mining engineering

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December Contents

Departments

Cover Story

In This Issue

Creation of infrastructure typically involves the use of large quantities of cement (principally for concrete) and steel, both of which have significant environmental impact. This impact includes the greenhouse-gas (GHG) emissions associated with their production. On page 14 Ian Whitehead and his co-authors present the findings of a study to reduce embodied carbon in tunnel projects. Cover design by Ted Robertson. Cover image: Shutterstock.

Feature Articles

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Tunneling & Underground Construction
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Chair's Column

Workforce issues remain pressing concern for a thriving industry

Leon "Lonnie" Jacobs
2025-2027 UCA Chair

Our industry continues to thrive. By the time you read this, the UCA Cutting Edge Conference will have concluded, registration for the George A. Fox Conference will be at its peak, and plans will be in motion for the Moles and Beavers Annual Awards Dinners. These events provide phenomenal opportunities to learn and connect with fellow colleagues; events like these make our industry unique due to our complex camaraderie. Though we may compete fiercely in business, we consistently support one another as partners and professionals.

Across the country, project progression and activity remain strong. The New York region currently has four major underground projects underway, with two additional projects in the negotiation and completion stages. The Pittsburgh's Alcon program's first project is entering procurement, with at least two more to follow. Northern and Southern California, Seattle, the Mid-Atlantic, Midwest and Texas are also busy with active projects. Our Tunnel Demand Forecast reflects this intense momentum, and if you have updates to contribute, please contact Sanja Zlantanic at szlatanic@hntb.com.

With this level of activity, demand for new talent has never been greater. Owners, engineers, contractors, consultants, trades and suppliers are all seeking young, energetic individuals eager to join the underground industry. We each have a responsibility to promote these opportunities by visiting local schools and encouraging our elementary, middle and high school students to pursue STEM or trade programs and reach out to colleges and universities to explain the diverse employment opportunities within our industry. These talks can inspire lifelong, rewarding careers. Please notify Everett Litton at Everett.Litton@wsp.com about your outreach, so he can track and support your efforts.

The success of current projects is critical not only for our industry's growth but also for future funding. We must complete projects safely, on time and within budget to demonstrate and promote how our industry performs, and the social, environmental and economic benefits that result from our work. Too often, short-term decisions overlook long-term value. The UCA should consider reexamining past decisions where underground designs or project elements were entirely abandoned or eliminated for less costly surface structures. We must ask ourselves how might our communities have benefited had the underground option proceeded? Retrospectively, what should they have chosen, which course of action would they decide today?

On a different note, I recently had the opportunity to attended SME's Midyear Meeting in Denver, CO, where I was reinvigorated by our shared focus on workforce development. I saw a great potential for collaboration between SME and UCA as we pursue aligned goals. Though our missions differ,

(continued on page 13)

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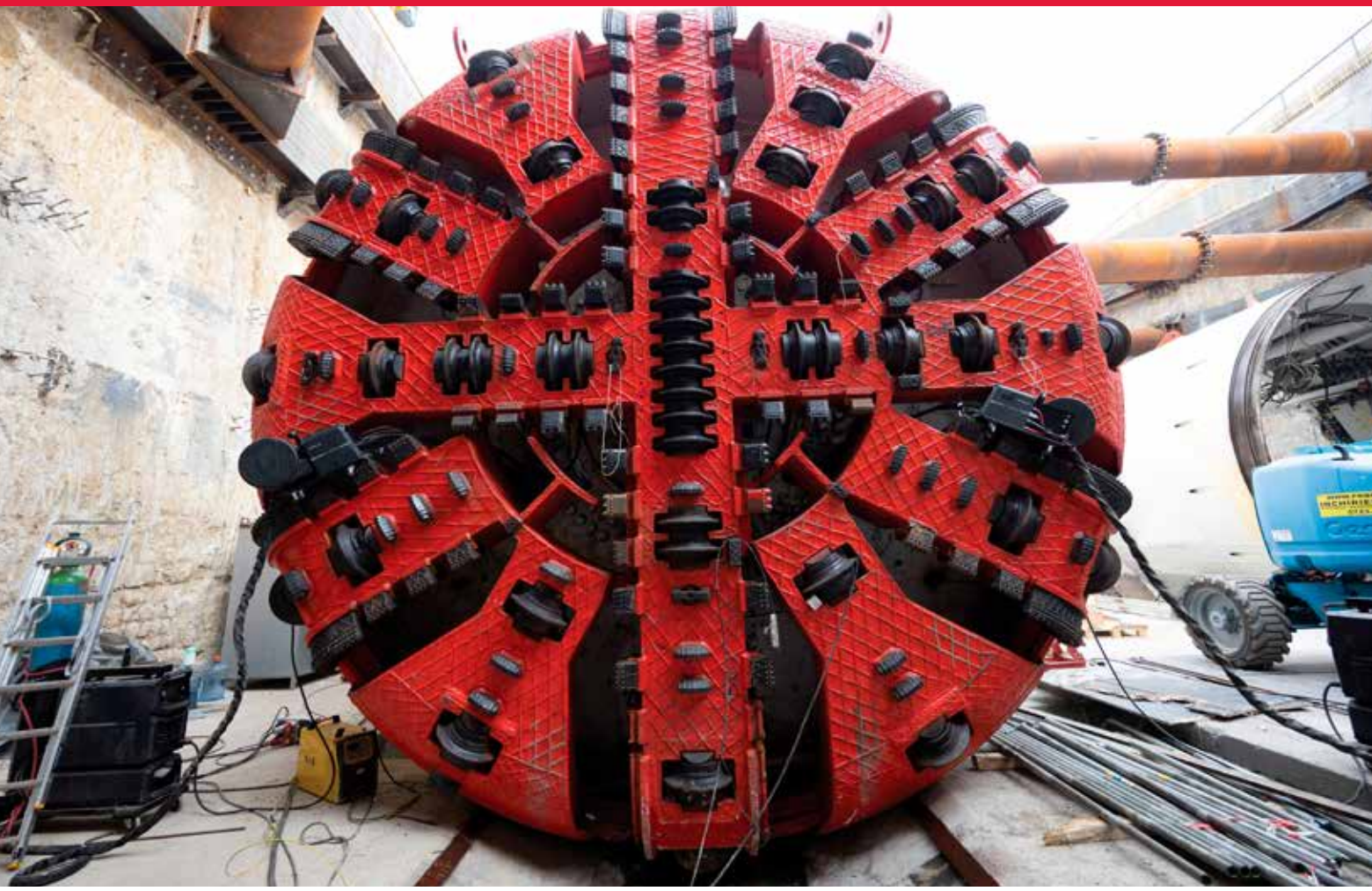

BUCHAREST METRO LINE M6 PROJECT

TERRATEC's 6.39m Earth Pressure Balance TBM is being used on the South Section of the Bucharest Metro Line M6 in Romania. This important metro line will offer the city's first direct connection to Henri Coandă International Airport, greatly reducing traffic congestion and connecting smoothly with Metro Line M4.

Previously deployed on the Dudullu-Bostancı Metro Line in Istanbul, Turkey, the TBM was refurbished and now deployed for its new mission. Excavation involves challenging abrasive ground and tunnelling beneath Herăstrău Lake, reinforcing TERRATEC's reputation for delivering reliable solutions again and again in complex ground conditions.

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Funding for Hudson Tunnel Project and other projects in doubt after comments from President Trump

The fate of the Hudson Tunnel project was put in doubt on Oct. 1 when President Donald Trump said funding for major transit projects in New York, including the Hudson Tunnel and the Second Avenue Subway would be paused while the U.S. Department of Transportation (USDOT) reviews whether any small-business contractors are engaged in improper diversity initiatives.

The USDOT's sudden announcement was based on a new agency rule that has yet to go into effect, but was intended in part to pressure Democratic lawmakers in Congress over the partial government shutdown that began hours earlier.

Senate Minority Leader Chuck Schumer, a Democrat from New York, has championed both projects and is leading the Democratic opposition in the showdown with President Donald Trump and other Republicans over the federal budget.

In its unusual announcement, the USDOT invoked partisan political discord and personally blamed Schumer, House Minority Leader Hakeem Jeffries and other Democrats for any delays in reimbursements to New York for the projects.

New York Governor Kathy Hochul, a Democrat, said in a statement that Trump was "intent on using his reckless government shutdown to hurt the American people." Hochul said, "This is political payback and an attack on New York and its residents."

The immediate impact of the announcement was unclear beyond a pause to a $300 million reimbursement for the subway project.

The future for the projects remained cloudy in mid-October, when a person at USDOT seemed to contradict the president by telling *Politico* that it had no plans to kill the projects. The official was granted anonymity to discuss sensitive matters.

Any substantive delays in federal funding over partisan political squabbles are almost certain to face swift legal challenges from New York and New Jersey.

Reuters reported that the department said its forthcoming rule changed how it approached decades-old programs enacted by Congress to help small businesses run by "socially and economically disadvantaged individuals." Following a district

(continued on page 8)

WSP to design Eglinton Crosstown West Extension stations, rail and systems

WSP in Canada (WSP) has been named as the primary lead designer for the Eglinton Crosstown West Extension Stations, Rail and Systems (ECWE SRS) contract.

The 9.2-km (5.7-mile) extension of the Eglinton Crosstown West Extension in Toronto will run from Mount Dennis Station to Renforth Drive. The contract includes the construction of one at-grade, two elevated and four underground stations, track construction, electrification, communication, signaling and train control systems, and tunnel and elevated guideway fit out and tunnel ventilation. The project is being developed as a progressive design-build.

"The Eglinton Crosstown West Extension is a vital east-west transit connector for Toronto, one that will significantly reduce commuting times for people throughout the city. We are proud to be part of a project that, once complete, will make it easier for thousands of people in the Greater Toronto Area get to the places and people they value most," said Corina Moore, executive vice president for transportation and infrastructure, WSP in Canada.

WSP will lead the design as part of the Trillium Rail Partners (TRP) consortium. The consortium also includes primary construction team members Amico Major Projects Inc., Alberici Constructors Ltd. and Acciona Infrastructure Canada Inc. The SRS contract is one of four that will complete the Eglinton Crosstown West Extension. The three additional contracts relate to advanced tunneling and elevated guideway work necessary in sections of the line.

"The project represents an important step forward in the expansion of efficient, low-emission transit services in the Greater Toronto Area. For our team, this represents another opportunity to demonstrate our experience and expertise in the delivery of high-quality transportation solutions in Canada, and especially, the City of Toronto," said Jennifer Verellen, senior vice president for transportation systems, WSP in Canada.

The Eglinton Crosstown West Extension will bring even more rapid transit to Etobicoke and Mississauga, making it easier for people to get where they need to be each day. Once complete, the Eglinton Crosstown LRT will create a continuous rapid transit line that stretches from Scarborough, through midtown Toronto and into Mississauga.

The extension will connect with other local and regional transit options that will make it faster and easier to get around, including the UP Express and GO Transit rail services, TTC bus services, and MiWay and GO Transit bus services along the 18-km (11-mile) Mississauga Transitway.

Plans are also being explored with the Greater Toronto Airports Authority to extend the line to Pearson International Airport. Construction on the project is underway. ■

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Gateway Development Commission launches new phase of public-private infrastructure delivery contract

The Gateway Development Commission (GDC) board of commissioners authorized the commission to expand its successful use of the delivery partner model to support construction of the Hudson Tunnel Project.

As a special-purpose entity with the mandate to build the Hudson Tunnel Project, the Gateway Development Commission has a limited number of staff by design. GDC has oversight of the project. Its delivery partner acts as the "arms and legs" of the agency.

This has allowed GDC to significantly accelerate construction across five active sites. Since onboarding MPA Delivery Partners in March 2024, GDC has:

- Secured full funding for the Hudson Tunnel Project.
- Awarded contracts for three construction packages, including the first construction project that involves tunnel boring.
- Advanced the first Hudson Tunnel Project construction package — the Tonnelle Avenue Bridge and Utility Relocation Project — toward on-time completion.
- Procured and overseen manufacturing of the two tunnel boring machines that will be used to build the section of the new tunnel in New Jersey.
- Managed the procurement process for four additional construction packages, including two that will be awarded in the next six months.

The board's action will enable GDC to retain the team that achieved these milestones and build on this success by adding engineers, project managers, planners, safety experts, and other key personnel, bringing MPA's support to 350 to 400 full-time equivalents over the next five years.

New York GDC commissioner and co-chair Alicia Glen, New Jersey GDC commissioner and co-chair Balpreet Grewal-Virk and GDC Amtrak commissioner and vice chair Tony Coscia said, "The delivery partner model is an innovative approach to project delivery that has brought together the best of the industry to make sure the Hudson Tunnel Project stays on track. This public-private partnership has made GDC nimble, flexible, and innovative while staying on scope, schedule, and budget. We're proud that GDC is using this model to drive performance in service of the hundreds of thousands of riders who travel on the Northeast Corridor every day. GDC's track record of success since onboarding MPA Delivery Partners is undeniable, and we are confident the team will continue to deliver going forward."

GDC chief executive officer Tom Prendergast said, "Massive infrastructure projects like the Hudson Tunnel Project require huge teams of highly specialized experts. The delivery partner model enables GDC to bring in the right experts and resources for each aspect of this huge, multifaceted project while remaining a lean, efficient organization. As the past 18 months have shown, the model is working well. The MPA team has integrated seamlessly into our day-to-day operations, and the results speak for themselves. The GDC team looks forward to building on this successful partnership in the months and years to come."

"This is a once-in-a-generation project and a true collaboration between the public and private sectors that will serve as a model for delivering future mega infrastructure projects around the world," said Joe Marie, senior vice president at MPA Delivery Partners.

"We are united in our goal of successfully completing this critical project, which will transform the Northeast Corridor and deliver billions of dollars of economic growth to the U.S. economy. GDC and MPA function as a fully integrated partnership, working closely together to ensure the Hudson Tunnel Project is completed on time and within budget," Marie said.

The delivery partner model has a proven track record of enabling public agencies to deliver large, complex infrastructure projects. The UK's Olympic Delivery Authority used a delivery partner to build the infrastructure for the 2012 Olympics in London ahead of schedule and under budget. In the United States, the Oregon Department of Transportation's award-winning OTIA III State Bridge Delivery Program used a delivery partner model to replace or repair 271 bridges.

GDC awarded the delivery partner contract for the Hudson Tunnel Project to MPA Delivery Partners — a joint venture of Parsons Corp., Arcadis of New York Inc. and Mace North America Ltd. — in March 2024 via a competitive procurement process.

The initial contract term ends in 2030, with the option for three subsequent three-year renewals. Since awarding the delivery partner contract, GDC has executed a series of task orders for its initial work with MPA.

The board's action delegates authority to GDC to execute a package of task orders that will enable the delivery partner team to provide all services and staffing needed to support delivery of the Hudson Tunnel Project through the end of the initial contract term in 2030. ■

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HS2 celebrates final tunnel breakthrough

The tunnel boring machine (TBM) being used to dig HS2's Birmingham approach tunnels broke through on Oct. 13, marking the completion of major tunnel excavation between London's Old Oak Common and the West Midlands.

The 125-m TBM — named Elizabeth after the 19th century philanthropist Elizabeth Cadbury — was launched near the Warwickshire village of Water Orton in March 2024.

Two identical machines were used to dig the 5.6 km (3.5-mile) Bromford tunnel that will carry high-speed trains under the M6 and eastern outskirts of the city, with the first one — Mary Ann — breaking through earlier this year.

Together, Elizabeth and Mary Ann have excavated more than 1.8 Mt (2 million st) of material and installed 5,804 concrete ring segments for the twin, eastbound and westbound tunnels. The spoil — made up of various grades of Mercia Mudstone — is being used to landscape the railway on the approaches to the city.

All the excavation is now complete for the 37 km (23 miles) of deep bore tunnel between Old Oak Common in west London and the railway's terminus at Birmingham Curzon Street. Construction teams are now mainly focused on internal walkways, ventilation shafts and cross passages.

Once complete, HS2 will improve journeys between the UK's two largest cities while freeing up space on the existing West Coast Main Line for more freight and local services.

Although the tunnel milestone marks a significant achievement for the teams in Birmingham, other parts of the railway's civil engineering are further behind.

Mark Wild, HS2 Ltd's chief executive, is now leading a comprehensive reset of the program to deliver the railway in the most efficient way possible and for the lowest reasonable cost.

"Today's breakthrough is a major milestone for the tunneling team here in Birmingham and for the HS2 project. All eight of the TBMs digging our tunnels between Old Oak Common and Curzon Street have now broken through, which means that the focus is now on the internal concrete work, ventilation shafts and cross passages," Alan Morris, HS2 Ltd's construction delivery director, said.

"I'm immensely proud of the men and women who have worked round the clock to bring our TBMs and their crews home safely, and I look forward to seeing more progress inside the tunnels in the years ahead," he added.

Eight TBMs have been used on the project so far, with 9.4 Mt (9.8 million st) of material excavated during their tunnel drives. The longest tunnel — under the Chilterns — stretches for 16 km (10 miles), while the Northolt tunnels run for 13.5 km (8.4 miles) from West Ruislip to Old Oak Common in west London. Additionally, there is a short 1.6-km (1-mile) twin bore tunnel beneath Long Itchington Wood in Warwickshire.

Two more TBMs are expected to launch next year to begin digging the tunnels from Old Oak Common to HS2's final destination, London Euston. A short section of mined tunnel is also being dug between the Victoria Road Crossover Box and Old Oak Common.

Alongside these deep tunnels, HS2 is also delivering around 8 km (5 miles) of shallow "cut-and-cover" tunnels in rural areas such as Burton Green in Warwickshire, Chipping Warden in West Northamptonshire and Wendover in Buckinghamshire.

The Bromford tunnel is being delivered by HS2's main works contractor Balfour Beatty VINCI (BBV) with a team of more than 450 people involved in the complex logistical operation required to keep the TBMs moving around the clock.

During their year-and-a-half-

(continued on page 13)

Hudson Tunnel: Future funding is in doubt

(continued from page 4)

court ruling in its favor last year, women and some people belonging to minority racial groups will no longer be "presumed" to be economically disadvantaged when bidding for contracts.

USDOT sent letters to New York transit leaders on Oct. 1 saying both the Second Avenue Subway extension and the Hudson Tunnel reconstruction project would now need to be reviewed to "ensure nondiscrimination."

USDOT said it had focused on the two projects in New York, which is governed by Democrats, in part for their symbolism: "They are arguably the largest infrastructure initiatives in the Western Hemisphere, and the American people want to see them completed quickly and efficiently."

It said the remaining federal funding earmarked for the projects was $18 billion, but it was unclear how much of that was through Disadvantaged Business Enterprise programs now under review.

The $17.2 billion Hudson River tunnel project, which received more than $11 billion in federal grants, involves repairs to an existing tunnel, and the building of a new one for passenger railroad Amtrak and state commuter lines between New Jersey and Manhattan.

Any failure of the current Hudson tunnel, which was heavily damaged by 2012's Hurricane Sandy, would hobble commuting in the metropolitan area that produces 10 percent of the country's economic output.

Representative Frank Pallone, a Democrat from New Jersey, said in a statement that Trump was engaged in a "fabricated culture war" that could cause havoc for tens of thousands of commuters.

In 2023, the administration of U.S. President Joe Biden, a Democrat, awarded $3.4 billion to extend the Second Avenue Subway up into Harlem. ■

DC Water TBM passes key factory test for Potomac River Tunnel Project

DC Water announced that it has reached a major milestone in the Potomac River Tunnel Project with the successful completion of factory acceptance testing for its final tunnel boring machine (TBM), Emily. This test confirms that Emily is ready to begin excavating the southern leg of the Potomac River Tunnel — a critical step toward reducing sewer overflows and protecting local waterways.

Led by chief executive officer and general manager David L. Gadis, DC Water's team traveled to the German factory where Emily was built to ceremonially activate the cutterhead — a massive drill-like component that will carve the tunnel beneath the river.

"Seeing Emily in action was a powerful moment for our team and underscores the scale and impact of what we're building," said Gadis. "It's one thing to plan and design a tunnel boring machine, but watching it take shape reminds us why we do this work — to build a cleaner, healthier future for the district."

During the test, engineers from Herrenknecht, the TBM manufacturer, ran Emily through a series of operational checks. These included spinning the cutterhead, cycling the thrust rams and activating the conveyor system — all designed to simulate real tunneling conditions and confirm the machine's readiness.

Emily will join sister TBM Mary, which is scheduled to begin digging the northern leg of the tunnel in early 2026. Named after Emily and Mary Edmonson — courageous abolitionists from the DC area — the TBMs reflect DC Water's commitment to honoring local history while building a cleaner future. Emily is engineered for softer soils, while Mary is designed to cut through hard rock, accommodating the varied geology along the tunnel's path.

With testing complete, the next chapter begins as Emily prepares for her journey to Washington, DC. The machine will be disassembled for transport and reassembled at the West Potomac Park site in spring 2026. That is when Emily begins her underground mission beneath the river.

The Potomac River Tunnel is part of DC Water's Clean Rivers Program, a long-term initiative to reduce pollution in the Potomac River and Chesapeake Bay. Currently, about 650 million gallons of untreated sewer overflow enter the river each year. Once completed, the 8.8 km (5.5-mile) tunnel system will reduce overflow volume by 93 percent and cut the number of overflow events from 74 to just four in a typical year. ■

World's largest TBM launches in China

The world's largest-diameter earth pressure balance, double-shield convertible tunnel boring machine (TBM), independently developed by China Railway Construction Heavy Industry Corporation Ltd. came off the assembly line in Changsha, Hunan Province on March 26.

The TBM will be used in the construction of a 12.28-km (7.6-mile) water transfer tunnel for the southern segment of the Hangzhou-Jiaxing-Huzhou West Channel Tunnel, marking a breakthrough in the field of ultra-large-diameter TBMs in China and injecting new momentum in science and technology for urban flood control and drainage, and underground space development.

The excavation diameter of the TBM, named Strong Foundation, is 12.68 m (41.6 ft), its length is 107 m (351 ft), and its total weight is about 3.5 kt (3,900 st).

To address complex ground conditions such as uneven hard and soft strata, and alternating hard and soft geology, the TBM adopts the TBM + Shield Machine coexisting dual-muck discharge system and modular dual-mode cutterhead design, which solves the complex strata and tunneling problems and improves the overall TBM construction quality and efficiency.

The TBM is integrated with digital technology and equipped with an intelligent auxiliary tunneling system and segment automatic lifting and transportation system.

The operator can monitor more than 20 parameters, such as cutterhead rotation speed and thrust speed, in real time through the intelligent interface, and tunneling error is controlled at the millimeter level by relying on the automated guidance system.

The application of digital twin technology enables visual control of the whole construction process and promotes the transformation of underground engineering to "less manned and intelligent."

The Expansion of Hangzhou-Jiaxing-Huzhou South Drainage West Channel Tunnel Project is the largest drainage-scale, tunnel-diameter and buried-depth project of Chinese deep-tunnel drainage system projects.

The project's main task is to prevent flooding and drainage while improving the water ecological environment. Once completed, it will further reduce the flood control pressure in the Taihu Lake basin, ensure the safety of flood control and drainage in the west of Hangzhou, and construct a safety barrier for the main city of Hangzhou. It is of great significance in promoting the high-quality development of the regional economy and providing water safety guarantee. ■

VTA confirms preferred tunnel alignment and configuration following expert review

The Santa Clara Valley Transportation Authority (VTA) has confirmed the large single bore as the preferred tunnel configuration for BART Silicon Valley Phase II, following a peer review conducted by tunneling and transit experts from major transit agencies across the country.

The VTA board of directors heard an extensive presentation on the peer review and its recommendations on moving forward with the largest public infrastructure project in Santa Clara County.

Following the discussion, the board voted in favor of the single bore as the most viable option, offering the best balance of constructability, feasibility and lower overall risk. It avoids the high cost, complexity and downtown disruption associated with an alternative concurrent tunneling approach of using two boring machines. This alternative would have required a cut-and-cover excavation in the heart of San Jose.

Construction of the tunnel boring machine entrance is underway at the BART Silicon Valley Phase II west portal site in Santa Clara.

The board's decision allows VTA to advance project design toward 60 percent, stay on a critical path to tunnel construction and meet the projected revenue service date.

The panel also included recommendations to ensure greater cost estimation, accuracy and budget alignment, reduce schedule delays and manage tunnel risk.

With VTA owning the tunnel boring machine, the agency assumes full responsibility for its performance. To manage this risk, VTA will deploy a top-tier tunneling team and embed Herrenknecht engineers to support operations and reduce delays.

The panel also highlighted the limited pool of qualified contractors and skilled labor for large-diameter tunneling.

VTA will continue early engagement with the industry to secure experienced construction teams and develop a contract strategy to increase bidder participation.

Lastly, the peer review reinforces the importance of a strong VTA-BART partnership. Both agencies have agreed to reestablishing regular touchpoints and prioritizing communications between agencies.

VTA remains committed to delivering this critical regional project with expert guidance, sound engineering and continued collaboration. ■

Tunneling under Fraser River completed for Annacis Water Supply Tunnel project

Metro Vancouver has completed the tunnelling phase of the Annacis Water Supply Tunnel, a critical infrastructure project that will increase capacity to deliver high-quality drinking water to growing communities south of the Fraser River.

"Metro Vancouver is always working to ensure the drinking water system is in good condition — from routine repairs and maintenance to constructing new mains and tunnels to accommodate growth, replace aging infrastructure and prepare for a major earthquake," said Mike Hurley, chair of Metro Vancouver's board of directors.

"These projects happen out of sight but are critical to ensuring that everyone in the region continues to receive the high-quality water they expect when turning on their taps," Hurley added.

The new 2.3-km (1.4-mile) Annacis Water Supply Tunnel was excavated approximately 50 m (164 ft) below the Fraser River between New Westminster and Surrey, just north of Annacis Island. A tunnel boring machine, nicknamed Anna (short for Annacis), launched from a vertical entry shaft on the south side of the river at a site on Grace Road in Surrey and broke through a vertical exit shaft on the north side at 11th Street in New Westminster.

"The successful excavation of this new water supply tunnel is a huge step toward ensuring residents south of the Fraser River continue to receive drinking water as their communities grow," said Brad West, chair of Metro Vancouver's Water Committee.

"Investing in these kinds of major projects is an important part of protecting the health and well-being of our region now and into the future," he said.

Now that the tunneling phase is complete, the contractor will begin installing a 2.6-m (8.5-ft) diameter steel water main inside the new tunnel. At the same time, valve chambers will be constructed near each shaft so that the new water main can be connected to the regional water transmission system.

Once construction is complete, Metro Vancouver will restore both shaft sites. This will include replanting trees in Surrey and creating a new green space in New Westminster, with input from the community, the city and local First Nations.

Construction on the Annacis Water Supply Tunnel began in 2022, and the project is expected to be completed in 2028. The project budget for construction is $450 million.

Metro Vancouver supplies high-quality drinking water each day to more than three million people, over half of British Columbia's population.

This project is one of several new regional water supply tunnels being designed to meet current seismic standards, ensuring the reliable delivery of water in the region in the event of a major earthquake.

The award-winning Second Narrows Water Supply Tunnel, located between Burnaby and New Westminster, was substantially completed in September.

Metro Vancouver has successfully delivered some of British Columbia's largest public infrastructure projects and has more than 300 large projects underway — including upgrades to water and wastewater systems, regional park expansions, and affordable rental housing developments — all designed to serve the growing needs of the region. ■

LJB acquires Aldea Services for tunneling, geotechnical and structural expertise

LJB has acquired Aldea Services, a leading provider of engineering solutions for complex underground structures. Founded in 2011, Aldea has worked on some of the most challenging and important underground infrastructure projects in North America.

"Their team brings unmatched tunneling, geotechnical and structural expertise in the underground engineering field," LJB said in a statement.

With years of experience on more than 100 tunneling projects worldwide, Aldea brings a unique new service offering to LJB's multidiscipline infrastructure team. Aldea's current clients will work with the same team they know and trust, while also having access to additional support from LJB's diverse service offerings and staff located across the country.

Michael Derr, president of LJB, said, "We're thrilled to welcome Aldea to the LJB team. Their proven leadership in underground design and construction management strengthens our collective ability to address the most complex infrastructure challenges facing our clients throughout North America."

In addition to its unique underground services, Aldea expands LJB's reach with an additional staff of more than 50 employees and an expanded geographic footprint, with U.S. offices in Frederick, MD; Los Angeles, CA; Denver, CO; Atlanta, GA; Columbus, OH; Houston, TX; and Canadian locations in Vancouver, Calgary and Toronto.

"Our team's unique expertise and vast experience have allowed us to provide unrivaled support to our clients over the years," said Bob Goodfellow, president of Aldea Services. "Joining LJB gives us additional business and technical muscle to deliver even more value." ■

Colorado River's largest user endorses Delta Conveyance Project as California's water fix

In a significant and unusual endorsement, the Imperial Irrigation District (IID) — the largest irrigation district in the United States — has formally backed California's proposed Delta Conveyance Project, a plan to modernize the State Water Project and secure water supplies for seven out of 10 Californians.

The IID board of directors adopted a resolution in support of the project, which faces key legislative votes in September.

IID's move is notable because Imperial County is the only county in Southern California that does not receive State Water Project water. The district draws exclusively from the Colorado River. Its endorsement underscores recognition that the state's two major water systems — the Bay-Delta and the Colorado River — are deeply connected, and that improving reliability in one provides relief to the other.

"A stronger Delta relieves pressure on the Colorado River, and that benefits us all," said IID chairwoman Gina Dockstader.

The Delta Conveyance Project would add new Sacramento River intakes and construct a 72-km (45-mile) tunnel to move water beneath the Delta. State officials say it is critical to capturing storm flows, reducing seismic and levee risks, and ensuring reliable supplies for 27 million people and 750,000 acres of farmland.

For Southern California, Delta reliability directly affects the Metropolitan Water District and the Coachella Valley Water District, both of which rely on the drought-stricken Colorado River, particularly when State Water Project deliveries falter. IID leaders said stabilizing the Delta helps ease that strain on a river already stressed by historic drought.

"When the Delta is stable, the Colorado River is stronger," said IID director Alex Cardenas. "One system supports the other — and California needs both to succeed."

"Modernizing the Delta is an investment in a resilient water future for California and more certainty for the entire state," said IID general manager Jamie Asbury.

The endorsement positions IID as an ally of the state and other agencies backing the project.

The resolution will be transmitted to Governor Gavin Newsom and legislative leaders, underscoring a growing recognition that California's water systems cannot be managed in isolation. ■

Chair column: UCA aligns well with SME

(continued from page 2)

challenges and opportunities often overlap and build upon one another.

I also had the pleasure of meeting Melissa Russell, SME's new executive director. We had good discussions about the UCA, and its trajectory. Her experience and leadership will be valuable as we continue to evolve.

With SME updating its strategic plan this year, we will look to have UCA representatives participate in that process to later align our own strategic plan according to the updated focus areas and goals.

Lastly, I need to present a correction from my previous article: Mike Rispin has served 15 years with our organization and continues to serve as champion for our 2030 World Tunnel Congress bid.

I look forward to seeing you all at one of the upcoming events and hearing about your student outreach efforts. ■

HS2: Tunneling continues on massive project

(continued from page 8)

long mission, the team on board the 1,600-t (1,760-st) machines worked at depths of up to 131 ft (40 m). They skilfully navigated Elizabeth and Mary Ann under the M6 motorway, key National Grid infrastructure and the meandering River Tame — which they crossed four times, with a headspace as low as five meters.

Meanwhile, separate teams were focused on supplying the concrete ring segments and removing the spoil as well as beginning work on the cross passages and the ventilation shaft at Castle Vale.

With the breakthrough complete, Elizabeth will now be removed from the tunnel to allow work to progress on the concrete finishing works, base slabs, and emergency and maintenance walkways.

Jules Arlaud, Balfour Beatty VINCI's tunneling director, said, "Today is a historic moment for Balfour Beatty VINCI, as TBM Elizabeth completes her three-and-a-half-mile journey in Washwood Heath. This is BBV's fourth and final TBM breakthrough, delivered by our expert tunneling team who have worked around the clock over 19 months to arrive at this point."

As well as being the arrival point for the two Bromford tunnel TBMs, Washwood Heath will also become the nerve center for HS2's operations. Next to the tunnel portal, HS2's depot and network integrated control center will be built.

From this site, trains will be serviced and stored, and the real-time operation of the railway will be controlled. ■

Alternative study for reducing embodied carbon in tunnel projects

Tunnels serve as critical elements of infrastructure, particularly in urban areas. Whether for delivery of drinking water, underground transit and roads, or transfer of wastewater, tunnels are a fundamental part of the infrastructure that allows urban areas to function. The need for tunnels is expected to grow as cities across the world grow and densify.

However, creation of infrastructure typically involves the use of large quantities of cement (principally for concrete) and steel, both of which have significant environmental impact. This impact includes the greenhouse-gas (GHG) emissions associated with their production. The World Green Building Council (WGBC) reports (WGBC, 2019) that cement production accounts for approximately 7 percent of total global carbon dioxide (CO_2) emissions, while iron and steel production account for approximately 7 to 9 percent of global CO_2 emissions (together, a total of 14 to 16 percent).

As governments worldwide have committed to achieving net-zero GHG emissions on or before 2050 in the Paris Climate Agreement 2015, it is incumbent on the tunneling industry to chart its path to net zero. To do so, the tunneling industry needs to understand its current contribution to GHG emissions and develop new approaches so that GHG emissions associated with tunnels are significantly reduced. This article uses the term "embodied carbon"(EC), which refers to the GHG emissions associated with materials and construction processes through the whole life cycle of an asset (WGBC, 2019). Embodied carbon can be considered as a simplified proxy for the climate impact of that asset.

One of the challenges for project teams intending to reduce embodied carbon on their projects is deciding which areas to focus on. Resources are always limited and embodied carbon does not have the same status as cost and schedule estimates in terms of priority. Given that context, work to reduce the embodied carbon of projects needs to be able to focus on the "easy wins" or on those items with the largest significance to overall embodied carbon.

The starting point for the research presented here is an existing embodied carbon estimate for a tunnel project. This estimate was turned into a more "generic" tunnel project to omit project-specific elements that would skew the results and make the findings less broadly relevant. From that baseline the authors tested a series of scenarios to explore whether different decisions about design, methods or materials would significantly impact the embodied carbon of the project. This study used the life cycle analysis (LCA) methodology set out within the BS EN 15978 standard. The embodied carbon that was included in this study included emissions from the product (raw-material supply, raw-material transportation to manufacturing facilities, and manufacturing emissions) and construction process (transport of material to project site, and construction installation processes) life cycle stages. This is referred to as an "upfront" (or capital) embodied carbon assessment. This study omitted emissions from the use and end-of-life stages, including maintenance, repairs and demolition.

Ian H. Whitehead, Madeleine Gaul, Courtney Forth and Erica Frederickson

Ian H. Whitehead, Madeleine Gaul and Courtney Forth are decarbonizing tunnels lead, engineer in training and project engineer in training, Mott MacDonald and Erica Frederickson is project manager, Traylor Bros Inc., email ian.whitehead@mottmac.com.

Existing embodied carbon publications

There is a growing body of guidelines and standards related to embodied carbon in infrastructure. Examples include ISO 14064-2, PAS 2080, "How to Calculate Embodied Carbon" (IStructE, 2020), and the RICS Whole Life Carbon Assessment standard. While these are not tunnel specific, they provide useful guidance to practitioners undertaking embodied carbon assessments.

The tunneling industry has recognized the need for more industry-specific guidance. In 2024, the International Tunnelling Association (ITA) published a report on low-carbon tunnel linings (ITAtech, 2024). This report provides guidance to clients, designers and constructors to significantly reduce the carbon emissions associated with concrete tunnel linings. The report includes a range of key topics, including reducing carbon through contracts and procurement, carbon accounting, selection of low-carbon concrete materials, specifications, design, construction, and operations and maintenance. One of the recommendations of the report is for the industry to publish carbon footprints of recently completed tunnels — this article is a response to that.

At the Tunnelling Association of Canada (TAC) conference in 2023, Mott MacDonald presented the results of an embodied carbon comparison of various tunnel configurations (Whitehead, 2023). The authors undertook a comparison between two common configurations used for transit tunnels: single bore and twin bore. The study focused on embodied carbon during the construction phase, using data from a project in North America where both options were considered. The results of the embodied carbon assessment showed that the twin-bore configuration station had approximately 60 percent higher

TABLE 1

Embodied carbon of baseline tunnel project, by material used.

Material	Embodied carbon (tCO_2e)	% of total embodied carbon
Concrete/grout	17,500	58%
Steel	3,600	12%
Muck/fill	2,000	7%
Fuel	4,300	14%
Electricity (grid)	1,800	6%
Misc.	1,000	3%
Total	**30,200**	**100%**

TABLE 2

Embodied carbon of baseline tunnel project, by project component.

Project component	Embodied carbon (tCO_2e)	% of total embodied carbon
Launch shaft	8,200	27%
Reception shaft	3,300	11%
Tunnel	14,000	46%
Ancillary structures	4,700	16%
Total	**30,200**	**100%**

embodied carbon than the single-bore configuration station. However, it was found that the single-bore running tunnel embodied carbon was approximately three times greater than the twin-bore tunnels. Hence, unless stations are less than 500 m (1,640 ft) apart, the overall embodied carbon for single-bore tunnel and stations could be substantially higher than for a twin-bore configuration. Another notable finding presented by Whitehead and Gaul was that the embodied carbon of jet grouting was disproportionately high relative to its target strength. They reported that the embodied carbon per unit volume of jet grouted ground was similar to a standard 50-MPa (approximately 7,000-psi) concrete.

Baseline tunnel project

The baseline tunnel project created for this research consists of a bored tunnel of approximately 6.5 m (21 ft) excavated diameter and 1 km (0.6 mile) long, a launch shaft, a reception shaft and ancillary structures. Project field data were used to determine material quantities. To create a broadly relevant baseline, some project elements were removed. Additionally, emissions factors for materials were selected based on regional or national averages. For the baseline tunnel project, the approximate embodied carbon of the tunnel was 13,000 metric tons of CO_2 equivalent (tCO_2e) per km.

Tables 1 and 2 show the absolute and proportion of embodied carbon split by materials used and project components.

Table 3 presents a high-level breakdown of the baseline embodied carbon of the components of just the tunnel. Jet

TABLE 3

Embodied carbon of baseline tunnel project, by tunnel component.

Tunnel component	% of embodied carbon
Tunnel lining	18%
Annular grout	9%
TBM launch block	6%
TBM procurement	14%
TBM power	10%
Invert concrete	6%
Safe haven	14%
Muck transport	6%
Equipment fuel	8%
Tunnel misc.	9%
Total	**100%**

TABLE 4

PCTL concrete emissions factors.

Concrete mix	Emissions factor ($kgCO_2e/m^3$)
Baseline (30% FA mix)	483
Ultra-low-carbon concrete (Vinci)	117

TABLE 5

Potential embodied carbon savings from ultra-low-carbon PCTL.

Comparison	Baseline (30% FA mix)	Ultra-low-carbon mix (Vinci)
Change in PCTL relative to baseline	0%	–73%
Change in tunnel EC relative to baseline	0%	–13%
Change in total construction phase EC relative to baseline	0%	–6.2%

TABLE 6

Grout mixes emissions factors.

Grout type	$kgCO_2e/m^3$
Annulus grout standard two-part (Aldrian, 2023)	310
Annulus grout optimized one-part (Aldrian, 2023)	40

grout blocks were included for the tunnel boring machine (TBM) launch and for a safe haven along the tunnel alignment. "TBM procurement" represents an estimate of the embodied carbon of TBM manufacture and ocean transport from Europe to North America. "TBM power" is based on diesel gensets on site. Supplied grid electricity is included within "Tunnel misc." for powering other fixed equipment and facilities on site. "Muck transport" is based on road haulage of all tunnel muck.

Embodied carbon comparisons

A series of comparisons is described in this article. In each case the baseline tunnel project was compared against alternative options. Results are presented in terms of estimated change in embodied carbon of that item and percentage change in the embodied carbon relative to the overall construction phase of the baseline tunnel project. If applicable, the change in embodied carbon relative to baseline is also presented with respect to the embodied carbon of a component of the baseline project: for example, the tunnel.

Low-carbon precast concrete tunnel lining. The baseline tunnel project was based on a steel fiber-reinforced precast concrete tunnel lining (PCTL) used on a recent project. As shown in Table 3, the estimated embodied carbon of the PCTL represented 18 percent of the tunnel total, the highest component share. To investigate the potential for embodied carbon reduction in PCTLs, this study compared the embodied carbon of the PCTL on the baseline tunnel project to an ultra-low-carbon precast concrete mix.

The emissions factor derived for the baseline tunnel project was based on a mix design used on a recent project. It was calculated using the material weight of each ingredient and applying material emissions factors from environmental product declarations to calculate the embodied carbon per cubic meter of concrete. The PCTL design for the baseline had a strength of 60 MPa and a steel fiber content of 35 kg/m^3. The cementitious materials used in this design consisted of 70 percent general-use cement and 30 percent fly ash (FA, assumed to be trucked approximately 2,000 km to the precaster).

The alternative mix was an "ultra-low-carbon concrete" used by Bessac/Vinci on a pipe jacking tunnel project in France (Paul-Dauphin, 2023). The requirements for this mix included a concrete strength of 50 MPa; however, the paper by Paul-Dauphin reported results in excess of 70 MPa, so this was considered comparable to the baseline PCTL mix design. The paper also reported on a different ultra-low-carbon concrete mix used for PCTL application — that mix was not used for this comparison because some of the data required were not available.

The resulting emissions factors are shown in Table 4. While the potential reduction is large, the authors note that this is not a direct comparison because this concrete mix was used in a different application (precast pipe). Table 5 shows the potential savings to the tunnel and total project embodied carbon if this alternative were used.

Annular grout. During tunneling, grouting behind the PCTL can be completed with a two-part grout or a one-part grout system. For the baseline tunnel project, the standard grout was assumed to be a two-part cement grout. This baseline was compared to the one-part sanded grout mix as described by Aldrian (2023) for optimization

TABLE 7

Potential embodied carbon savings from various grout mixes.

Comparison	Baseline (two-part cement grout)	Optimized one-part sanded grout
Change in backfill grout relative to baseline	0%	–90%
Change in tunnel EC relative to baseline	0%	–12%
Change in total construction phase EC relative to baseline	0%	–5.5%

TABLE 8

Potential embodied carbon savings if procuring remanufactured TBM.

Comparison	Baseline (new)	Remanufactured
Change in TBM procurement EC relative to baseline	0.0%	–64%
Change in tunnel EC relative to baseline	0.0%	–9%
Change in total construction phase EC relative to baseline	0.0%	–4.1%

TABLE 9

Embodied carbon variations based on TBM launch method.

Baseline jet grout launch			Launch lock		
Component	**tCO_2e**	**% of total**	**Component**	**tCO_2e**	**% of total**
Jet grout block + traditional eye seal	812	89%	Launch Lock and steel eye	167	93%
Steel starter rings	96	11%	PCTL starter rings	12	7%
Total	**908**		**Total**	**179**	

of embodied carbon. Tables 6 and 7 show the emissions factors of the grout mixes used in this study, and the impact on tunnel and total project embodied carbon of the alternatives, respectively.

Tunnel boring machine. The baseline tunnel project assumed use of a new TBM. The associated embodied carbon was estimated based on weight, with the simplifying assumption that all the material was steel. A weight of 1,005 t was used based on a recent project. An emissions factor for steel plate was used (U.S. average). No manufacturing-related emissions were considered due to lack of data. An alternative scenario was tested with procurement of a remanufactured TBM. Based on calculations by Herrenknecht (*T&UC*, 2023), remanufacturing can reduce embodied carbon by 71.42 percent relative to use of all new components. This reduction factor was applied to the baseline estimate. The results are presented in Table 8.

Launch lock versus jet grouting. A traditional launch from a shaft was assumed for the baseline tunnel project, representing 6 percent of the tunnel embodied carbon. The traditional launch approach was assumed to include a jet grout block in front of the shaft so that the TBM can excavate through the shaft and gradually increase the face pressure while within the jet grout block.

This was compared with an alternative "launch lock" approach developed by Traylor Bros. and used on recent tunnel projects. The launch lock consisted of a steel can connected to the shaft wall at the tunnel eye which can be pressurized in excess of the expected full-face pressure at break-out. This approach allows for complete testing and commissioning of the TBM prior to break-out. Since full-face pressure can be achieved, the ground can be stabilized by the TBM, so ground treatment is not required.

When comparing the two launch options, the thrust frame, TBM cradle, and platform are components used in both launch options and were excluded from the calculation. Table 9 shows the main components considered for each option and the associated embodied carbon.

By removing the jet grout block and utilizing a launch lock approach the embodied carbon was reduced by 80 percent. This approach reduced the total embodied carbon for the project by 2.4 percent (Table 10).

Jet grout versus artificial-ground-freezing safe haven. A safe haven along a tunnel alignment can provide an area to depressurize the tunnel face and perform maintenance on the TBM. If required, an artificial safe haven can be constructed through jet grouting or by artificial ground freezing (AGF). In the baseline tunnel project a safe haven constructed with jet grout is assumed. This has

TABLE 10

Potential embodied carbon savings from using a launch lock versus jet grout.

Comparison	Baseline (JG)	Launch lock
Change in TBM launch relative to baseline	0%	–80%
Change in tunnel emissions relative to baseline	0.0%	–5%
Change in total construction phase emissions relative to baseline	0.0%	–2.4%

TABLE 11

Potential embodied carbon carbon savings from AGF.

Comparison	Baseline (JG)	AGF (gensets)	AGF (US avg grid)	AGF (Canada avg grid)	AGF (BC grid)
Safe haven EC (tCO_2e)	1,983	758	473	126	18
Change relative to baseline	0%	–62%	–76%	–94%	–99%
Change in tunnel EC relative to baseline	0.0%	–9%	–11%	–13%	–14%
Change in total construction phase EC relative to baseline	0.0%	–4.1%	–5.0%	–6.1%	–6.5%

been compared to performing AGF with power supplied by generators for the cooling of a brine-based system to establish and maintain the freeze. The emissions factor for jet grout was determined based on field data from recent projects where the quantity of cement used per column was known (with no cement replacement by supplementary cementing materials, SCMs). The fuel consumed for the AGF alternative was estimated based on recent project data for a ground-freeze safe haven formed in silty sands, with a freeze plant operational duration of 19 weeks. A shorter duration could be considered, depending on project requirements.

Additional scenarios were developed based on using grid power as opposed to on-site diesel generators. To compare the potential reduction in embodied carbon, the estimated power rating for the gensets was used to convert the diesel consumed into kilowatt-hours of grid electricity. Table 11 presents the results.

Transport method for muck disposal. The baseline tunnel project was assumed to require the transport of approximately 91,000 m^3 of muck. To assess the sensitivity of muck disposal method, different scenarios were created using various transport modes and distances. The emissions factors for these modes of transportation were sourced from U.S. Environmental Protection Agency (EPA) and Texas A&M Transportation Institute (TTI) reports (EPA, 2024; Kruse, 2022).

Dump trucks are the standard method of muck disposal as they are the most accessible for many projects. The assumed baseline travel distance was 65 km (40 miles) by road. This was compared against rail and barge alternatives. Rail transport, although requiring infrastructure and energy, tends to have a lower carbon footprint over the same distance because of its higher capacity and greater energy efficiency compared to trucking. The rail scenario was assumed to include a rail leg of 65 km (40 miles) and a truck leg of 10 km (6.2 miles). Similarly, barges have a relatively low energy intensity per tonne-kilometer. Three barge scenarios were tested: a long barge (188 km or 116 miles) plus 2 km (1.2 miles) truck leg; a short barge (63 km or 40 miles) plus 2 km (1.2 miles) truck leg; and a short barge (65 km or 40 miles) with disposal at sea. As shown in Table 12, barge plus disposal at sea offers the biggest potential embodied carbon saving; however, the environmental impact of marine disposal must also be considered. For tunneling projects, the presence of manmade contaminants in the muck (for example, grease, ground conditioners) and risk of naturally occurring harmful substances (for example, potentially acid-generating rock) may dictate whether disposal at sea can be considered as an alternative disposal method or not. The comparison shows that replacing trucking with barge transportation, where possible, can generate large savings in embodied carbon, even when traveling further distances.

Lattice girders versus steel sets. For shaft construction in rock, steel sets and/or lattice girders are often used as a method of excavation support. The embodied carbon difference between using steel sets versus lattice girders for supporting shaft excavation primarily stems from their structural efficiencies. Lattice girders employ a truss-like structure that is designed with a more efficient use of material and requires less steel than standard steel sets to support an equivalent load. To compare the magnitude of the embodied carbon associated with the selection of

TABLE 12

Potential embodied carbon savings by muck disposal method.

Comparison	Baseline truck	Rail + truck	Long barge + truck	Short barge + truck	Barge + disposal at sea
Change in muck transport EC relative to baseline	0%	–68%	–73%	–89%	–92%
Change in construction process EC relative to baseline	0%	–13%	–14%	–18%	–18%
Change in total construction phase EC relative to baseline	0%	–3.3%	–3.6%	–4.4%	–4.5%

TABLE 13

Potential embodied carbon savings by support element.

Comparison	Baseline (steel sets)	Lattice girders
Change in shaft support steel EC relative to baseline	0%	–63%
Change in reception shaft EC relative to baseline	0%	–8%
Change in total construction phase EC relative to baseline	0.0%	–0.8%

TABLE 14

Ready-mix concrete regional embodied carbon variations.

Comparison	Baseline (US avg)	British Columbia	Ontario	US Northwest	US So. Central	US Eastern
Change in concrete EC relative to baseline	0%	–11%	–9%	+4%	–3%	+3%
Change in total construction phase EC relative to baseline	0%	–6.6%	–5.4%	+2.2%	–2.0%	+1.7%

shaft support, two scenarios were created. The baseline tunnel project assumes use of steel sets. This was compared against an alternative scenario using lattice girders. The weight of steel required for the steel set design was approximately 2.7 times more than that of the lattice girder design. To calculate the embodied carbon, the same emissions factor for structural steel was used, sourced from the American Institute of Steel Construction (AISC) Fabricated Steel Plate EPD (AISC, 2016). The results in Table 13 show the potential saving in embodied carbon by support element, relative to the shaft, and relative to the baseline tunnel project.

Ready-mix concrete regional variation. The baseline tunnel project was assumed to use approximately 31,000 m^3 of ready-mix concrete. The ready-mix concrete mixes for the baseline tunnel project were assessed using U.S. national average emissions factors. This resulted in ready-mix concrete comprising 35 percent of the total embodied carbon of the baseline tunnel project. This baseline served as a reference point to evaluate the environmental impact of ready-mix concrete in tunneling projects. The embodied carbon of concrete varies regionally due to differences in raw material sourcing and energy mixes across regions. The carbon intensity of concrete produced in regions that rely heavily on fossil fuel energy is typically higher compared to regions with less reliance on fossil fuel energy sources. To highlight the variability in embodied carbon of ready-mix concrete, the project embodied carbon assessment was modified using emissions factors for five different regions across North America sourced from the Carbon Leadership Forum (Waldman, 2023). The results, shown in Table 14, highlight the differences between regions and the relative impact the ready-mix concrete source region was found to have on total emissions.

Discussion

Table 15 provides a summary of the alternative options that were studied and a sorted list of those alternatives that were found to have the largest potential savings in project embodied carbon relative to the baseline tunnel project.

For alternatives that are based on regional differences — ready-mix concrete and grid electrical power — the intent in presenting these alternatives is not to imply that

TABLE 15

Alternative options to reduce project embodied carbon.

Variable	Alternative option	% reduction in project EC
Ready-mix concrete region	British Columbia	–6.6%
Safe haven	Artificial ground freeze (BC grid)	–6.5%
PCTL	Vinci ULC mix	–6.2%
Electricity grid	British Columbia	–5.6%
Backfill grout	Optimized 1-part sanded grout (Aldrian)	–5.5%
Muck transport method	Barge + disposal at sea	–4.5%
TBM	Remanufactured	–4.1%
TBM launch	Launch lock	–2.4%
Shaft rock support	Lattice girders	–0.8%
Total embodied carbon savings potential identified		**–42%**

projects should be built elsewhere. Rather, this is intended to provide project teams awareness of the potential savings with existing technologies. For projects in regions where the electricity grid is relatively high in embodied carbon, there may be options to purchase greener power, if that is aligned with project sustainability goals. For ready-mix concrete, some of the potential savings in embodied carbon that other regions have ready access to may be available via alternative mix designs with higher cement replacement with SCMs or with Portland-limestone cement.

All of the options investigated in this study are based on approaches that have been used on actual projects, rather than hypothetical alternatives. However, the authors acknowledge that not all alternatives would be feasible currently on any particular project due to local availability of alternative materials or proximity to lower carbon solutions. Therefore, this list is intended to assist project teams in determining what to focus resources on when there is a requirement to reduce the embodied carbon of a project.

Conclusions and recommendations

The results above show that significant reductions in embodied carbon can be obtained on tunnel projects. However, to achieve such reductions it is not sufficient to just focus on one element of the tunnel project, such as the PCTL.

Embodied carbon estimates can be undertaken at any stage in a project, particularly once material quantity information is available. The authors recommend that project teams do such estimates. This will allow embodied carbon reduction opportunities to be identified early and discussed in a workshop setting so that the most suitable options for that project can be investigated further. This early effort is valuable so that there is sufficient time for further research, enabling works and industry engagement to be done.

Additionally, the authors recommend that project teams in the construction phase of projects collect data on actual quantities and use the data to estimate as-built embodied carbon. This data can be extremely valuable in improving the accuracy of future embodied carbon estimates for tunnels.

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Innovative design and construction of new passageway tunnel connecting No. 7 Flushing Line to Grand Central

The new passageway tunnel at the 42nd Street-Grand Central Station of the Flushing Line project site is located adjacent to Grand Central Terminal at the intersection of East 42nd Street and Lexington Avenue in Manhattan, NY. This location is one of the most congested areas in the nation, both above grade at street level, and below grade. Grand Central Terminal is a transportation hub for New York City and is the connection point between the Metro North Railroad (MNR) coming to Grand Central Terminal from the north, the newly constructed Long Island Rail Road (LIRR) service via Grand Central Madison Station, and the New York City transit system. Millions of passengers are transferred between different services via underground passageways in this area every day. Passengers and commuters traveling to and from Manhattan via the MNR and LIRR use this terminal and surrounding stations and connection points to transfer to the Numbers 4, 5 and 6 subway-line trains on the Lexington Avenue Line, the No. 7 train on the Flushing Line, and the S train on the 42nd Street Shuttle.

The original Flushing Line station was constructed in the early 1900s, using the drill-and-blast tunneling method lined by unreinforced concrete liner, and due to high ridership demand, the platform length was increased from 45 m (150 ft) to approximately 180 m (600 ft) 15 years later, after the initial opening.

The purpose of this project is to reduce congestion at the platform level of the Flushing Line 42nd Street Station during the rush hours and to improve the passenger circulation capacity by constructing a new passageway and adding a new stair at the existing platform. Figure 1 shows the existing condition, and Fig. 2 shows a rendering of the added stair after completion of the project.

Due to limited number of track outages available for this line, most of the construction activities had to be planned to be performed during live train and passenger traffic with minimal impact on daily operation of this station in the heart of Manhattan. The proposed site plan illustrates the alignment of the passageway tunnel, as depicted in Fig. 3. To construct a passageway tunnel

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FIGURE 1

Flushing Line 42nd Street Station platform.

parallel to the existing station cavern and establish a connection from the top of the station, along with installing stairs descending to the center platform, it was necessary to demolish and remove half of the cavern's roof. To ensure the stability of the existing cavern structure, which was more than 100 years old, project requirements and design criteria (PRDC) that were part of the contract documents mandated bracing of the structure. Given that this is one of the busiest subway stations in the nation, a complete station shutdown was not feasible. Consequently, all tunneling, and modification activities were required to proceed with minimal disruption to subway operations, while ensuring the safety of passengers on the platform.

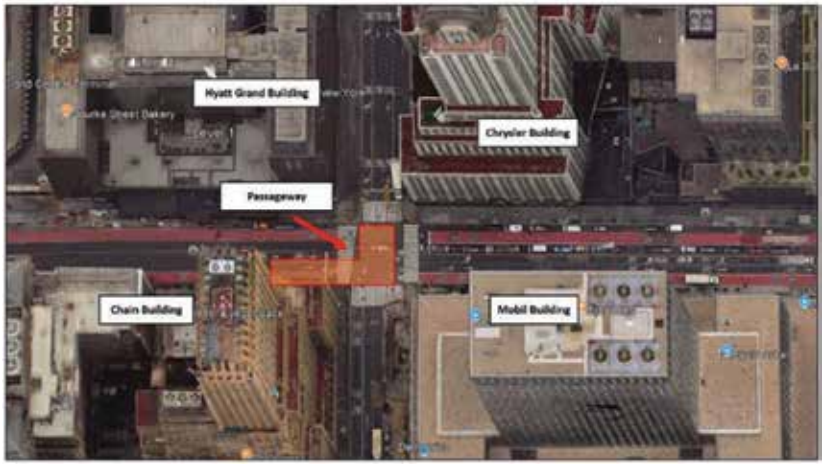
The preliminary design documents outlined concepts for bracing and strengthening the cavern structure while prescribing measures to protect the track and platform from construction activities occurring above the station. Figure 4 illustrates a rendered representation of the existing cavern layout along with the newly proposed passageway. Figure 5 provides a detailed view of the relationship between the existing structure and the planned addition, highlighting key features such as radial beams, header beams and steel columns, which form an integral part of the bracing system.

Design challenges and innovative solutions

Design challenges. One of the requirements of the request for proposal (RFP) was that the cavern arch be braced and supported by steel beams and columns near the planned cut-out area. Additionally, a track and platform protection system (shield system) was

FIGURE 2
Proposed new stair rendering.

FIGURE 3
Proposed site plan location of passageway.



envisioned to be installed flush with the intrados of the arch roof, supported by a series of curved steel beams. These beams would be supported by another beam anchored to the station wall at one end, with the other end supported by temporary steel columns placed in the middle of the platform, as shown in Fig. 5.

During the proposal phase, this solution was discussed with the builders and agreed upon for advancement to the final design. To minimize potential deformations and movements during roof demolition, the steel columns and supporting beams would be jacked and preloaded from a pit at the platform level. Due to the tight timeline for investigating existing conditions and the short design schedule — particularly the lead time required for ordering and fabricating steel members — finalizing the design and fabrication of these components became a critical-path task in the project's overall schedule.

To design the supporting elements, the team utilized the results obtained from the finite element modeling (FEM) developed to estimate stress levels within the existing structure. However, there was very limited information available regarding concrete compressive strength, concrete thickness and the presence of any reinforcement — parameters that are essential for designing the steel bracing elements and protection shield. To address these gaps, the team planned and conducted both destructive and nondestructive testing on the existing cavern.

As part of this effort, a 3D laser scan of the cavern structure was performed to develop a 3D point cloud. This was used to identify potential conflicts, verify clearances and determine the precise locations and elevations for new bracing elements, framing systems and the protection shield during the construction of the passageway.

The team also proposed and conducted nondestructive testing (NDT) to investigate the presence of reinforcement in the concrete walls and arch above the platform near the future passageway break-in area. The goal was to use ground-penetrating radar (GPR) to detect any metal objects, such as rebars, beams or other embedded materials, within the concrete. A specialty contractor employed ground-coupled antennas of varying frequencies, integrated into both a GPR pushcart and a handheld unit. After processing and analyzing the GPR data, it was concluded that no reinforcement was used during the construction of the station cavern. Figure 6 shows GPR testing on the wall and arch of the existing cavern.

Results of the core testing performed on the arch during RFP development revealed compressive strengths ranging from 2,860 psi to 9,010 psi. Additionally, supplemental geotechnical core testing conducted by the team reported compressive strengths ranging from 4,370 psi to 12,760 psi.

Design innovations

Protection shield. The proposed design for the protection shield, as outlined in the RFP documents and shown in Fig. 7, was straightforward and a simple design task. This system would provide the required protection during tunneling and arch demolition activities. The challenge was that a different secondary protection shield would be needed after the completion of the arch break-in for the contractor to be able to continue with construction of the passageway slab and stairs over the track and platform. Construction and installation of this secondary shield would be both time-consuming and costly. Furthermore, the limited availability of track outages, due to the station's critical location, made

obtaining additional outages almost impossible. To address these challenges, the team developed an innovative shield design that could be installed once and remain in place until all the tunneling activities, cavern arch demolition and passageway construction were completed. This approach did not only reduce the cost of construction and installation of the temporary protection shield but also eliminated the need for the multiple track outages required for the installation and removal of two different shield systems.

This solution was developed by working backward from the final geometry requirements of the passageway and stair structure and considering the new design concept of the protection shield. To be able to do this, a series of steel beams would be embedded into the cavern arch/wall by coring the existing structure at the penetration locations, as shown in Fig. 8. These beams served as the primary support for the shield, with a roadway steel plate installed over them to provide a continuous protection surface. This design needed to be strong enough to withstand all incidental and accidental construction loads while accommodating the limited space due to the cavern arch geometry and train clearance requirements.

After determining the sizes of all the supporting elements and discussing constructability with the contractor, the final design details for the system were developed. The assumed loads for the shield design were based on PRDC requirements, with the expectation that during the arch demolition, the roof sections would be broken into smaller concrete pieces and removed through the excavated passageway. There was no allowance for the shield to resist the impact of fallen concrete pieces or any additional object impact loads.

As is common with any design-build contract, there was a change in approach, and the team was asked to investigate whether the shield could be redesigned to resist impact loads from fallen concrete pieces. This redesign would eliminate the need to hoist concrete pieces during the arch demolition and accelerate construction. An investigation result indicated that while the shield beam sizes could be increased to resist additional loads, the steel plate installed over the

FIGURE 4

New proposed passageway.

FIGURE 5

Proposed bracing system and protection shield for new passageway (RFP).

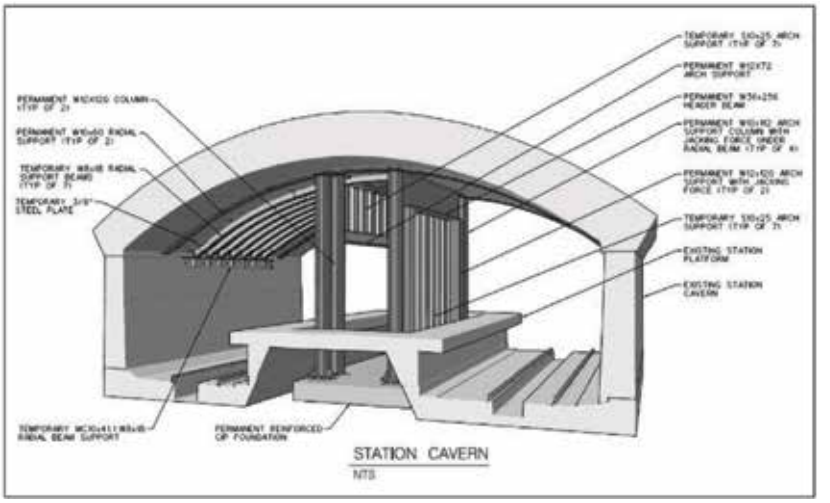


FIGURE 6

GPR test in wall and arch.

FIGURE 7

Proposed shield configuration in the PRDC.

FIGURE 8

Core extraction for shield beams installation.

beams was the controlling element. Its required thickness would need to be increased significantly, to the point of impracticality.

Another option considered was to reduce the spacing between the support members, but this was also deemed impractical. At one point, a continuous wood block support system was envisioned to address the issue, but this option was ultimately rejected primarily because of the height of the void space above the shield, which caused significant impact loads from fallen concrete sections.

To resolve this, and after consulting with the builders, it was decided to eliminate the impact loads by filling the void space with a compressible fill material. This material had been successfully used in a previous project to create a safe temporary working platform, making it a proven and effective solution for this challenge.

The use of the compressible fill material offered two key benefits:

1. It effectively eliminated the impact force from falling debris without adding significant weight to the structure.
2. It served as a temporary working platform for construction activities inside the passageway and above the shield.

The new shield design streamlined the construction process while enhancing safety and reducing cost.

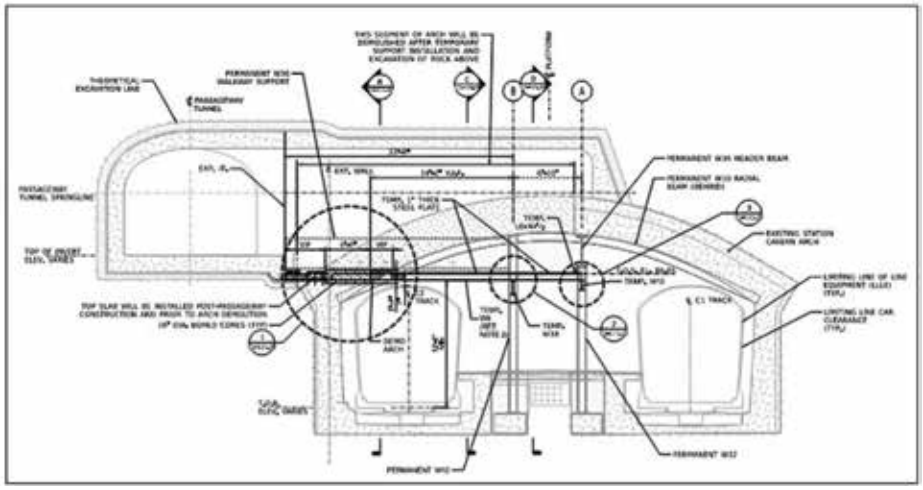
Radial beams. As shown in Fig. 9, the radial beams are primary structural members designed to support the cavern arch during tunneling operations and after the arch roof is broken to connect the passageway tunnel to the platform via new stairs. These beams will be supported by a pair of steel columns installed in the middle of the platform area.

According to the RFP documents, these arch-shaped beams will span the cavern from wall to wall and will be jacked simultaneously at one end and at the column intersection points using a set of jacks installed beneath each column. This arrangement ensures support for the arch roof and allows for control of excessive movement or cracking in the arch by adjusting the jacking pressure as needed during construction. To monitor significant movement during construction, a series of instruments had to be installed on the structure to provide real-time updates.

To install these elements,

FIGURE 9

Final shield and radial beams design.



several system cables mounted along the walls on each track would need to be relocated to create space for supporting and connecting the radial beams to the walls. However, continuous access to the trackside of the station during construction was deemed infeasible. To address this challenge, the design of the supporting members was modified to eliminate these conflicts.

The radial beam profile was revised to eliminate conflicts at wall intersections. This adjustment removed the need to relocate sensitive radio and signal system cables installed along the walls, which lack slack or flexibility for repositioning. The jacking assembly at the ends of the radial beams was also eliminated. Additionally, the jacking system for the columns supporting the radial beams was moved to the top of the columns, avoiding the need for jacking operations in the confined space of the pit beneath the platform. This area is occupied by a massive duct bank buried under the platform, leaving minimal room for column installation and jacking operations.

All the previously mentioned modifications were validated by performing multiple series of 2D and 3D finite element analyses. The results, presented to demonstrate compliance with the RFP and PRDC requirements, confirmed that the revised design is safe and effective.

Break in sequence. Breaking into a station cavern structure that is more than 100 years old under live train and passenger traffic presents significant challenges and requires meticulous planning. Modifying such a historic structure necessitates a comprehensive understanding of both the existing and future stress states, as well as the redistribution of stresses during construction. Unfortunately, information about the cavern's original structural properties, construction techniques and materials was extremely limited.

To address these uncertainties, several ground-structure interaction models were developed to analyze and establish procedures that ensure the structure's safety and stability during tunneling and the break-in process. Destructive testing revealed diverse material properties, while GPR scans provided useful data but had depth limitations. These scans could not confirm the presence of steel or timber supports used during the original excavation. Furthermore, the concrete thickness varied significantly — from 0.7 to 1.5 m (2.5 to more than

FIGURE 10
Break in sequence in the cavern arch.

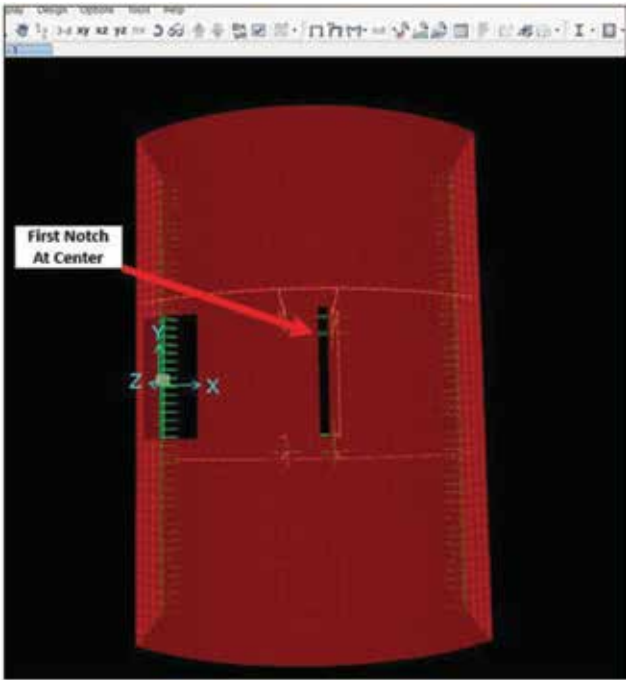


FIGURE 11
Radial beam target points.

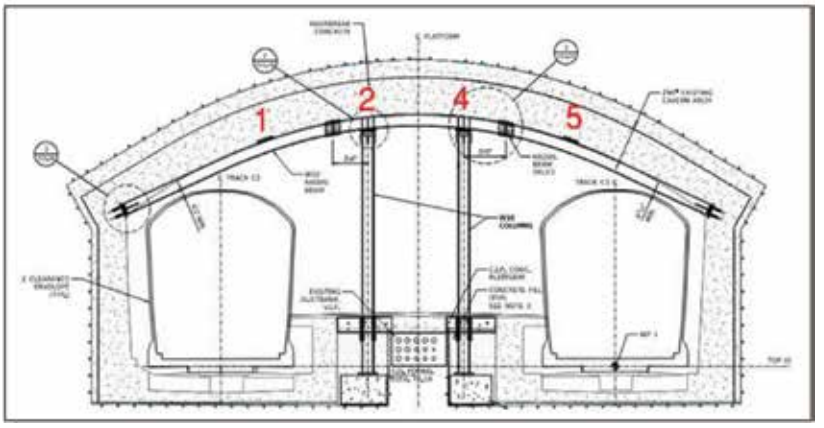
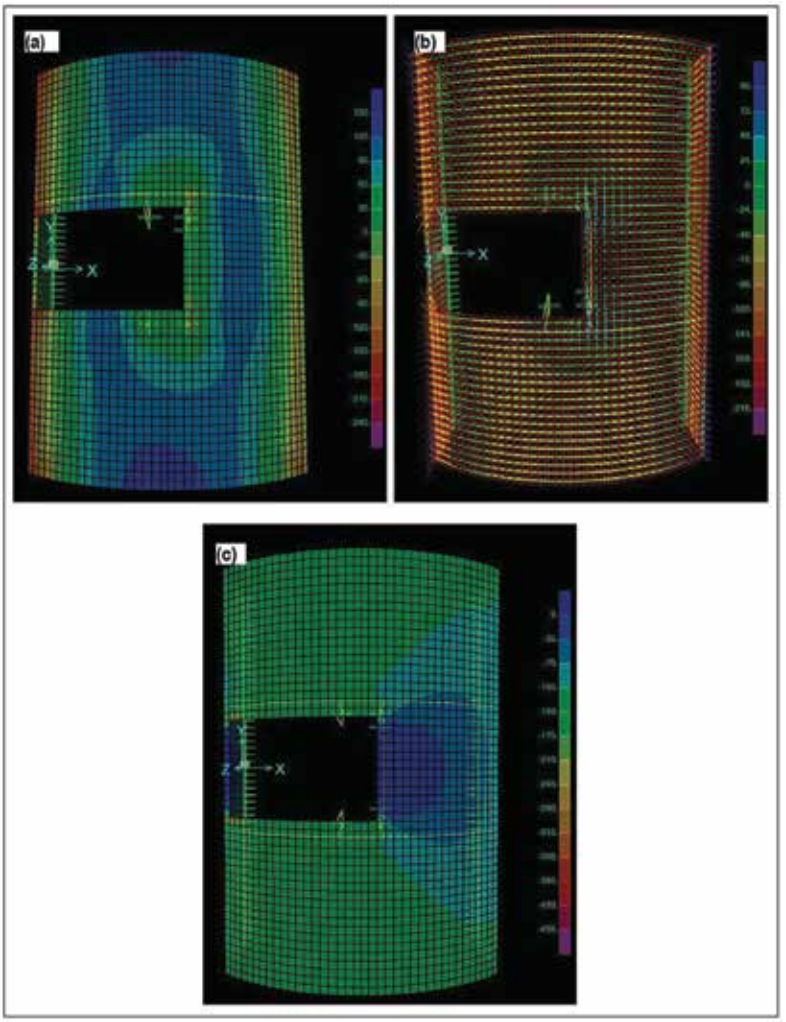


FIGURE 12
Jacking and target point on the header beam.

FIGURE 13

Bending moment (a), stress distribution (b) and axial force (c) on the cavern roof in stage 14.



5.5 ft) — due to the drill-and-blast excavation method.

To account for these variables, multiple 2D and 3D finite element (FE) models were created to analyze stress distribution and evaluate the impact of various break-in sequence scenarios. Additionally, a 3D construction-staged FE model was also developed to simulate construction-induced loads during tunneling activities, the installation of radial beams, the jacking of supporting columns, and stress distribution during arch demolition and the break-in process.

Based on this analysis, it was recommended to start the arch demolition from the center of the cavern and progress toward the sidewalls. However, the contractors preferred to begin at the sidewalls for ease of execution. To safely accommodate this approach, creating a stress-release notch at the center of the arch was proposed. This notch would redistribute axial stresses around the demolition area, ensuring worker safety. Ultimately, the demolition was carried out as initially proposed by the design team. Figure 10 shows a creation of the notch and advancement of the roof demolishing from the wall toward the center of the cavern.

Jacking columns. Based on PRDC requirements, the entire framing system for cavern bracing — comprising radial beams on each side of the break-in, header beams and all additional supporting columns at the platform level — had to be installed and fully engaged with the cavern arch before any tunneling activities for the main passageway could begin. This was achieved by installing jacks at selected locations to preload these members and engage them with the structure.

One of the biggest challenges in designing underground structures is that, unlike above-grade structures such as bridges or buildings, the intensity and magnitude of loads and boundary conditions vary from point to point. This makes it extremely difficult to accurately estimate the loads and stresses in the structure. In addition to the uncertain ground conditions, there was limited information regarding the structural properties of the station cavern. Core samples from the arch revealed significant variation in thickness, ranging from 0.7 to 1.5 m (2.5 to more than 5.5 ft).

Given the limited time and the critical nature of the steel member installation, a series of parametric studies were conducted to investigate the effects of variations in structural properties and loadings on stress estimations, stress redistribution and overall structural behavior during construction. Another uncertainty considered was the boundary conditions and their impact on the cavern and bracing system.

After performing these analyses using both 2D and 3D FE models, charts and tables to guide the jacking operation were developed. To improve accessibility, the jacking locations for the columns were moved to their top portions, providing more working space for the jacking crew. Structural monitoring devices, such as shape arrays and conventional surveying equipment, were employed to accurately measure deformations during the jacking process.

By combining the results of our parametric studies with measured deformations from the initial jacking, our team identified the required preloading levels needed to ensure structural stability prior to tunnel excavation.

Finite element modeling. To strengthen the existing station cavern arch around the new break-in area, two permanent radial beams, one header beam and eight steel columns were designed and installed. Four of these columns are jacked at connection point with radial beams against the concrete arch before any cutting and

FIGURE 14

Maximum force in columns from FEM analysis.

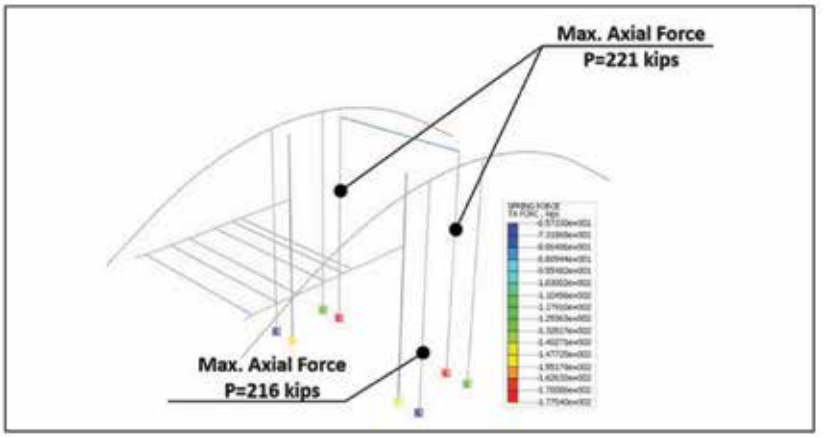
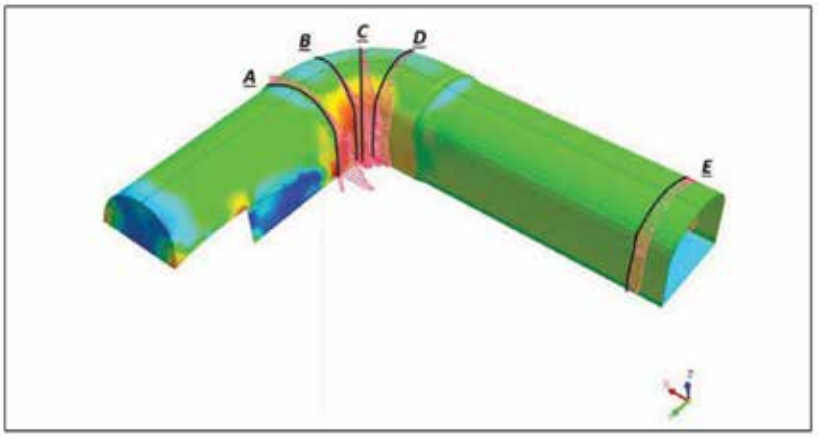


FIGURE 15

Passageway tunnel elbow sections stress distribution.



demolition of the concrete arch.

This section outlines the method used to design the permanent arch support system. External loads such as vertical and lateral rock load, hydrostatic pressure on the existing cavern liner is estimated using the data obtained from geotechnical investigations. The existing cavern 3D FE model is created, and the boundary conditions between the cavern and rock is modeled using compression-only springs to mimic the interaction between rock and the structure. Steel sections for radial beams and columns were added, and estimated load from tunneling activity was also applied to the structure. Service loads cases and their combinations are used for the design of the steel radial beam and columns.

The intent of the jacks was to pre-load the columns and radial beams and to maintain the elevation of the existing arch through all construction stages. The jacking process is performed by adjusting the pressure in the jacks and measuring deformations. The maximum upward movement of a jack will be prescribed by the team based on the results obtained from our parametric study. The movement will be controlled by measuring deformations using survey shots above each jacking assembly and additional target points specified on the radial beams (see Figs. 11 and 12).

The developed 3D FE model was utilized to investigate the behavior of existing unreinforced concrete arch and effect of jacking loads in the cavern structure using construction staging approach. Deflection, bending moment, axial force and shear forces for the cavern structure under staged construction sequence cases were calculated and tabulated to be used during the jacking operation. The construction staged analysis was developed to monitor stress variations and distribution for each stage of the break-in (total of 14 stages). Figure 13a-c show the bending moment, stress distribution and axial force generated on the existing cavern at the last stage 14 of the construction sequence.

The FEM analysis accounted for a concrete arch thickness ranging from from 0.7 to 1.5 m (2.5 to more than 5.5 ft)and evaluated both the lower and upper limits of jacking forces on the columns. The analysis indicated that based on the P-M interaction capacity diagram, the existing unreinforced concrete arch can carry the loads on all the construction staged analysis without being overstressed or developing cracks beyond acceptable limits.

One of the challenges was to estimate the jacking force required to engage the steel supporting members with the cavern structure without damaging the concrete arch. As highlighted before, providing a single magnitude for jacking loads was not possible, considering the variations in the stiffness of the structure and surrounding rock and their interaction with the structure. Lower-limit and upper-limit jacking forces for preset deformations magnitudes were estimated for each stage of the construction and for variation of equivalent stiffness of the cavern structure. Estimated jacking force and column loads for one of these cases are shown in Fig. 14.

The following section outlines the methodology used to design the permanent structural elements for the new passageway. This passageway will be constructed first using a temporary access shaft and drift, which will facilitate the construction of the new tunnel beneath 42nd Street. The tunnel will serve as a connection between the Flushing Line cavern on the east end and the existing mezzanine floor on the west end.

To design the permanent structural elements, the intensity of vertical rock load, water pressure and lateral earth pressure loads over the cavern structure

are used. The cavern sections, including the elbow area, are analyzed using several FE models. These models provided detailed insights into the stress distributions in the final liner, which were used to determine the required section reinforcement for the sections. The results of force distribution in the new passageway tunnel elbow area from Maidas FE modeling are presented in Fig. 15.

Summary

This article presents the innovative design and construction of a new passageway tunnel connecting New York City's 42nd Street-Grand Central Station to the Flushing Line (No. 7) of the New York City Transit system. Located at one of the busiest transit hubs in the world, the project faced unique challenges due to the integration of the new tunnel with a century-old cavern structure.

In this article, the design process is explored, including the estimation of in situ stresses and the creation of a robust supporting framing system to ensure structural integrity during the tunneling and arch demolition phases. A key element of the project was the sequential demolition of the cavern's arch, which required careful planning to maintain the stability of the cavern while accommodating future construction.

To address these complexities, advanced modeling techniques, including ground-structure interaction models and finite element analysis, were employed to analyze stress redistribution and predict the effects of construction activities on the existing cavern.

Additionally, this article discusses the challenges associated with the installation of the initially proposed bracing system and presents an innovative design solution developed by our team to eliminate the need for relocating system components within the station. It also highlights some of the constraints posed by limited space and access during construction.

A significant focus is the collaboration between the project's design engineers, contractors and the project owner to ensure a successful design-build process. The article underscores the importance of communication, innovation and strategic problem-solving in overcoming the various obstacles faced during the project execution.

Overall, the successful integration of the new passageway tunnel into the existing infrastructure represents a significant achievement in both design and construction, addressing technical challenges while meeting the operational demands of one of New York's busiest transit stations.

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Washington Metro Yellow Line Rehabilitation Project wins silver at ITA Tunnelling Awards

The Washington Metro Yellow Line Rehabilitation Project was honored with the Silver Medal in the category "Project of the Year (€100–€500 million)" by the International Tunnelling Association during the ITA Tunnelling Awards & Southeastern Europe Tunneling Conference in Belgrade, Oct. 1-3.

The Washington Metropolitan Area Transit Authority (WMATA) Yellow Line is a section of steel segmentally lined tunnels that have experienced leakage and significant corrosion in isolated areas. A 3,050-linear-ft section of a Yellow Line tunnel required major rehabilitation after suffering advanced corrosion of the steel liner and significant deterioration following decades of use, water infiltration and the consequences of an in-tunnel fire in 2015.

Engineers from RK&K LLP, Schnabel Engineering Inc., Burns Engineering Inc., working with joint venture contractor Kiewit-Shae-Traylor created a three-part rehabilitation design that includes curtain grouting, structural repairs and corrosion protection to provide continued performance. As WMATA's first construction-manager-at-risk (CMAR) project, the design development benefited from collaboration with the contractor through the final design development process.

"The project benefitted significantly from the use of the CMAR delivery method," James Parkes, principal tunnel engineer now with Kiewit told *T&UC*. Parkes worked with Schnabel Engineering on the WMATA Metro Yellow Line Rehabilitation Project.

"Having a contractor on-board early during the design project was very beneficial and prevented delays and cost overruns in the long term. The ability to discuss means and methods and adjust the design and construction documents, as well as the ability to test different methods, sequencing, and products through pilot programs, was extremely beneficial to the project," he said.

In part because of the complexity of the project and the success of the work the project was earlier named UCA Project of the Year during the Rapid Excavation & Tunneling Conference (RETC) in June in Dallas, TX.

"The project was very complicated from a logistical and coordination standpoint. The construction required several different operations to be performed in the tunnel either concurrently or in close sequencing, including sand blasting and grinding for paint and rust removal, curtain grouting, welding and steel repairs, bolt replacement, and applying coatings, plus systems removal, replacement and reinstallation, all in a worksite that has one way in and one way out," said Parkes.

The custom steel liner replacement includes a cathodic protection, a system rarely used in transit tunnel

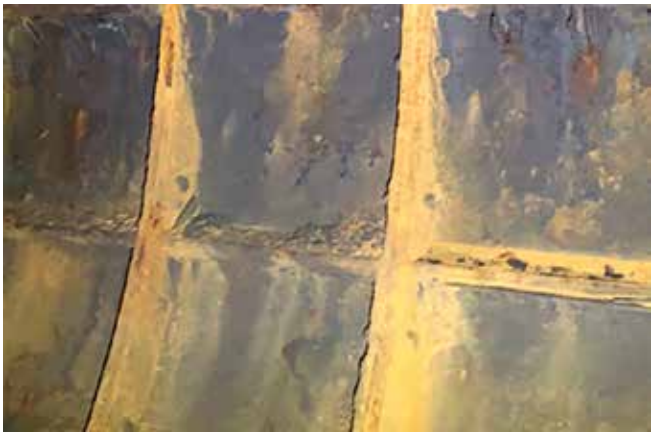
William Gleason, Editor

Grinding of steel liner coating for ultrasonic testing of steel tunnel liner at the WMATA Yellow Line project.

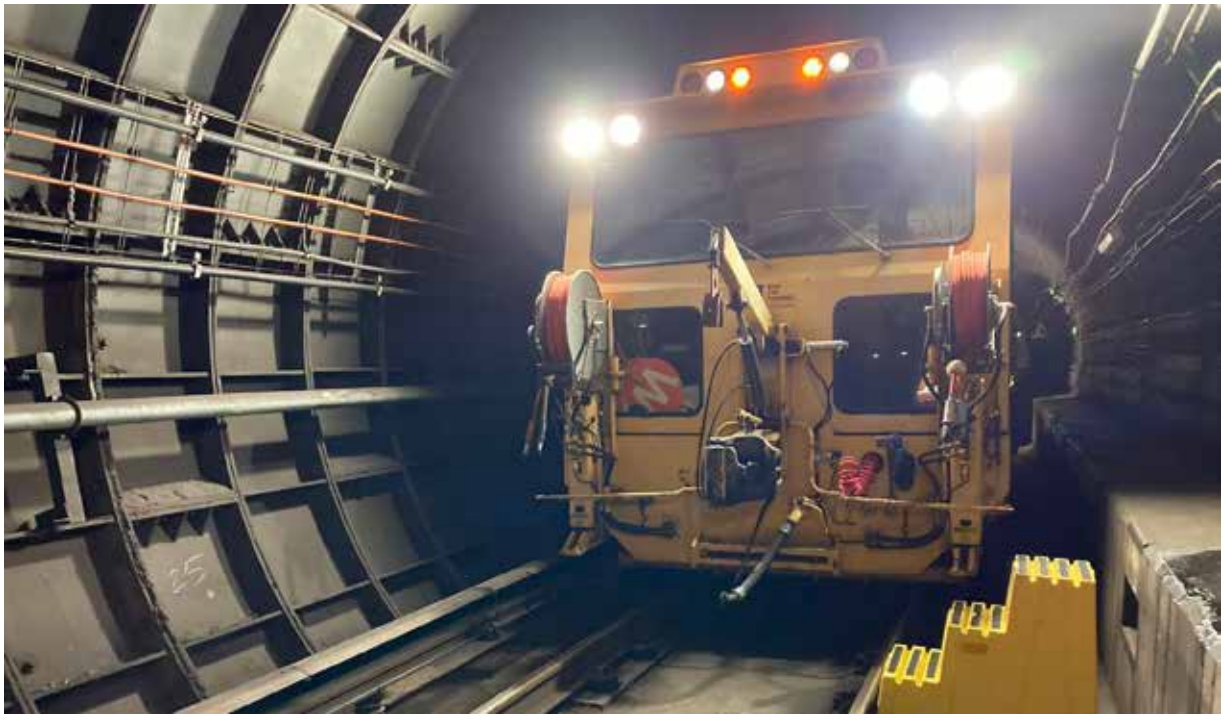
rehabilitation. Civil works of the $303.85 million project were advanced under the terms of the CMAR delivery model that enabled early contractor involvement and was completed on an aggressive eight-month shutdown of the Yellow Line, with crews working 24/7 across 17 distinct work phases. Despite complexity and constraints, the tunnel, originally constructed in the 1970s, returned to service two weeks early and within 0.18 percent of the original contract value.

The rehabilitation required removal of the systems cables, which opened the possibility to upgrade or replace elements of the systems. In addition, there were elements of the cut-and-cover concrete portal structure and the Potomac River bridge that required repairs and upgrades.

"This required very careful and detailed construction planning and logistics, including custom-built work



Observed corrosion and soil inflow in the steel-lined tunnel.



Work train for field trial pilot program at the WMATA Yellow Line project.

trains, on-site fabrication shops, careful supply-chain management, and early procurement of long-lead time items and equipment," said Parkes. "Planning also had to include anticipation of the unexpected, such as unforeseen conditions, uncontrolled leaks and other issues that required adapting the work on site with short notice and limited resources. The same was true of the design phase, which involved developing designs based on limited data collected during limited track outage inspection windows, coordination of different stakeholders within and external to the project, and coordination of dozens of permits. And this all had to be done on a limited and aggressive schedule, both in design and construction phases."

Explaining the rehabilitation of the tunnel, Parkes said, "The tunnel liner consists of steel liner plates, the edges of which bolt together to form circumferential ribs. The ribs are the main load-carrying elements of the tunnel. Overall, the ribs were in good condition with only spot repairs needed. The exterior skin plates of the liner segments transfer the external loads to the ribs. The skin plates had experienced the most deterioration. Some were effectively completely corroded and had virtually no remaining structural capacity. Others were still relatively intact but had experienced enough section loss that their remaining service life was limited." The scope of the work was to rehabilitate the tunnel to extend its service life for at least another 50 years. "Multiple solutions were considered, including the chosen alternatives (repairs of installation of new steel cover plates within the segment bays) as well as individual segment panel overlays with shotcrete or cast-in-place concrete, fully encasing the steel liner with shotcrete or concrete, removal and replacement of compromised liner segments, and variations of these. A weighted decision matrix was used to evaluate the possible options. Certain criteria were pass/fail, such as impacts to the dynamic envelope and safety walk — any option that impacted those would automatically fail. Other criteria were scored on a scale of 1 to 5 and included precedence or past performance, constructability, maintenance cost, service life, impact on systems and operations. Ultimately, the option of using new steel cover plate repairs to the existing steel liner had the highest score and was selected," Parkes added.

Rehabilitation work started in the fall of 2022 and was completed in the spring of 2023.

When asked what lessons from the project he could share Parkes stated, "These types of projects are very complicated from the standpoint of logistics and sequencing. Detailed planning is critical and must start early in the project during the design phase. A pilot program, performed at the 60 percent design stage and consisting of a weekend outage, was instrumental in developing logistics, cost and schedule certainty for the project. Subsequent pilot and fit-up programs in factory shops add additional benefit to evaluate sequencing procedures and different products or methods of applications. Detailed planning goes beyond the construction — flexibility in the contract, such as contingency quantities and measures, are helpful to adapt to actual field conditions.

"For all aspects of the project, well-defined scope, requirements and documentation are beneficial," Parkes explained. "The project benefited from good organization — a well-defined scope, plans for quality management, project management, and risk management; design criteria checklists; formal decision making processes and tracking; and regular coordination meetings kept the project focused and on track." ■

UCA updates Tunnel Watch List to elevate the visibility of important tunnel projects

The 2025 Tunnel Watch List includes five new projects that if approved and constructed will add economic and environmental benefits to the communities in which they are built. The additions to the 2025 Tunnel Watch List include projects in Alabama, Alaska, California, Massachusetts and New York.

Five projects were removed from the 2024 list. The committee, chaired by Greg Hallett, also chose to leave the Gateway Hudson Tunnel Project off the list despite recent confusion regarding its funding status. In September, President Donald Trump cast doubt over the future of the $16 billion Gateway Project when he seemed to suggest federal funding would be terminated.

Transportation Secretary Sean Duffy seemed to contradict those statements when he said the projects are "important" and should "move forward fast."

The five projects added to the 2025 Tunnel Watch List are the Southeast Gateway Line — Phase 2 transit project in Los Angeles, CA; the New York DEP Flushing Bay CSO tunnels in Queens; the MWRA — Metro Water Tunnel Program in Boston, MA; the Knik Arm Highway Tunnel in Anchorage, AK and the TVA Pump Storage Hydropower Plant in Pisgah, AL.

The Southeast Gateway Line, which will eventually stretch more than 19 miles between Union Station in downtown and Pioneer Boulevard in the City of Artesia in Los Angeles, faces a daunting funding shortfall. More than $2 billion has been identified for the project's first phase but the final cost of the project could be as high as $7.75 billion.

(continued on page 32)

2025 Tunnel Watch List

Project	City	State	Owner	Tunnel use
Southeast Gateway Line — Phase 2	Los Angeles	CA	LA Metro	Transit
Savannah River Crossing	Savannah	GA	Georgia DOT	Transit
Second Avenue Subway — Phase 2	New York City	NY	MTA	Transit
NY DEP Flushing Bay CSO	New York City/ Queens	NY	DEP	Wastewater
Sandag Del Mar Tunnel	San Diego	CA	San Diego	Transit
US 64 Corridor K Tunnel	Polk County	TN	Tennessee DOT	Highway
Delta Conveyance	Sacramento	CA	California Department of Water Resources	Water
Sepulveda Transit Corridor Project	Los Angeles	CA	LA Metro	Transit
Red Line Blue Line Connector	Boston	MA	Massachusetts Bay Transit Authority	Transit
Ontario International Airport (ONT) and Cucamonga Station Tunnel	San Bernardino	CA	San Bernardino County Transportation Authority	Transit
MWRA — Metro Water Tunnel Program	Boston	MA	MWRA	Water
Knik Arm Highway Tunnel	Anchorage	AK	Alaska DOT	Transit
White Pine Pump Storage Hydropower Project	Ely	NV	White Pine Waterpower LLC	Energy
California High Speed Rail	Los Angeles to San Francisco	CA	California HSR Authority	Transit
TVA Pump Storage Hydropower Plant	Pisgah	AL	Tennessee Valley Authority	Hydro
Houston Flood Control Tunnels	Houston	TX	Harris County Flood Control District	Wastewater
West Seattle Extension	Seattle	WA	Sound Transit	Transit
Ballard Extension	Seattle	WA	Sound Transit	Transit
Amtrak Hub — redevelopment	Chicago	IL	Amtrak	Transit
Eastside Transit Corridor — Phase 2	Los Angeles	CA	LA Metro	Transit

Tunnel Watch List: Five new projects added

(continued from page 31)

The NY DEP Flushing Bay CSO is a water quality initiative by the New York City Department of Environmental Protection to reduce combined sewer overflows into Flushing Bay.

The Redundancy Tunnel Program for the Massachusetts Water Resources Authority (MWRA) will allow reliability of a vital drinking water system that was impacted by a 2010 main break that resulted in an estimated impact of $310 million per day.

The proposed Knik Arm Highway Tunnel in Alaska would connect the largely undeveloped Point MacKenzie area to the Government Hill neighborhood in Anchorage. A recently commissioned study was prompted by recent advances in tunneling technology and increased traffic along the aging Glenn Highway between Mat-Su and Anchorage.

The study will examine tunnel costs, construction methods, engineering challenges, economic benefits and environmental impacts, among other factors. It is expected to cost at least $1 million and is set for completion late next year.

The Tennessee Valley Authority, the federal utility responsible for providing power to millions of people in north Alabama and parts of six other states in the southeast, has proposed the TVA Pump Storage Hydropower Plant. The stored hydropower would be used to generate additional electricity in times of high need, like cold winter days and peak summer heat.

The Tunnel Watch List is a forward-looking list of tunnels and underground construction projects that are being considered but have not yet secured funding. The goal of the Tunnel Watch List is to elevate the visibility of these important tunnel projects.

All projects are ranked based on five criteria and each project is then scored against those criteria to identify tunnels that will provide the most benefit to society. The rankings help the committee determine the importance of each project to the environment and to the people who live in the area in which it will be built.

Among the many benefits tunnels provide are transportation tunnels that can help reduce carbon emissions, and water tunnels that provide freshwater or provide for the storage of wastewater for treatment. ■

UCA Executive Committee call for nominations

Each year the UCA seeks nominees for the executive committee, and the division is requesting help from the division membership to identify and recruit outstanding leaders for the future.

The UCA Executive Committee consists of 20 individuals, with four officers — chair, vice chair, past chair and secretary/treasurer filled by the SME Executive Director (nonvoting) — and up to 16 members in the following categories: owner (four); contractor (four); supplier (four); engineer (four) and a member at large, such as an academic, may be substituted for any of the categories above.

Terms are for four years, beginning July 1 and ending June 30 annually. Executive committee members are eligible to renew their four-year term one time. Every year, between one to four new members are selected. The vice-chair position is the start of a progressive six-year term, serving two years each as vice chair, chair and past chair. Every two years, a new vice chair is selected. UCA will not select its next vice chair until 2027.

Nominations opened in mid-October 2025 and will close Jan. 19, 2026. The UCA Nominating Committee then reviews the nominations and selects a slate of candidates. The UCA Executive Committee votes on the slate of candidates at its April Executive Committee Meeting.

Requirements

Nominees should be a current UCA member who can show a record of service industry and has previously served on other committees reporting to the Executive Committee, have held senior positions with a record of accomplishments within the industry, and demonstrate a willingness to bear the financial burdens of travel to meetings.

Nominees should have an interest in one or more UCA activities, including educational conferences, publications, promotion and outreach of the tunneling business, and/or interest in international activities, such as the International Tunnelling Association.

Nominees should desire a greater involvement in the leadership of UCA and commit to attend all required executive committee meetings including in-person meetings: January at the George A. Fox Conference and June at the North American Tunneling Conference (NAT) or Rapid Excavation & Tunneling Conference (RETC) biennial conferences.

Submit the following by Jan. 19, 2026: A letter of interest that includes your bio (300 words or less); committee member category with which you are affiliated (owner, contractor, supplier or engineer); a statement that includes your UCA history of involvement, why you want to be on the Executive Committee, and a commitment to attend all meetings and make this committee a priority; and your resume (three pages maximum).

Selection process

Send nominations to Mary Thomas, SME Operations Administrator, at thomas@smenet.org no later than Jan. 19, 2026, 6 pm MT. All materials will be collected, vetted for qualifications, and submitted to the UCA Nominating Committee for review. Final selection will take place at the UCA Executive Committee Meeting in April. New members will be invited to the in-person June UCA Executive Committee Meeting. ■

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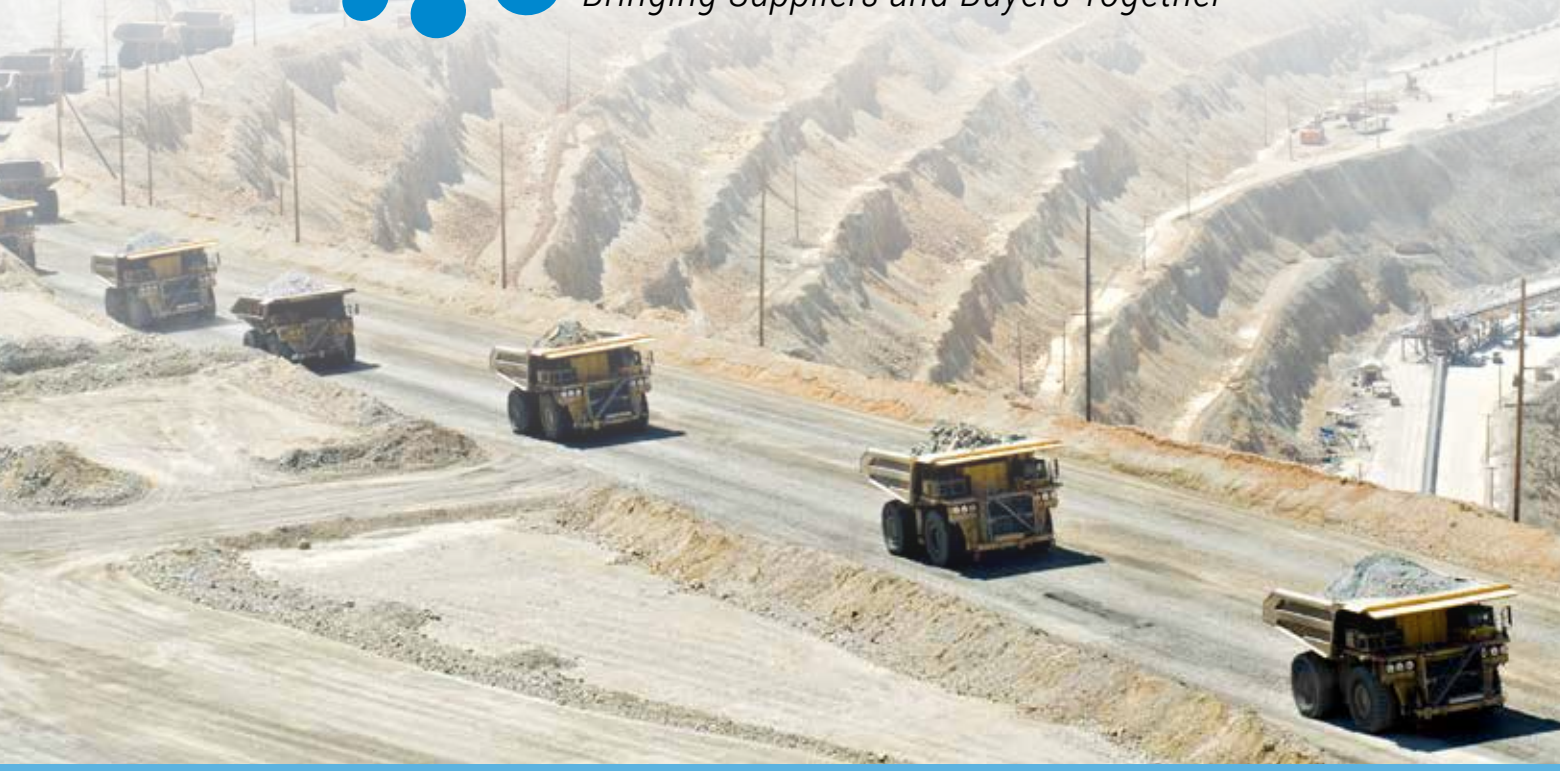

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TUNNEL NAME	OWNER	LOCATION	STATE	BID YEAR	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	STATUS
Minneapolis Central City Parallel Tunnel	City of Minneapolis	Minneapolis	MN	2024/2025	CSO	4,200	10-19	Final planning
Alameda Wet Weather Conveyance	Commission (SFPUC)	San Francisco	CA	2025	CSO	3,800	12	Under procurement
The Portal (Downtown Extension)	Transbay Joint Powers Authority (TJPA)	San Francisco	CA	2025	Transit	3,400	Varies	Shortlist announced
CA High Speed Rail (Northern Section)	CA High Speed Rail Authority	Fresno	CA	2026/2027	Transit	TBD	TBD	Design 1Q 2026
CA High Speed Rail (Southern Section)	CA High Speed Rail Authority	Bakersfield	CA	2026/2027	Transit	TBD	TBD	Design 1Q 2026
Eastside Connection	LACMTA	Los Angeles	CA	2025/2026	Transit	TBD	20	Under design
Ontario Airport Tunnel	San Bernardino Co. Trans. Authority	San Bernardino	CA	2025	Transit	22,000	24	Under procurement
Gateway Manhattan Tunnel	Gateway Development Commission	New York	NY	2025	Rail	2 x 700	varies	Awarded Frontier Kemper
Gateway Hudson River Tunnel	Gateway Development Commission	Hoboken/ NYC	NJ/NY	2025	Rail	2 x 7,400	25.17	Proposals due 10/08/2025
Gateway Systems and Fit Out	Gateway Development Commission	Secaucus to NYC	NJ/NY	2026	Rail	2 x 22,000	varies	Procurement TBD
Gateway NJ Surface Alignment	Gateway Development Commission	Secaucus to North Bergen	NJ	2025	Rail	2 x 7,400	N/A	Procurement TBD
Gateway Existing Tunnel Rehabilitation	Gateway Development Commission	Union City/ NYC	NJ/NY	2036	Rail	2 x 13,000	varies	Procurement TBD
2nd Ave. Phase, Contract 2	NYS-MTA	New York	NY	2025	Subway	16,000	20	Awarded FCC/ Halmar
2nd Ave Phase, Contract 3	NYS-MTA	New York	NY	2025/26	Transit	89,600	20	RFQ due Sept. 2025
2nd Ave Phase 3& 4	NYC-MTA	New York	NY	2027/29	Subway	varies	20	Under study
Three Creeks Tunnel	City of Columbus	Columbus	OH	2027	Sewer	12000	14	Planning
Yonge North Subway Extension	Metrolinx / Infrastructure Ontario	Toronto	ON	2025	Subway	40,000	20	Awaiting Award
Blue Line Extension	Societe de transport de Montreal	Montreal	QC	2025	Subway	19,000	33	Awarded Pomerleau
REM-S Project	Societe de transport de Montreal	Montreal	QC	2026	Subway	23,000	33	Under design
Quebec City - Levis Tunnel	Quebec Transportation Ministry	Quebec City	QC	2026	Transit	27,300	60	Under design
Mill Creek Trunk Improvements	City of Nashville	Nashville	TN	2026	CSO	13,800	10	Delayed for additional study
Nose Hill Project	City of Calgary	Calgary	AB	2024	CSO	10,800	10	Delayed for additional study
Silver Line Extenstion	Boston Transit Authority	Boston	MA	2024	Transit	8,400	22	Delayed for additional study
Stanley Park Water Supply Tunnel	City of Vancouver	Vancouver	BC	2025	Water	5000	15	Bidding
ALCOSAN Ohio River Tunnel #1	Allegheny Co. Sanitary Authority	Pittsburgh	PA	2025	CSO	20,000	18	Under procurement
ALCOSAN Ohio River Tunnel #2	Allegheny Co. Sanitary Authority	Pittsburgh	PA	2025	CSO	5,800	14	Under procurement

To have your major tunnel project added to the Tunnel Demand Forecast, or to update information on a listed project, please contact Sanja Zlatanic at szlatanic@hntb.com.

TUNNEL NAME	OWNER	LOCATION	STATE	BID YEAR	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	STATUS
ALCOSAN Allegheny River	Allegheny Co. Sanitary Authority	Pittsburgh	PA	2028	CSO	33,000	18	Planning
ALCOSAN Mononghahela River Tunnel	Allegheny Co. Sanitary Authority	Pittsburgh	PA	2030	CSO	28,000	18	Planning
Germantown Winghocking Relief	City of Philadelphia Water	Philadelphia	PA	2025	CSO	28,000	20	Under design
West Seattle to Ballard Extension	Sound Transit	Seattle	WA	2026	Transit	2,800	19	Under design
Downtown to Ballard Extension	Sound Transit	Seattle	WA	2027/28	Transit	22,500	19	Under design
Taylor Massey Tunnel	City of Toronto	Toronto	ON	2027	CSO	20,000	15	Under study
Del Mar Bluffs Tunnel	SANDAG	San Diego	CA	2025	Transit	TBD	TBD	Under design
Fraser River Tunnel	BC Ministry of Transportation	Vancouver	BC	2024	Highway	3,000	TBD	Awarded FCC Pomerleau
Stormwater Control Program	Harris Co. Flood Control District	Houston	TX	2028	CSO	52,800	25-40	Under study
LA Metro Sepulvada Pass Corridor	LACMTA	Los Angeles	CA	2026	Transit	55,000	TBD	LOI received - EIS submitted Q3
D2 Subway - 2nd light rail alingment	Dallas Area Rapid Transit	Dallas	TX	2028	Transit	7,230	22	Delayed
Flushing Bay CSO Tunnel	NYC-DEP	New York	NY	2026	CSO	16,500	22	Under study
Cross Harbor Freight Tunnel	NYC Regional Develop. Authority	New York	NY	2028	Rail	25,000	30	Delayed
Superconducting Maglev Project -	TNEM/BWRR	Washington	DC	TBD	Rail	146,500	43	Delayed
Big Creek Storage Tunnel	NEORSD	Cleveland	OH	2026	CSO	22,450	20	Under design
I-94 Drainage Tunnel	MDOT	Cleveland	OH	2025	Storm	6,000	14.5	RFQ Q3 2025
Metro Tunnel Program - Northern Tunnel Southern Tunnel	MWRA	Boston	MA	2028 2027	Water Water	23,760 50,160	10 10	Under final design Under final design
Horizon Lateral Tunnel	Southern Nevada Water Authority	Las Vegas	NV	2027	Water	42,000	9	Delayed
Inner Harbour West Tunnel	City of Toronto	Toronto	ON	2027	CSO	18,400	20	Under design
Piney Branch Tunnel	DC Water & Sewer	DC	MD	2024	CSO	2,200	18	RFQ May 2024
West Transmission Line Relocation tunnel	Hydro One	Toronto	ON	2024	Cables	11,500	10	RFP Ongoing
Pickering Outfall	Ontario Power Generation	Toronto	ON	2024	Water	5,000	43	RFQ ongoing
Delta Conveyance Tunnel	CA Dept. of Water Resources	Sacremento	CA	2027	Water	236,500	36	Under design
Blue Line Extension	Societe de transport de Montreal	Montreal	QC	2024	Transit	19,000	33	Shortlist announced
Black Creek STS Relief System	CA Dept of Water Resources	Sacramento	CA	2027	Water	236,500	36	Under design

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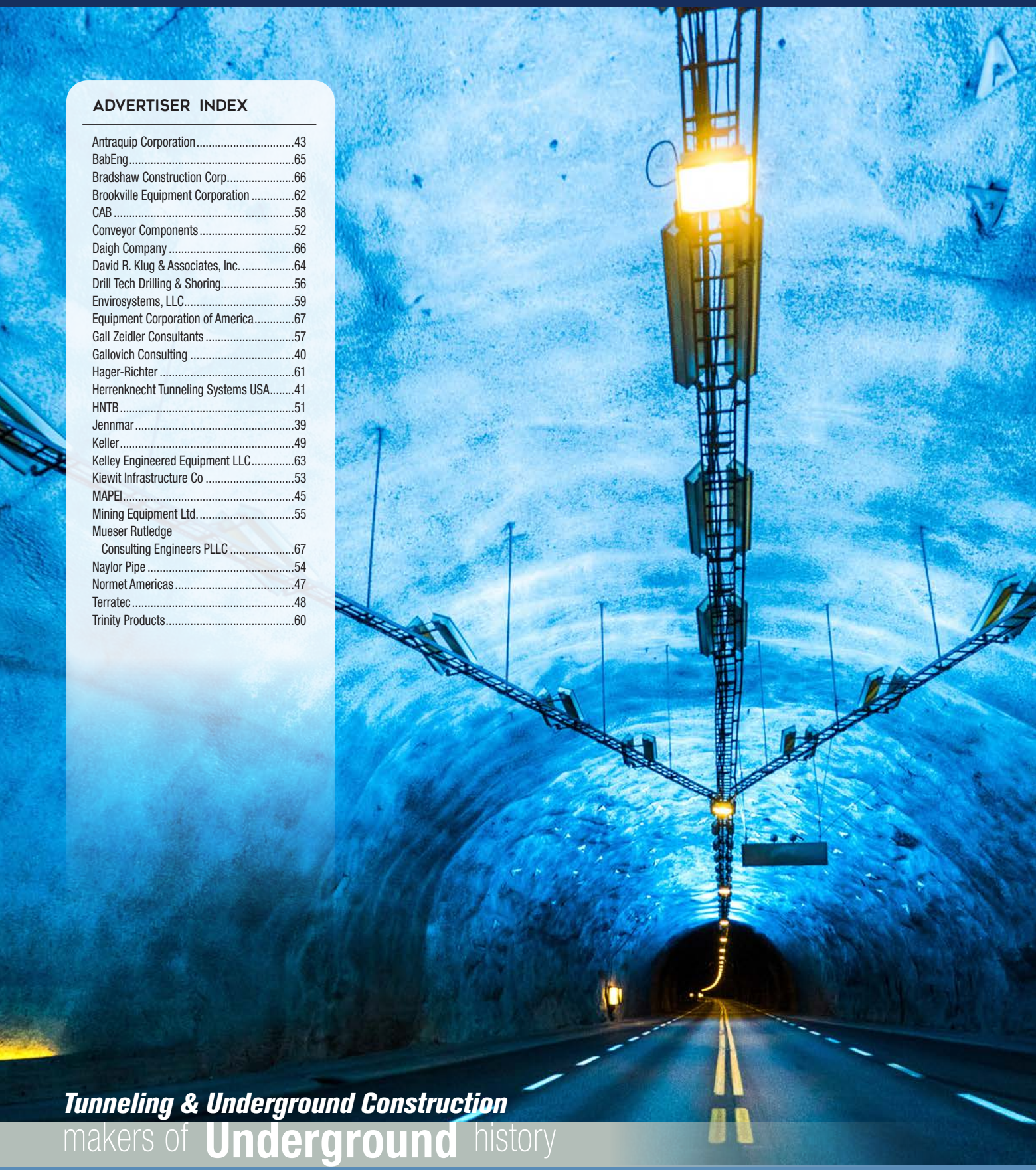

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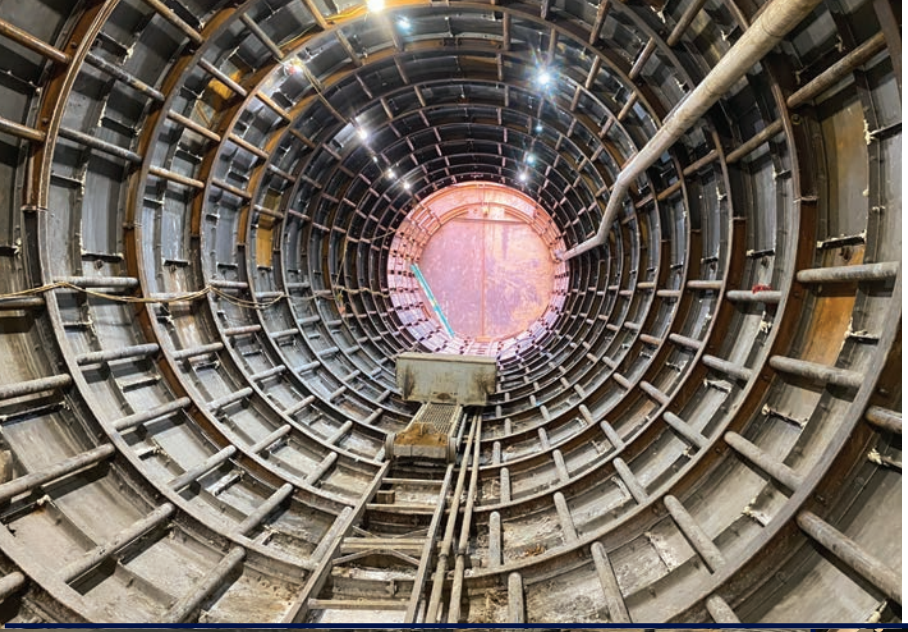

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Fiori Group SpA has its headquarters in Finale Emilia (MO) Italy, that designs, develops and manufactures off-road Concrete Batching Vehicles and Dumpers for the construction industry. The company's product portfolio is rounded off by the Group's capabilities in finding the most effective solution for any customer in making and transporting concrete on-site with great flexibility, minimizing energy costs and reducing environmental impact.

Let us help you to set up your concrete production and transportation equipment for your next tunneling project.

info@gallovichconsultingllc.com
P: +1 (786) 762-4068
M: +1 (240) 893-6580
8333 NW 53rd Street
Suite 450
Doral, FL 33166




PIONEERING UNDERGROUND TOGETHER

With the experience of more than 45 years, Herrenknecht is a technology and market leader in the area of mechanized tunnelling technology. Herrenknecht is the only company worldwide to deliver cutting-edge tunnel boring machines for all ground conditions and in all diameters – ranging from 0.10 to 19 meters. The product range includes tailor-made machines for traffic, supply and disposal tunnels, technologies for pipeline installation as well as drilling equipment for vertical and inclined shafts and deep drilling rigs.

The Herrenknecht Group achieved a total output of 1,394 million euros in 2024. The independent family-run business employs 5,495 people worldwide, including around 200 trainees. With more than 60 subsidiaries and associated companies working in related fields in Germany and abroad, Herrenknecht is able to provide a comprehensive range of services close to the project site and the customer, quickly and in a targeted way. Under the umbrella of the Herrenknecht Group, a team of innovative specialists offers integrated tunnelling solutions with project-specific equipment and service packages upon request: separation plants, belt conveyor systems, navigation systems, rolling stock systems as well as segment moulds and even turnkey segment production plants.

As a reliable project partner, Herrenknecht supports its customers with an extensive range of services from the beginning of the project to breakthrough. From the initial project idea through manufacturing, transport, assembly, tunnelling support and spare parts service to disassembly, Herrenknecht accompanies the process at the customer's side. Even personnel solutions for the temporary supplementing of jobsite crews are provided if required. With competent service specialists, the company regularly supports around 300 jobsites worldwide and offers customized service packages tailored to individual project requirements.

Road, metro, and railway tunnels for efficient traffic network. By the middle of this century, the world´s population is expected to reach nine billion, and two thirds of these people will live in large conurbations. To keep people and goods on the move, the way ahead for new efficient infrastructures is leading underground. With state-of-the-art technologies, efficient infrastructures are created exactly where they are needed, even in cramped and complex jobsite conditions. Herrenknecht technology pushes the boundaries of feasibility and creates new tunnelling standards worldwide. Herrenknecht technology extends existing transport networks and creates new connections in urban and rural areas – under mountains or deep beneath water.

Innovative solutions for underground supply and disposal systems. As the world's population grows the need for underground supply tunnels is also increasing; in emerging and developing countries as well as in modern metropolises. That is why around 1,000 Herrenknecht Utility Tunnelling Machines are in operation around the world constructing or laying water and wastewater systems, gas and oil pipelines, as well as conduits for electricity and telecommunications. Here, trenchless tunnelling technology offers a range of advantages compared to conventional construction procedures: transport, business and the environment remain mostly undisturbed when Micromachines, HDD rigs or shaft sinking equipment are being used. Innovations such as Direct Pipe® set new standards in the semi-trenchless installation. The new technology E-Power Pipe® allows the secure and quick installation of underground cable protection pipes with smaller diameters and long advance lengths. Innovative HDD tools simplify pipeline construction operations at key sections. The Herrenknecht product portfolio is completed by a broad range of equipment for the areas of mining (construction of underground infrastructures around raw material deposits) and exploration (oil, gas and geothermal energy).

HERRENKNECHT TUNNELLING SYSTEMS USA INC.
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HERRENKNECHT
Tunnelling Systems

ANTRAQUIP CORPORATION – your reliable, innovative partner

Antraquip Corporation continues to solidify its position as a leading designer, manufacturer and supplier of roadheaders, hydraulic rock cutting attachments, shaft sinkers, specialty tracked machines with a variety of boom options as well as ground support solutions for NATM tunnels.

Within Antraquip's rock cutting attachment product line, Antraquip has introduced diamond and carbide saw attachments for excavators ranging from 1 to 60 tons.Additionally, Antraquip has designed and manufactures the world's most powerful rock cutting attachment with 400 kW+ cutting power for excavators in the 80+ ton weight class. By continuing to invest heavily into research and development Antraquip strives to be able to cut hard rock which has previously not been possible with mechanized excavation methods.

As to roadheaders, Antraquip offers not only standard roadheaders in the 12 – 85 t on class but is proud to offer project oriented engineering solutions whenever requested and necessary. Some of the recent projects have included AQM roadheaders equipped with customized drilling attachments, fully automated remote control systems and automated guidance systems.

Within its ground control program, Antraquip specializes in any support product needed for NATM as well as drill and blast tunnels like lattice girders, steel ribs, specialized rock bolts, spiles, wire mesh and arch canopy systems (barrel vault system or arch pipe system).

In addition to offering project consultations, innovative cutting and support solutions, Antraquip recognizes the importance of after sales service. This commitment to offering the best service and technical support is carried out by highly proficient and experienced service engineers and technicians, all reinforced with large spare part inventories at hand. Innovation, reliability and experience offered by Antraquip makes them a reliable partner for any tunneling project.

Antraquip's main goal is: SAFETY, SAFETY and again SAFETY! Antraquip continues to strive to offer innovative products to make any job safer, faster and increase the bottom line for any contractor and owner.

Antraquip is well represented all over the world, but takes pride in paying detailed attention to any local tunneling challenge small or large.

IN THE FUTURE, THE WORLD WILL NEED MORE AND MORE TUNNELS – AND ANTRAQUIP INTENDS TO BE AN IMPORTANT, RELIABLE PARTNER FOR ANY UNDERGROUND PROJECT!

AQ6 Hydraulic Cutting Attachment

AQC180 on CAT336

AQM 175 Roadheader

AQ-6 Drumcutter in PC650

WHAT WE DO

Antraquip Roadheaders, Rock and Concrete Cutters, Scaling Attachments and Tunnel/Ground Support systems are Built For The Toughest Applications.

- → Tunneling
- → Mining
- → Trenching
- → Demolition
- → Scaling
- → Rock Excavation
- → Soil Mixing
- → Profiling

GROUND SUPPORT PRODUCTS

Proudly Made in the USA from Domestic Steel

- → Lattice Girders
- → Pipe Roof System
- → Spiles & Rock Bolts
- → Arch Canopy Systems
- → Liner Plates
- → Steel Ribs

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MAPEI Corporation

MAPEI's Underground Technology Team (UTT) provides the construction market with a range of products dedicated to underground construction work. MAPEI's UTT group and the products it represents were created to meet the expectations of these challenging environments. From the project specification to the admixtures for shotcrete and concrete to the final protective coatings, MAPEI's UTT group and technology are there "for the whole job," said Cristina Onate, PhD, UTT Business Development Manager — Tunneling.

The UTT group is a successful division of MAPEI Group, which has provided proven construction system solutions for more than 80 years. Established in 1937, MAPEI Group is a global corporation, based in Milan, Italy, and with 91 subsidiaries that include 84 plants in 35 nations. MAPEI is the world-leading manufacturer of mortars, grouts and adhesives, as well as complementary products for installing floor and wall coverings. MAPEI manufactures chemical products for building, including waterproofing products, admixtures for concrete and repair products, and decorative and protective exterior coatings — as well as the UTT product line.

MAPEI's UTT products were used to help a tunnel boring machine dig the Anacostia River Tunnel, which extends for 2.37 miles from Robert F. Kennedy Stadium in northeast Washington, D.C., to Poplar Point in southeast D.C.

"The UTT group started in earnest in the U.S. in 2015," stated James Pinkley, Country Manager UTT – North America. "But the business has grown substantially since then." In the underground industry, speed is essential – not only of the products themselves, but also of the evolution of technology. MAPEI reinvests a considerable percentage of its annual profits back into research and development to maintain a leading technological advantage. MAPEI's commitment to R&D ensures that the UTT line comprises the most innovative and technologically advanced products available. In addition to the latest in cutting-edge products, the UTT team is trained in their use, with decades of experience in the underground marketplace.

The UTT product line is divided into six categories: Mechanized Tunneling; Injections for Heavy Civil and Mining Applications; Waterproofing & Water Membranes; Shotcrete Products; Renovation, maintenance and repair; and Coatings for underground construction. No matter the division or the product line, MAPEI is known for quality products and for providing system solutions. As Pinkley stated, "The distinguishing point for UTT is our field support, and our applied technology in the field. Simply put, we don't just sell a product, but rather we go into the field and help our customers use our products – on their jobsite, with their conditions, personnel and equipment. MAPEI UTT services a project from the very beginning to the very end like no one else in the industry does," he said. "UTT also has the agility to adjust to the customers' needs when necessary per the demands of changing geological settings"

For more information, contact MAPEI's UTT group at www.utt.mapei.com.

YOUR DURABLE TUNNELING PARTNER.

Underground works have unique characteristics that can be different in every project. This is why the MAPEI UTT team stands side by side with the professionals in the tunneling and mining industries, offering not only quality and environmentally friendly products, but also consistent technical services. **For every product, there's a team at your service.**

Learn more at
utt.mapei.com
hq.utt@utt.mapei.com

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MAPEI

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TAMPUR RBG ROCK BOLT GROUT

for securing rock and anchor bolts, even for overhead installations

TamPur RBG produces a non-sag resin that can be used for all types of soft rock bolts that require early tensioning/loading along with full rock bolt encapsulation. TamPur RBG is available in varying grades to suit both an automated or manual injection process and to allow for local ambient and rock formation temperature.

INCREASED SAFETY
Ensures early safety for operator, especially when working in fractured ground

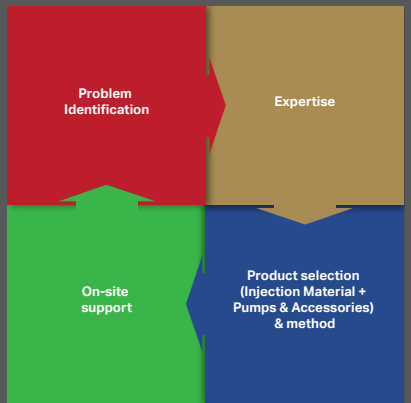
IMPROVE PRODUCTIVITY
With early re-entry time due to fast strength development

APPLICABLE TO FRACTURED GROUND
Can be used where capsules & cement fails or struggle

APPLICABLE EVEN WITH WATERFLOW ISSUES
Can be used even if water is present

ENVIRONMENTALLY FRIENDLY
Overall cleaner process than cement

"TOGETHER WE ARE PROVIDING SAFETY UNDERGROUND



NORMET HAS THE COMPLETE PACKAGE

The extensive knowledge and experience of Normet helps to identify the problems. Together with our comprehensive portfolio of injection resins and our in-depth knowledge of the technology, application and associated equipment, we can provide technical solutions to solve your problems and meet the project demands. Our goal is to ensure that your project is handled in the safest and most productive way possible.

normet

NORMET.COM

HIGH PERFORMANCE TBM TAIL SEALANTS

Introducing TamSeal TG91 (Driving Grade) and TamSeal TG92 (First Fill), developed using renewable plant-based oils. These sealants offer technology advancements with lower consumption, improved performance, and superior technical characteristics. We also offer TamSeal TG66, ideal for areas with minimal ground water and easily excavated geology, and TamSeal ES90, designed for leak proofing in case of tail seal damage. Our products are manufactured globally and we provide on-site support to ensure your project operates efficiently.

- **> Exceptional Sealing**
- **> Pumpability**
- **> Anti-Wash-Out and Self-Extinguishing**
- **> Eco-Friendly**
- **> Proven Reliability**

"Global Expertise, Unmatched Support

DEFINING THE FUTURE UNDERGROUND

Terratec

Incorporated in 1990, TERRATEC is a world renowned designer & manufacturer of Tunnel Boring Machines, encompassing all ground conditions and diameters – ranging from 0.60 to over 16 metres – as well as TBM back-up equipment, Raise Boring Machines and other custom-engineered products for the tunnelling and mining industries. TERRATEC's success is based on the experience and excellence of its global engineering team. TERRATEC is also fully managed by engineers enabling quick and efficient solutions that meet customer expectations.

TERRATEC products are well-known in the industry as Robust, Durable and Safe, basic principles that must prevail in the design of any equipment made to work in the extreme conditions encountered underground. As a provider of Total Tunnelling Solutions, TERRATEC's scope of work extends to custom engineering, as well as the operation and maintenance of tunnel boring equipment and the supply of ancillary equipment.

TERRATEC's capacity to provide a wide range of services means that it is not only an equipment supplier but a qualified and experienced partner in the execution of tunnelling works.

As a result, it is becoming more and more common for TERRATEC to supply a Total Tunnelling Solution package consisting of the TBM/s, other main equipment in the tunnel (Trains, Conveyors, Segment Moulds and Ventilation), spares and consumables for the equipment and a team of TERRATEC field personnel who can assist in the operation and maintenance of the supplied equipment throughout the duration of the project.

TERRATEC offers full range of equipment from pipe jacking machine to open TBM, soft ground to very hard rock machine. TERRATEC's continuing success on global projects is a result of tailor-made robust TBM design, prompt onsite assistance, readily available stock of TBM spares and highly-skilled specialised TBM support throughout tunnelling operations.

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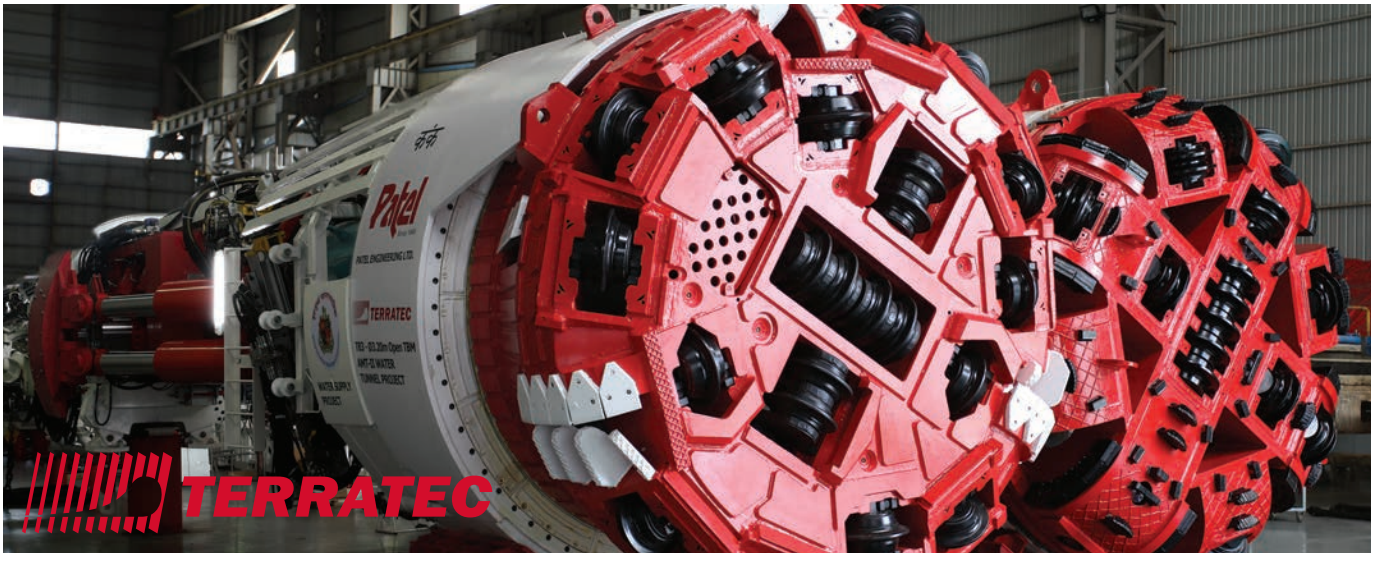
Company telephone number
+ 61 362233282



Keller – The leading geotechnical specialty contractor

Facing challenging subsurface conditions is a familiar scenario for tunneling contractors, and as the leading geotechnical specialty contractor, Keller has provided solutions to these challenges for almost 100 years. Our solutions for tunneling include diaphragm walls, ground freezing, secant piles, dewatering, jet, permeation and compensation grouting, and instrumentation and monitoring.

By connecting global resources and expertise with local knowledge and focus, Keller develops innovative, practical, and cost-effective solutions to geotechnical challenges. Keller builds projects designed by others and offers full design-build services for any geotechnical construction application.

Sector challenges we can solve

- Stabilizing soil for tunneling operations
- Earth retention for break-in and break-out shafts
- Controlling settlement of structures overlying tunneling operations

Contact us today about your next tunneling project.

Keller
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Hanover, MD 21076
Telephone: +410-551-8200
www.keller-na.com

Northgate Link Extension, Seattle, WA, ground freezing for groundwater control and support of excavation

DC Clean Rivers Project, Washington, DC: Division A - Blue Plains Tunnel, reinforced concrete slurry diaphragm wall shafts (pictured); and Division I Diversion Structure, jet grouting for underpinning, support of excavation, and groundwater control

HNTB

For more than a century, HNTB has helped create infrastructure that best meets the unique demands of its environment and keeps communities moving efficiently. With client relationships spanning decades, HNTB experts have the insight and knowledge to provide innovative solutions on a wide range of underground structures, including bored tunnels, cut-and-cover, conventional tunneling (SEM/NATM), immersed tube tunnels, shaft construction and micro-tunneling. Our history in design, planning, program management, construction management and technical services for tunnels and complex underground structures includes award-winning projects on some of the country's most prominent infrastructure projects.

hntb.com/tunnels

Sanja Zlatanic
Chair, National Tunnel Practice
szlatanic@hntb.com

Delivering the Extraordinary

HNTB

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Combining innovation and expertise to plan and design resilient tunnels through complex geologies and protected environments for sustainable connectivity.

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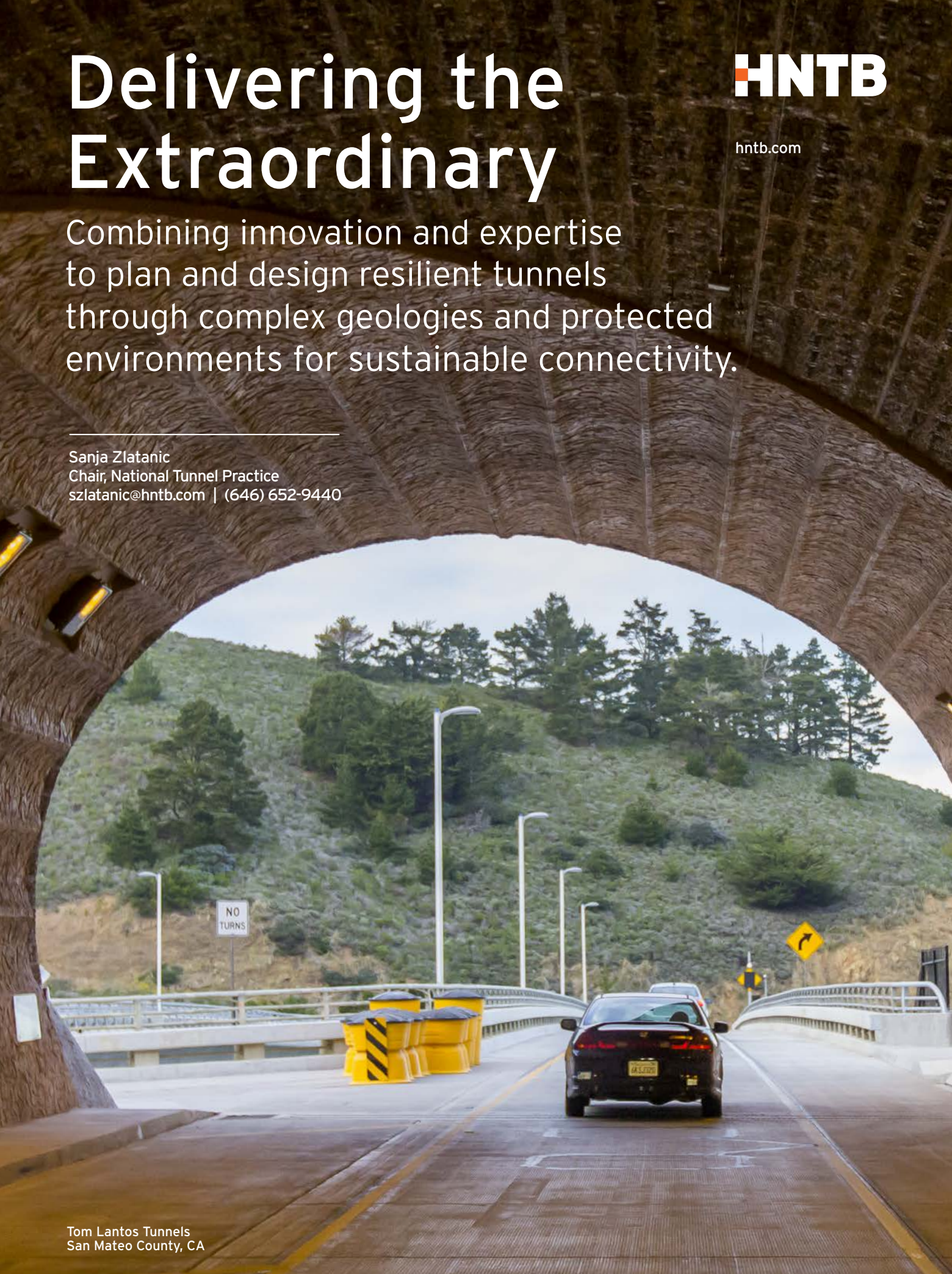


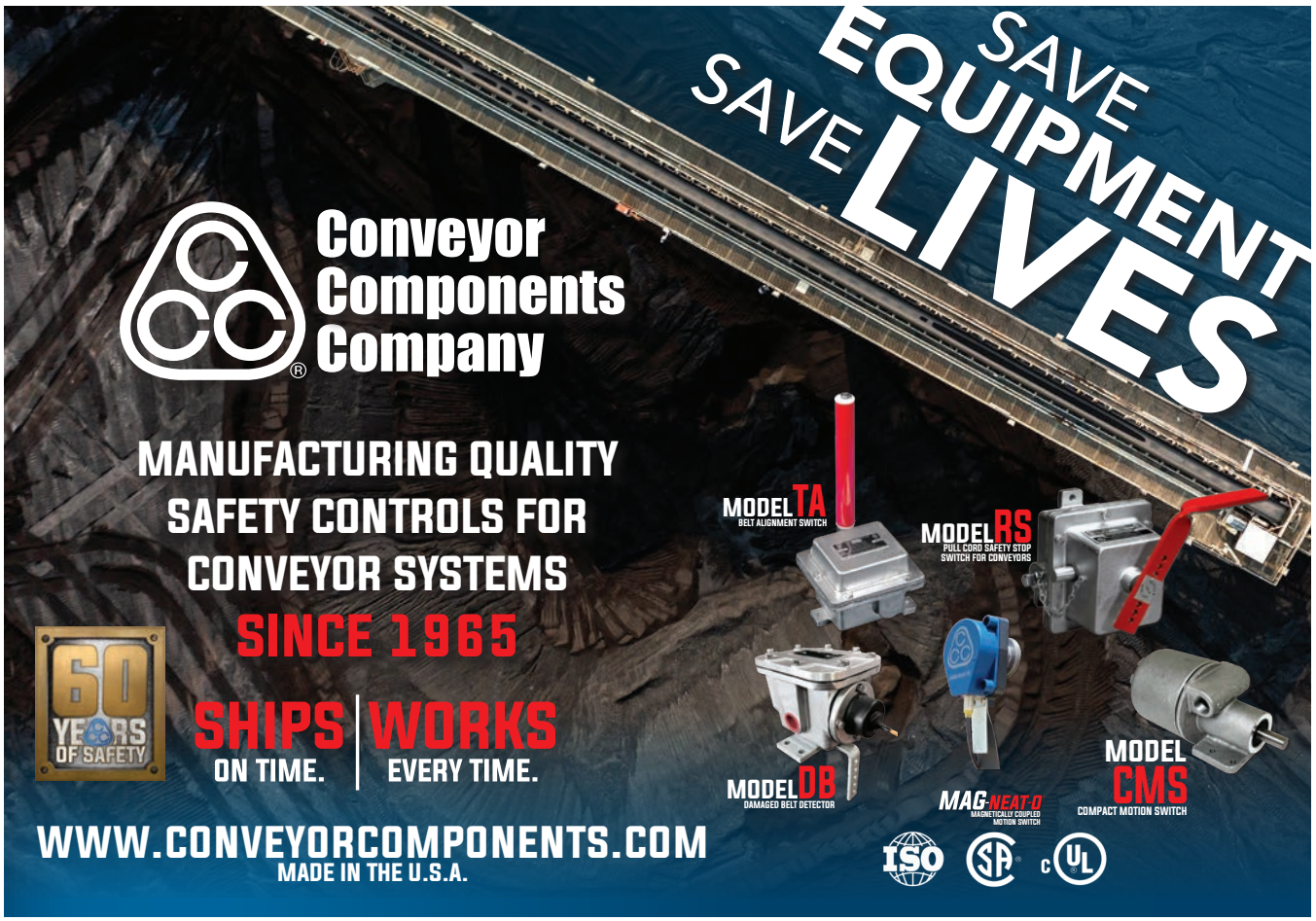
Tom Lantos Tunnels
San Mateo County, CA

Conveyor Components Company

The NEW Conveyor Safety System™

Conveyor Components Company® introduces an efficient and affordable way to protect both your workers and your equipment investment. The Conveyor Safety System™ provides peace of mind by combining key protective devices into one simple package. By bundling our Model RS Safety Stop Switch with the Model TA Belt Alignment Switch and the Model DB Damaged Belt Detector, your conveyor system is covered against common hazards.

Add one of our motion-sensing options, such as the Mag-Neat-O™ or Model CMS Motion Switch and you can operate with confidence knowing your people and equipment are safeguarded. This system delivers comprehensive protection for just a fraction of the cost of unplanned downtime, major repairs, or equipment replacement.



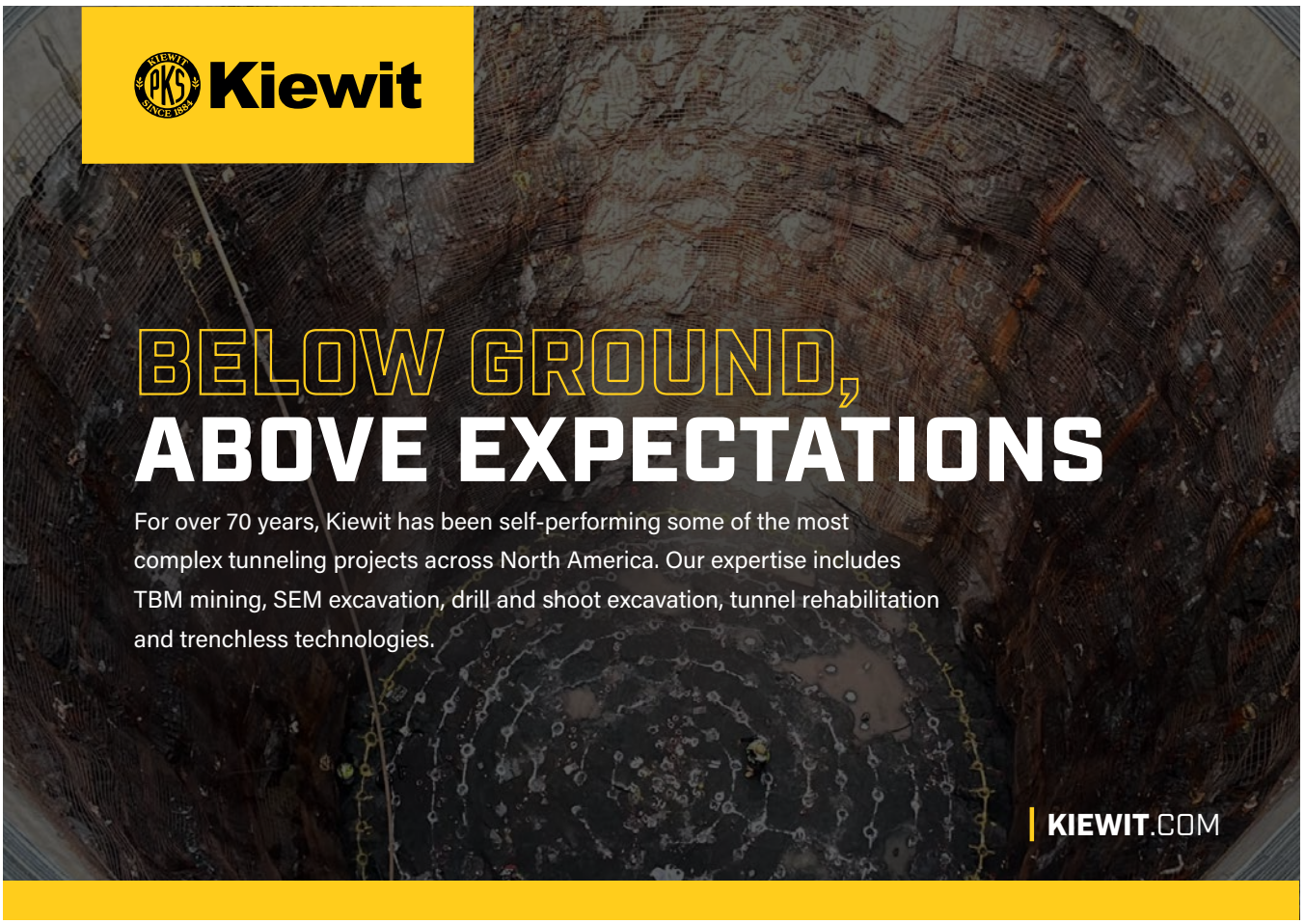
Kiewit

Kiewit is one of North America's largest and most respected construction and engineering organizations. Founded in 1884, our employee-owned company operates through a robust network of subsidiaries across the United States, Canada, Mexico, and Guam. We deliver integrated construction and engineering services across a wide range of markets—including transportation, oil, gas and chemical, power, building, water, marine, industrial, and mining.

For over 70 years, Kiewit has been a trusted leader in underground and tunneling construction. Our reputation is built on deep technical expertise, innovative execution, and an unwavering commitment to safety and collaboration. From soft ground to hard rock, our teams have successfully delivered complex tunneling projects using Tunnel Boring Machines (TBMs), drill-and-blast methods, and other advanced excavation techniques. We are also recognized for our ability to self-perform tunneling work under various contract models, ranging from under $1 million to over $1 billion. At Kiewit, we don't just build infrastructure—we build trust, innovation, and lasting value beneath the surface.

Kiewit

Kiewit Infrastructure Co.
1550 Mike Fahey St., 3rd Floor
Omaha, NE 68102
www.kiewit.com



Mining Equipment Ltd.

Mining Equipment Rolling Stock for Columbus, Ohio

"Rolling for more than 35 years"

Mining Equipment continues to supply the tunneling and mining industries with top-quality rolling stock, Jetair fans and steel ventilation ducting, as well as a large inventory of rebuilt equipment such as scooptrams, trucks, drill jumbos and other underground gear.

Mining Equipment is based in Durango, Colorado, with a main shop facility in Farmington, New Mexico. They also have steel fabrication capabilities near Shanghai.

Mine Hoists International, a sister company of Mining Equipment, is based in North Bay, Ontario. They boast the world's largest inventory of used mine hoist and large capacity stage winches for mining and shaft sinking projects. Their new 20,000 square foot shop in North Bay, Ontario can handle the largest of hoist and winch rebuilds.

Mining Equipment 10 Ton Locomotives for Columbus, Ohio

Drill Tech Drilling & Shoring Inc.

Since 1994, Drill Tech Drilling & Shoring, Inc. has successfully completed over 2,000 projects valued at more than $2 billion for both public and private clients throughout the United States. Specializing in tunnel and mine construction and remediation, earth retention structures, shallow and deep foundation support systems, marine/wetland construction and remediation, and rockfall mitigation, Drill Tech and its subsidiary companies continue to expand in geostructural engineering and construction expertise. For over a decade, ENR has ranked Drill Tech as one of the Top 20 Firms in Excavation and Foundation, attesting to the company's consistent growth and dedication to quality.

Drill Tech's capabilities are uniquely bolstered by a versatile workforce, extensive fleet of specialty in-house equipment, and custom fabrication shop. Drill Tech employs more than 600 personnel including engineers, managers, construction staff, and specialized craft. This crew includes over 30 licensed professional engineers who develop temporary work designs, construction drawings, and comprehensive work plans, providing a level of sophistication that maximizes understanding of the job's complete scope and further enables the team to develop solutions for highly technical and logistically complicated problems.

With approximately 150 employees regularly engaged in the mining and tunneling division, and four subsidiaries specializing in this field (Drill Tech Mining & Tunneling, Vadnais Microtunneling, Foxfire, and Mine Development), Drill Tech is an industry leader in underground construction. Experience in new and rehabilitation tunnel/shaft projects include water/sewer tunnels, highway/railroad transportation tunnels, large caverns, deep shafts, and limited access underground projects.

These jobs are performed in different ground types with excavation methods including hand mining, shield tunneling, drill/blast, and mechanized SEM/NATM means among other similar open face methods. Installation of tunnel support often includes shotcrete and steel systems in the various rock and soil ground conditions.

Drill Tech currently operates and maintains a full fleet of tunnel and mining equipment which includes roadheaders, specialty tunnel excavators, underground shotcrete equipment, underground drill jumbos/bolters, specialty casing rigs adapted for canopy tube drilling, muckers, mining haul trucks, shaft sinking cranes/headframes, and support equipment for ventilation/electrical/utilities required on all tunnel projects.

Gall Zeidler Consultants

Gall Zeidler Consultants proudly marks 25 years of delivering innovative solutions and engineering excellence. For a quarter-century, we have been dedicated to advancing tunneling and underground infrastructure, helping clients navigate complex challenges in a sustainable and responsible manner.

Using our broad expertise in transportation, infrastructure, water conveyance, energy, and mining, we deliver cutting-edge solutions and superior products from initial concept and planning to project completion and operation. Over the years, we have built a diverse portfolio of major projects across the U.S. and internationally, many of which rank among the most significant in the world.

To support these efforts, our services cover all stages of a project:
- Conceptual to Final Design
- Program & Construction Management
- Construction Site Support
- Tunnel Inspection & Rehabilitation
- Mine Access Tunnels & Shafts
- Independent Design Verification Services
- Tunnelling and Underground Subject Matter Experts
- Building Information Modeling (BIM) & Digital Twinning

With a diverse team, we operate globally through our offices across North America, Latin America, Europe, Asia, and Australia. As we celebrate this milestone, we remain committed to shaping the future of underground infrastructure by finding the right solutions for every project, maintaining technical excellence, and always treating our clients and our people with integrity and respect.

TBM DRY SCRUBBER

Project specific solutions, tailored to your exact needs!

16K TBM SCRUBBER

This is a 16,000 CFM Dry Scrubber used on a refurbished 4M Atlas-Copco TBM used for a short section of the Bill Bishop Toronto City Airport Tunnel. It was mounted centrally on the trailing gear and since there was not enough overhead clearance to accommodate a screw conveyor and rotary airlock, it discharged automatically from a unique clamshell dump hopper, through the trailing gear floor to the invert. This scrubber collected dust from the cutter head as well as several conveyor drops.

TBM SCRUBBER

Envirosystems has designed several TBM scrubbers for specific projects, and would welcome an opportunity to talk to you about yours. We have designed TBM dry scrubbers for TBM's from 1M to 5.5M in diameter. We can design to locate outside the gantry or inside the trailing gear and are very flexible with regard to volume required. Volumes above 30,000 CFM are not out of the question. We can now provide both Dry and Wet collectors.

Envirosystems has developed several types of roadheader scrubbers including both Dry and Wet collectors. We can design a custom "ride along" unit or one that sits nearby and collects dust, mud and spray as it comes off the cutter head. Give us a call and let's talk about your application!

Envirosystems™
A Dust Collection & Blasting Technologies Company

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SPIRAL WELD PIPE & TRI-LOC: ADVANCING TRENCHLESS PIPELINE TECHNOLOGY

Steel pipe has long been the backbone of trenchless construction, prized for durability, strength, and cost efficiency. Today's engineering demands materials and connections that maximize performance and adaptability—qualities exemplified by spiral weld pipe and Trinity's Tri-Loc press-fit system.

Evolution of Spiral Weld Pipe
Once thought to rotate excessively during trenchless installation, Modern spiral weld (helical) pipe is manufactured using precision, dual-submerged arc welding with laser guidance to produce full-penetration welds equal to or stronger than longitudinal seams. This method ensures uniform diameter, superior weld integrity, and smooth exterior surfaces that eliminate the concern of installation rifling, making spiral pipe ideal for trenchless applications such as auger boring, microtunneling, and pipe jacking. Widely recognized by leading contractors and agencies, spiral weld pipe now serves reliably in water transmission, piling, and flood protection.

Proven Performance
Independent testing by the U.S. Army Corps of Engineers and North Carolina State University confirmed spiral weld pipe's performance under extreme loads, matching or exceeding straight seam pipe. The results demonstrated lower cost, higher availability, improved holding capacity, and verified strength under severe conditions.

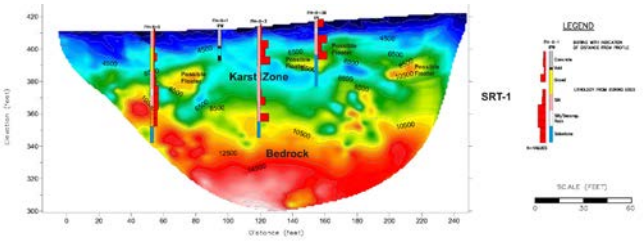
System Integration with Tri-Loc
Combined with Trinity's Tri-Loc mechanical joint, spiral weld pipe delivers a high-strength, leak-resistant, and easily assembled system. This synergy enhances installation efficiency, minimizes risk, and shortens project timelines while reducing lifecycle costs.

Conclusion
Validated through engineering and field testing, the Spiral Weld Pipe with Tri-Loc Connection offers the optimal solution for modern trenchless infrastructure—combining strength, precision, and long-term value.

HAGER-RICHTER GEOSCIENCE, INC.

Hager-Richter Geoscience (HRGS) is an established small business specializing in providing surface and borehole geophysical services for engineering and environmental applications (NAICS 541360) throughout the United States since 1984. In those 41 years, HRGS has earned a national reputation for quality geophysical services and is now one of the largest geophysical specialty firms in the eastern United States. The surface and borehole geophysical services offered by HRGS provide valuable support for characterizing subsurface conditions for tunneling projects of all sizes and scopes throughout the United States and beyond. HRGS has fully staffed and equipped offices in New Hampshire and New Jersey, and the firm owns the equipment used for the geophysical investigations eliminating the reliance on the rental schedules of others allowing rapid response to projects throughout the United States. HRGS works exceptionally well as a member of a project team providing specialty geophysical services that complement the expertise of clients and other project team members.

603.893.9944
www.hager-richter.com



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Brookville

BROOKVILLE 27-Ton MSHA Permissible Locomotives Boosting Safe Work Environment at Major Los Angeles Tunneling Project

Brookville Equipment Corporation (BROOKVILLE) recently shipped three 27-ton MSHA-permissible tunneling locomotives to the Walsh-Shea Corridor Constructors for use on the Crenshaw/LAX Transit Corridor Tunnel Project in Los Angeles. By design, the locomotives reduce the risk of explosion due to geological conditions that may host the presence of methane and other combustible gases. Cal-OSHA has classified the tunnel drives on this project "gassy", mandating the use of MSHA permissible locomotives.

The 27-ton locomotives' special safety features include air start, an enclosed engine block, an exhaust filtration system, wiring and piping guards, and an intake flame arrestor, among other upgrades, to fully comply with MSHA's permissibility requirements. Featuring an 8.3L Cummins six-cylinder diesel engine and four-speed transmission, the 185-horsepower locomotives operate on 36-inch rail gauge underground for Walsh-Shea Corridor Constructors.

"BROOKVILLE was selected based on past performance, simplicity of operation and diagnostics, their ability to communicate locally with MSHA, and knowing we would be dealing with the good people of Brookville, PA, U.S.A," said Walsh-Shea Corridor Constructors Tunnel Construction Manager David Girard, P.E.

Kelley Engineered Equipment

Kelley Engineered Equipment (KEE) enters their 18th year of supplying custom equipment solutions and professional engineering services to the tunneling and underground construction industries. A growing team of 40+ professionals, TBM experts, the Kelley team has decades of underground experience and PE Licenses in 12 states with more on the way. KEE accepts your challenges and provides solutions with unmatched quality and customer support.

We get it - We understand what you need and know how to build it
Unequaled Experience - We are licensed, qualified & utilized by all the major civil contractors
Simple-Safe-Fast - We deliver safe, elegant solutions to complex problems when you need them

Contact KEE for: Tunneling Equipment, Pipe Carriers & Installation Systems, Custom Cranes, Below the Hook Lifting Systems, Gantries, Mucking Systems, Trailing Gear, Tunneling Shields, Rolling Stock, Hydraulic Attachments, Conveyors, Lift Cars, Equipment Mod, Heavy Load Handling, Personnel Access Systems, Bespoke Engineered Solutions, etc.

KEE is proud to represent Terratec TBMs and Roxard Cutter in the USA and Canada.

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David R. Klug & Associates, Inc.

Since 1996, David R. Klug & Associates, Inc. has provided international and national manufacturer's representative services to the underground heavy civil and mine construction industries. The company specializes in the sale and coordination of specialty products, equipment and services for soft ground, conventional and NATM/SEM tunneling practices. Expertise is offered in the supply of various componentry used in the manufacture of one pass precast segmental tunnel linings inclusive of EPDM gaskets, plastic and steel connectors, grout lifting assemblies and precision steel segment casting moulds plus final lining forming systems for C-I-P final lining applications. Through their distribution company, Klug Construction Systems, LLC offers Nittetsu ultrafine cement, GFRP rock bolts and soft-eyes, steel and synthetic fiber reinforcement, prefabricated welded wire fabric and rebar reinforcing panels, and specialty grout systems for various tunnel backfill grout requirements for highway, rail, subway, water and CSO tunnel construction applications.

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Tunnelsoft, a division of BabEng, brings expert-driven software solutions tailored for tunnel construction. Backed by decades of engineering expertise, our team understands the intricate challenges faced in the tunnel construction industry. At Tunnelsoft, we don't just create software; we deliver solutions tailored to address the real, everyday needs of engineers on-site.

BabEng's skilled engineers bring invaluable insights from the field, allowing us to focus on practical features that simplify complex workflows, enhance safety, and optimize project timelines. By bridging engineering know-how with cutting-edge technology, our Tunnelsoft solutions empower construction teams to work smarter, faster, and with greater precision. Fully compatible with all interfaces and independently of TBM manufacturers, TPC brings unmatched flexibility to your project.

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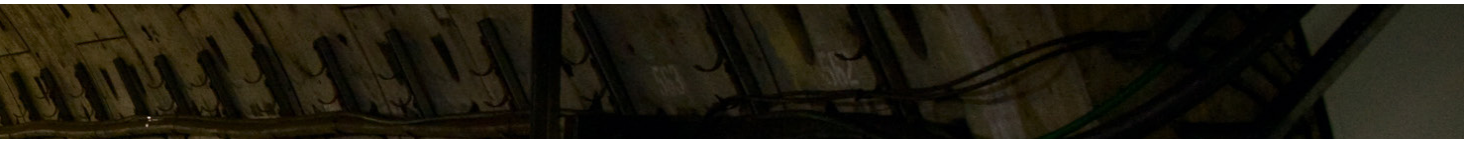

Bradshaw

Bradshaw Construction Corporation strives to apply the most appropriate tunneling technology to each project based on its purpose, subsurface conditions and surface restrictions. The company's management team is proud of its ability to construct any type of tunnel in any soil condition both above and below the water table. From small hand mined, wood-box and liner plate tunnels to large NATM shotcrete-lined tunnels; from small pilot tube guided auger bores to large rib-and-board shield and tunnel boring machine (TBM) tunnels; from conventional pipe jacking to slurry microtunneling (MTBM) to earth pressure balance (EPB) TBM tunnels; and from hand mined drill and blast to rock tunnel boring machines (TBMs), Bradshaw Construction has a solution.

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Current tunneling projects include design of shaft support of excavation (SOE) in soil and rock for the Narragansett Bay Commission's Pawtucket Tunnel, a 1.5-mile long CSO tunnel; ground freezing of overburden soils to provide SOE for construction of two deep, large diameter shafts that will connect to the New York City Water Tunnel No. 3; and (SOE) design for the East Bound Re-Route Construction for the LIRR East Side Access project. Other projects include the Charleston SC Fishburne Drainage Improvements Outfall and Pump Station, MD 355 Crossing in Bethesda for WMATA's NIH Medical Center station; the CSX Virginia Avenue Tunnel, VDOT Midtown Tunnel, DC Water's Blue Plains and First Street Tunnels; PSE&G Crossing #2 - Southern Reinforcement Project in Newark NJ; Toronto Subway Yonge-Eglinton Station, and New York City's NYCT Canarsie Tunnel, NYCT 2nd Avenue Subway, and the DEP Catskills and Delaware Aqueduct Rondout-West Branch Tunnel and Brooklyn to Staten Island Harbor Siphon Tunnel.

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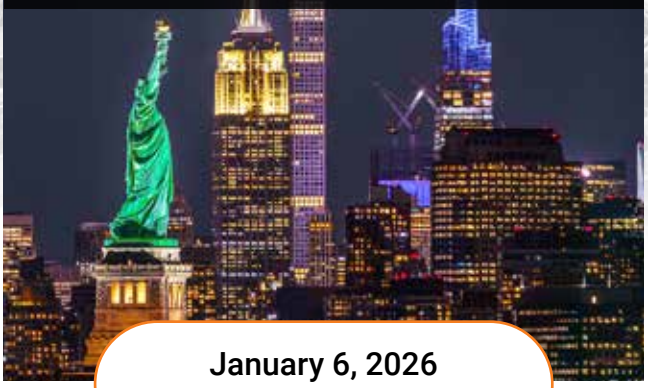

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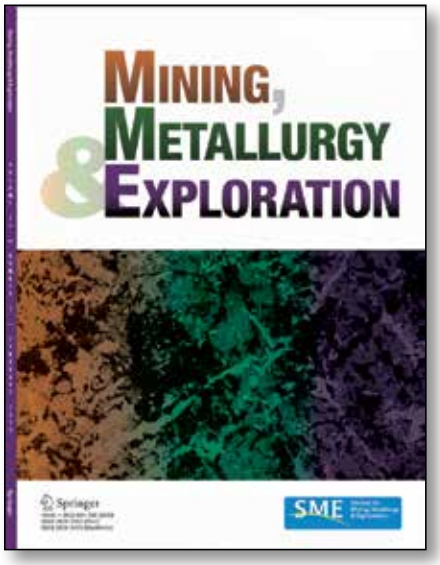

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• The Uptake of Innovation in the Mining Industry

"Miners want to be the first to be second" is a well-known proverb in the mining industry. At the same time, mining historically has been a driver and established playground for innovation, with examples going back to the first implementation of the steam machine, and recently the deployment of drones and autonomous haulage. This collection is inviting contributions to the subject of innovation in the mining industry. We are especially looking forward to submissions related to the actual implementation of innovative technologies in real mining use cases. Furthermore, we invite discussions on the innovation process at large, highlighting obstacles, challenges and opportunities for bringing innovative technology and processes to the mining industry.

Editor: Philipp Hartlieb, Priv.-Doz. Dipl.-Ing. Dr.mont.

• Industrial Minerals: Geology, Extraction and Use

Industrial minerals are naturally occurring materials that are mined for their commercial value and utility. Examples include bentonite, borate, calcium carbonate, clays, diatomite, feldspar, kaolin, limestone, silica sand and talc. We intend to compile a series of papers that highlight the: geology of industrial minerals, focusing on the geological processes, their geographic occurrences and exploration; extraction of industrial minerals, including mining and processing, encompassing the processes that prepare these minerals for use (such as how diatomite is mined and processed to make it usable); and the use of these minerals for specific industrial purposes. We will also feature a few papers on the important role these minerals play in the energy transition and circular economy.

Editor: Abani R. Samal, Ph.D.

• Collection in Honor of Prof. Raj Rajamani: Modeling, Grinding, Hydrocyclone Classification and Eddy Current Separation

The late Prof. Raj Rajamani received his Ph.D. at the University of Utah, joined the Metallurgical Engineering faculty in 1979 and served as distinguished faculty for more than four decades. He was an excellent teacher, a creative researcher, made several significant contributions in comminution and hydrocyclone classification, and was the inventor of a new eddy current separation technology. He made great contributions to the computational fluid dynamics modeling of hydrocyclones and pulp lifters of tumbling mills. Notably, his research on the fundamental understanding of grinding efficiencies of overflow and grate discharge ball mills was successfully applied in the industry. He developed the first discrete element method code for mills called "Millsoft" in the early 1990s, which led to a revolution in the use of simulations for mining.

Editor: Nikhil Dhawan, Ph.D.

• World Gold: Advances in Exploration, Mining and Processing

The International World Gold Conference has become a key gathering for professionals across the mining and metallurgy fields, with a strong focus on the exploration, extraction and processing of gold. This collection brings together updated and expanded versions of papers first presented at the 11th World Gold Conference, held in Denver, Colorado in 2025. It also includes a number of new contributions that reflect ongoing progress in mining technology — from improvements in exploration and processing methods to the increasing use of automation and digital tools across the sector.

Editor: Nick Gow, Ph.D.

• Collection in Tribute to Dr. Terry McNulty: Ramp-up Profiles — Minimizing Risk & Maximizing Profit

This collection honors Dr. Terence (Terry) McNulty, whose ongoing career has shaped generations of practice in mineral processing and extractive metallurgy. Known for his leadership in plant design, commissioning and operational ramp-up, Dr. McNulty introduced the widely used ramp-up curve — a practical framework for tracking project startup performance that remains relevant across the global industry today. This collection brings together contributions from professionals and researchers whose work reflects the broad scope of Dr. McNulty's influence. Topics include ramp-up methodology, process design, plant optimization, and advancements in extractive metallurgy for both base and critical metals.

Editor: Fangyu Liu, Ph.D.

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