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THANK YOU!

IM&AD | Industrial Minerals & Aggregates Division

Each year, a team of volunteers from SME's **Industrial Minerals & Aggregates Division** pulls together summaries of dozens of industrial minerals commodities for the July issue of *Mining Engineering*. This year the result is an impressive overview of 48 commodities that power the world.

The Editors of *Mining Engineering* would like to thank the committee for its hard work to make this issue possible each year. If you would like to contribute to next year's Industrial Minerals Review or if you would like to join the technical committee, please contact Jim Norman (Jim.Norman@tetratech.com) to inquire about becoming a vice chair or shadow for this effort.

A special thank you goes out to the Industrial Minerals Annual Review editors, Jim Norman and Tushar Gupta, Technical Committee chair, and the many vice chairs and authors of the individual commodity profiles.

- Technical committee chair Dr. Tushar Gupta, Sr. metallurgical engineer-research at MP Materials
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- Aneesh Kona, sr. mining engineer at Pike Industries, CRH Co.
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Feature Articles

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

(peer-reviewed and approved)

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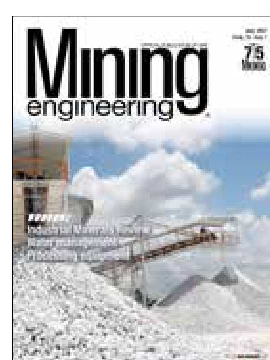
Further critical raw material (CRM) developments, the energy transition and continuing geopolitical hotspots are the chief factors that started to shape the global industrial minerals industry in 2022 and its near- to medium-term future. On page 22 Mike O'Driscoll provides an overview of the sector followed by the review of 48 industrial minerals provided by SME's Industrial Minerals & Aggregates Division. Cover design by Ted Robertson.



Local sections can and do make a difference;

We can all help promote mining to the next generation

Marc LeVier
2023 SME President

SME Local Sections are the backbone of SME. Local section meetings bring together members, colleagues and friends offering the chance to refresh contacts and make new ones along the way.

The immense value of the local sections working to increase SME visibility and promote mining is understated. The work required to organize events from securing a venue, planning the event, finding a speaker with a topic that is sure to draw an audience, securing sponsors and running the governance of the organization, "a mini-me" SME, is a daunting task.

In addition, local sections give their time and money in assisting students with scholarship funds and mentoring. Contacts that students make at these section meetings can last a lifetime, lead to a summer intern position or better yet, a full-time position. SME is very fortunate to have 48 local sections.

Recently, I had the opportunity to visit several local sections. The first was the Minnesota Section Annual Conference held in Virginia, MN, April 17-19. This was a meeting of members in iron ore operations and local polymetallic project development teams. The short courses and programming were central to local issues as well as topics of the day, such as the energy transition planning and execution, the drive to achieve carbon reduction with DR steel making, renewable energy development, and permitting issues at state and federal levels for the new projects. The tremendous efforts of the local members were evident in the programming and sponsorships and a full exhibitor space. Students were present from the University of Minnesota and the University of Minnesota-Duluth at an annual breakfast where scholarship checks were awarded.

A real personal bonus was meeting a couple of legends of our industry, Dr. Kenneth Reid and Dr. Charles Fairhurst. The opportunity to meet both gentlemen in person and hear some of the history behind their work at the University of Minnesota was an honor. The local sections provide opportunity to SME members to meet "giants of the industry" who have advanced the frontiers of science in technology, while mentoring and creating future generations of leaders.

The next meeting was the NYC Section's 8th Annual Meeting, "Trends in Mining Finance."

Safety Share: Lightning strikes the United States about 25 million times a year. Although most lightning occurs in the summer, people can be struck at any time of year. Lightning kills about 20 people in the United States each year, and hundreds more are severely injured.

What you should know:

- No place outside is safe when thunderstorms are in the area!!
- If you hear thunder, lightning is close enough to strike you.
- When you hear thunder, immediately move to safe shelter: a substantial building with electricity or plumbing or an enclosed, metal-topped vehicle with windows up.
- Stay in safe shelter at least 30 minutes after you hear the last sound of thunder.

Indoor lightning safety:

- Stay off corded phones, computers and other electrical equipment that put you in direct contact with electricity.
- Avoid plumbing, including sinks, baths and faucets.
- Stay away from windows and doors, and stay off porches.

More than 300 attendees covered a host of topics, while business discussions were found in the afternoon receptions, where the topics were new project financing and commodities futures. Tim Alch and team did a fantastic job of organizing a meeting of diverse topics with an equally diverse group of speakers. The meeting success and popularity were demonstrated by the generosity of the NYC Section's donation of $75,000 to the SME Foundation. Tom Rauch, SME Foundation President, was on hand to accept the donation.

A key success of this meeting was the SME students who volunteered from across the country to attend and assist in the meeting. They came from Stanford, Cornell, Utah, Colorado and New Hampshire. The students made new contacts and engaged in leading-edge discussions from regulatory and legal, to artificial intelligence enhancement of data treatment. A big thank you is appropriate for these future leaders of our industry for their professionalism

(continued on page 14)

Army Corps of Engineers revokes NorthMet water permit

A KEY WATER permit for the proposed NorthMet copper-nickel mine in northeastern Minnesota was revoked by the U.S. Army Corps of Engineers.

The Army Corps said the Clean Water Act "Section 404" wetland permit was revoked because it could not "ensure compliance with the applicable downstream water quality requirements" of the Fond du Lac Band of Lake Superior Chippewa, whose reservation lies downstream from the proposed mine on the St. Louis River.

Minnesota Public Radio reported that while it is a significant setback for NewRange Copper Nickel, a joint venture between PolyMet and Teck that was formed earlier this year, it does not kill the project. NewRange Copper can submit a new application for a wetlands permit or it can challenge the decision in federal court.

On May 30, NewRange Copper Nickel announced an $18 million project to begin salvaging and recycling scrap metal and concrete at the former LTV Steel processing plant, which it plans to use as a new processing facility for the mine.

But the wetlands permit is one of several key approvals that NewRange needs before it can begin actual construction of the NorthMet Mine that has now either been revoked or put on hold due to ongoing litigation and regulatory work.

The decision comes a little more than a year after the U.S. Environmental Protection Agency (EPA) recommended against reissuing the permit to PolyMet, saying the project risked increasing levels of mercury and other pollutants in the St. Louis River downstream from the proposed mine.

The 404 wetlands permit is one of several key approvals needed for the state's first mine for copper, nickel and precious metals.

The permit would allow NewRange to fill nearly 1,000 acres of wetlands at its proposed mine site with dredged material, something mine opponents have described as the largest permitted destruction of wetlands in the state's history.

PolyMet first secured its wetlands permit in early 2019. But the Army Corps suspended the permit in 2021 after the Fond du Lac Band sued, arguing that the EPA had failed to notify the Band that the mining project may affect its downstream waters, something required under the Clean Water Act.

Now, the Army Corps has sided with the EPA, which says that mercury discharged by the mine and released by wetlands impacted by construction of the mine would violate the Fond du Lac Band's water quality standards.

"The Corps' decision is one that requires careful review, determined action, and further engagement with regulators and all key stakeholders," NewRange Copper Nickel said in a statement.

The company added it is "reviewing all of our options as we chart a course forward for the development of the NorthMet Project in a safe and environmentally responsible manner that considers NewRange's communities of interest."

NewRange also argues the project would reduce mercury and sulfate pollution in the St. Louis River basin by installing water treatment and management systems at an old iron ore mining waste tailings basin that it plans to reuse.

"Today's decision by the U.S. Army Corps of Engineers is reversal of thoroughly reviewed water quality data that has been collected and assessed over the last decade," NewRange said.

In a statement, Minnesota Rep. Pete Stauber (R), said "The Biden Administration continues their assault on northern Minnesota and our way of life. Today's political decision highlights the need for serious permitting reform to limit frivolous lawsuits and modernize the Clean Water Act permitting process." ■

State requests more time for Piedmont lithium mine

REGULATORS IN North Carolina have asked Piedmont Lithium Inc. for additional information on 10 areas of its proposed mine. The state has requested information about the plans for arsenic testing, whether technical experts would be licensed in North Carolina, and how the mine's waste-rock storage pit would be lined.

Reuters reported that it is the third time that the state has asked for additional information since the review process began in 2021. Piedmont Lithium's proposed mine would be one of the largest lithium mines in the United States. However, it has faced extensive opposition from neighbors.

In January 2023, Piedmont agreed to deliver approximately 125 kt (138,000 st) of spodumene concentrate to Tesla through the end of 2025.

State officials gave the company 180 days to provide additional details on 10 areas. Piedmont first applied for the permit in August 2021. The state asked for additional information in October 2021 and in January 2022. The company's deadline to respond to the January 2022 request was extended twice.

"We remain extremely pleased with the significant progress we have made in our planning to date and are committed to taking the necessary time to appropriately complete the state permitting process," said Monique Parker, Piedmont's senior vice president of safety, environment and health.

Reuters reported in 2021 that Piedmont's failure to detail its plans for residents of North Carolina's Gaston County, just west of Charlotte, had prompted local officials to delay necessary zoning changes until after the company received its state mining permit.

Amid the North Carolina review process, Piedmont in 2021 invested in Quebec-focused Sayona Mining Ltd. and Ghana-focused Atlantic Lithium Ltd., deals that give it access to lithium from both companies. Piedmont said it expects to start receiving shipments from Sayona by September. ■

Talon Metals submits plans for nickel mine; **Proposed mine would supply nickel to Tesla**

TALON METALS CORP. has submitted its environmental assessment worksheet to the Minnesota Department of Natural Resources (DNR) to begin the state's environmental impact statement scoping process for the Tamarack nickel-copper-cobalt project, an underground mine in northern Minnesota. The proposed mine is a small-footprint, high-grade underground nickel mine that would be located near the city of Tamarack in Aitkin County, MN.

"Our team in Tamarack is excited to have reached the milestone of submitting the initial worksheet form to begin Minnesota's environmental review process, the starting point for any project seeking a permit in the state," Henri van Rooyen, chief executive officer of Talon said in a statement. "We have worked very hard and invested millions of dollars to understand the environment and cultural resources in the area where we are proposing the Tamarack Nickel Project outside of Tamarack. Environmental data collection started in 2006 and today includes data from the deep bedrock where the high-grade nickel deposit is found, to the surface water in the glacial till layer that contains wetlands, streams, rivers, lakes and homestead wells. This baseline data has helped the team to design the proposed project to safeguard the environment."

Last year, Talon signed a memorandum of understanding with Tesla to supply roughly half the nickel it produces to the automaker for its electric-vehicle batteries.

Like other projects in Minnesota, this one will likely receive heavy scrutiny. Two other copper-nickel mines in Minnesota, the NorthMet project and Twin Metals Minnesota have both been stalled in recent months.

The Tamarack project would have a 32-ha (80-acre) footprint on the surface that would include an access portal to the underground mine, temporary storage for ore and waste rock, and facilities to collect and treat water. The project would mine ore-bearing rock containing nickel and other precious metals at depths of approximately 152 to 610 m (500 to 2,000 ft) below the surface. Mined rock would be transported by rail to a processing facility in Mercer County, ND. Disposal of waste tailings would also occur at the Mercer County facility.

"We understand that Minnesotans have widely differing perspectives regarding this proposed project and nonferrous mining more broadly. The DNR, however, must base its decisions on the facts and the law," said Katie Smith, director of the DNR's Ecological and Water Resources Division.

"Today's announcement by Talon Metals marks a key milestone in Minnesotans showcasing their dedication to a clean energy future powered with domestic minerals. Our state is committed to clean car standards and clean energy goals that are dependent upon reliable, sustainably developed sources of nickel, cobalt, copper and iron, which would all be provided with the development of the Tamarack Nickel Project," Julie Lucas, executive director of Mining Minnesota said in a statement. "Community engagement and collaboration create stronger projects, both socially and environmentally, and Talon Metals has consistently demonstrated its promise to their neighboring community ... Domestic mining projects provide valuable opportunities for meaningful cooperation between all necessary stakeholders, which we do not have when we choose as a nation to source our minerals, such as nickel, from Indonesia or Russia." ■

Newswatch contents

Norway plans to open its waters **to offshore mining**

THE NORWEGIAN government announced a proposal to open parts of the Norwegian continental shelf for commercial seabed mineral activities.

In a statement published on the government's website, Petroleum and Energy Minister Terje Aasland said the proposal would help Norway become a leader in the production of critical minerals while it decreases its reliance on foreign sources.

Norway outlined a strategy to become "a global leader in a fact- and knowledge-based management of seabed mineral resources."

"We need minerals to succeed in the green transition. Currently, the resources are controlled by a few countries, which makes us vulnerable. Seabed minerals can become a source of access to essential metals, and no other country is better positioned to take the lead in managing such resources sustainably and responsibly. Success will be crucial for the world's long-term energy transition," said Aasland.

Norway said it has significant anticipated mineral resources on the seabed. If proven to be profitable and extraction can be done sustainably, seabed mineral activities can contribute to value creation and employment in Norway while ensuring the supply of crucial metals for the global energy

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Expansion investment at Kennecott nears $1 billion; **Rio Tinto to expand operations underground at copper mine**

RIO TINTO announced further investment in its Kennecott operation near Salt Lake City, UT to strengthen its supply of copper in the United States by increasing production from underground mining and improving the health of key assets.

Included in the investment is $498 million of funding that was approved to deliver underground development and infrastructure for an area known as the North Rim Skarn (NRS). Production from the NRS will commence in 2024 and is expected to ramp up over two years, to deliver around 250 kt (275,000 st) of additional mined copper over the next 10 years alongside current opencut operations.

In September 2022, Rio Tinto approved development capital totaling $55 million to start underground mining in an area known as the Lower Commercial Skarn (LCS). Underground production within LCS started in February 2023, and it is expected to deliver a total of around 30 kt (33,000 st) of additional mined copper through the period to 2027.

"These two investments will support Kennecott in building a world-class underground mine that will leverage battery-electric vehicle (BEV) technology, following a successful trial in 2022. BEVs create a safer and healthier workplace for employees underground, increase the productivity of the mine and reduce emissions from operations," the company said in a statement.

A $300 million rebuild is also underway at the Kennecott smelter. The rebuild is the largest in Kennecott's history and commenced in May 2023. A further $120 million is being invested to upgrade the refinery tank house structure and update Kennecott's molybdenum flotation circuit with a state-of-the art, fully automated system. As the second largest copper producer in the United States, this will allow Kennecott to continue to deliver a high-quality product to customers.

"We are investing to build a world-class underground mine at Kennecott and strengthen our processing facilities, to meet the growing demand for copper in the United States, a key material for domestic manufacturing and the energy transition," Rio Tinto Copper chief operating officer Clayton Walker said. "This investment will position Kennecott to continue the strong contribution it has made as part of the Salt Lake Valley community for 120 years, injecting about $1.5 billion annually to the local Utah economy."

Studies to inform decisions on the next phases of expanding underground production continue in parallel with work that is being advanced to extend openpit mining at Kennecott beyond 2032. ■

Judge blocks approval of phosphate mine; **Sage grouse population holds up permitting process**

APPROVAL FOR THE Caldwell Canyon phosphate mine in southeastern Idaho was withdrawn by a federal judge who ruled federal land managers in the Trump administration didn't in part properly consider the mine's impact on sage grouse, a bird species that has seen an 80 percent decline in population since 1965.

Fox News reported that U.S. District Judge B. Lynn Winmill's decision came five months after he found fault with the way the U.S. Bureau of Land Management (BLM) approved the project in 2019.

The mine has been proposed by P4 Production LLC, a subsidiary of German pharmaceutical giant Bayer AG. Three environmental groups — the Center for Biological Diversity, Western Watersheds Project and WildEarth Guardians — sued.

Winmill ruled that the BLM violated the National Environmental Policy Act and other laws on several counts when it approved the mine. Among the faults were failing to consider the indirect effects of processing ore at a nearby plant and the cumulative impacts on sage grouse.

Winmill's decision issued remedies for those violations: Vacating both the mine's approval and the environmental analysis of the project, as well as any other decision that relied on those documents.

"We believe the court's decision to vacate the BLM's approvals is excessive," Bayer AG said in a statement. The company is assessing its next steps, which could include an appeal.

"We believe the few specific deficiencies the court identified in the BLM's assessment can and should be fully addressed expeditiously," the statement said. Bayer said it plans to have the mine operational in the next few years.

The proposed venture would include two new openpit mines to extract phosphate ore, according to court documents. It would have resulted in the disturbance of about 1,550 acres of previously undeveloped land nearly 300 miles southeast of Boise.

The mine was projected to last for 40 years, with ore taken by truck or rail to a nearby processing plant.

There, the ore would be processed to produce glyphosate, the active ingredient in Roundup, the most widely used herbicide in the world. Bayer acquired the herbicide's original producer.

Bayer this year began transitioning glyphosate out of its U.S. residential lawn and garden products and using other ingredients as a way to reduce future litigation risks. Agriculture and professional products will not be changed, and the company said it stands behind the safety of its glyphosate products. ■

First Quantum Minerals rebuffs Barrick Gold;
Barrick looks to grow its copper interests

THE GLOBAL energy transition will require massive amounts of copper. Mining companies around the world are attempting to position themselves to meet the demand. Newmont Corp. agreed to acquire Newcrest Mining in May for $19.2 billion. That deal not only makes Newmont the clear leader in the gold sector but it also greatly increases its copper position.

Newmont president and chief executive officer Tom Palmer said of the acquisition, "This transaction also increases Newmont's annual copper production — a metal vital for the new energy economy — and adds nearly 50 billion pounds of copper reserves and resources from Newcrest to our robust and balanced portfolio."

Bloomberg News reported that Newmont's gold sector rival, Barrick Gold Corp. is also pursuing opportunities to grow its copper business. Barrick recently approached First Quantum Minerals Ltd. to discuss a potential takeover. First Quantum Minerals rebuffed the advancements.

A deal with First Quantum would transform Barrick into a significant copper miner when the industry's largest players are all seeking to expand production of the wiring metal. BHP and Rio Tinto are actively looking to grow their copper exposure, while Glencore Plc is pursuing an unsolicited $23 billion takeover bid for Canada's Teck Resources Ltd., chiefly to acquire its giant South American copper mines.

Mark Bristow, Barrick's chief executive, has talked for years about his desire to grow in copper.

Copper is critical "if you want to be relevant" in mining, Bristow said on the company's latest earnings call. "As a gold miner, you're going to have to grow and include copper in your portfolio."

Bloomberg reported that Barrick's biggest investment project is a $7 billion copper-gold project in Pakistan, which Barrick plans to start up in 2028 and could operate for at least four decades. It is also studying an expansion at its Zambian copper mine, while scouring for new deposits across the Middle East, Asia and Africa.

Bristow isn't alone in his hunt for copper. Mining executives and analysts have been sounding an alarm over growing shortages starting in the mid-2020s, as demand increases for copper in electric vehicles, wind and solar farms, and high-voltage cables. The world's biggest miners are all looking to grow in copper to take advantage of future price rises, at a time when there are few new projects being planned.

Bristow has stressed that Barrick is still, at its core, a gold company. But the firm's gold production has fallen to its lowest level since 2000 and its shares are down 5 percent this year. Newmont's takeover of Newcrest Mining would cement its position as the world's top gold miner. The only metal output that has increased at Barrick since the Randgold merger is copper.

"It's as strategic as gold is precious," Bristow said recently. ■

Norway: Sea floor mining could expand resources

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transition. Extraction of minerals could become a new and important industry for Norway.

"To acquire more knowledge, we need to gather expertise and open for commercial mapping, exploration and extraction of seabed minerals. Therefore, we are proposing to open an area on the Norwegian continental shelf for mineral activities," said Aasland.

Existing knowledge indicates that mapping, exploration and closure have minimal environmental impact. Any extraction will only be approved if the rights holder's recovery plan demonstrates that the extraction can occur in a sustainable and responsible manner.

"Seabed mineral activities are a new industry, both globally and in Norway. Currently, we have limited knowledge about the deep-sea areas where the resources are located. I firmly believe that if the industry identifies resources that they consider economically viable to extract, it will be possible to extract these resources sustainably and responsibly. We will proceed step by step, continue building experience, and base our regulatory framework on facts and knowledge. Environmental considerations will weigh heavily throughout the value chain," said Aasland.

Before an area can be opened for mineral activities, an opening process must be carried out. The opening process was initiated by the Ministry of Petroleum and Energy in 2020 and consists of two main parts: an impact assessment process and a resource assessment.

A growing number of countries including Germany, France, Spain, Chile, Costa Rica, New Zealand and Panama, have asked the United Nations-affiliated International Seabed Authority (ISA) to not rush into enacting mining regulations by July 2023, a deadline that was set in 2021. ■

Minnesota to rewrite mining rules around **Boundary Waters Canoe Area Wilderness**

MINNESOTA'S Department of Natural Resources (DNR) announced that it will rewrite its mining rules to expand the surface mining buffer zone around the Boundary Waters Canoe Area Wilderness. The announcement comes after the agency determined its existing rules didn't do enough to prevent light and noise pollution.

The *Star Tribune* reported that the agency was ordered by a court to re-examine regulations for nonferrous mines. Mining of any kind is already banned in the Boundary Waters, and any mining that disturbs the surface is banned in the corridor. The new rules will expand the size of a protective minerals management corridor next to the Boundary Waters.

The agency will also request lawmakers address concerns about tailings and storage that were raised by the public through comments collected about its rule in 2021. The agency reviewed 4,000 messages and letters.

The DNR's decision stems from a 2020 lawsuit filed by Northeastern Minnesotans for Wilderness (NMW). The suit argued that the DNR hadn't done enough to protect the Boundary Waters from pollution and degradation because the state's rules didn't cover all of the Rainy River headwaters watershed, which flows south to north, through the 1.1 million acre preserve, the *Star Tribune* reported.

Twin Metals, a company attempting to open a copper mine near Ely, MN, intervened in the suit. Company spokeswoman Kathy Graul wrote in a statement that it was reviewing the DNR's decision, and that the state already had "some of the most rigorous standards in the world."

In January, the Biden Administration imposed a 20-year ban on mineral leases on 225,000 acres of national forest land in northern Minnesota, including Twin Metal's mine site.

Last year, the administration also canceled Twin Metal's mineral leases. The company sued in federal court, where the case is still pending.

Graul wrote that "we remain committed to advancing a modern mining project that is protective of the environment and that meets or exceeds all state and federal standards."

While the DNR is taking action based on light and noise concerns, the agency will not consider air and water issues as it re-examines its rule. In its decision, it pointed to existing Minnesota Pollution Control Agency regulations that already protect air and water quality.

NMW and Twin Metals both have 30 days to challenge the decision by asking for a contested case hearing, where parties can bring experts before a judge to analyze the details of the DNR's decision. ■

NASA aims to block mining at desert site in Nevada; **Lithium deposit is at site used for satellite calibration**

LITHIUM IS A crucial mineral needed for batteries for electric vehicles (EVs) which in turn are an important part of the global energy transition. Demand for lithium is high and is expected to continue to rise in coming years, yet mining the metal still faces stiff opposition from environmentalist, farmers, ranchers and in the case of one lithium deposit in Nevada, opposition from the National Aeronautics and Space Administration (NASA).

In Railroad Valley, NV an ancient lakebed that is "flat as a tabletop and undisturbed like none other in the Western Hemisphere — is indispensable for calibrating the razor-sharp measurements of hundreds of satellites orbiting overhead," according to a report from the *Associated Press*.

At the request of NASA, the U.S. Bureau of Land Management (BLM) has agreed to withdraw 92 km^2 (36 sq miles) of the eastern Nevada terrain from its inventory of federal lands open to potential mineral exploration and mining.

NASA has used Railroad Valley for nearly three decades to get measurements just right to keep satellites and their applications functioning properly.

"No other location in the United States is suitable for this purpose," BLM concluded in April after receiving NASA's input on the tract 400 km (250 miles) northeast of Las Vegas.

The bureau has spent nearly three years fighting mining challenges of all sorts from environmentalists, tribal leaders, ranchers and others who want to overturn approval of the Thacker Pass Mine.

In December, the bureau initiated a review of plans for another lithium mine conservationists oppose near the California line where an endangered desert wildflower grows, about 370 km (230 miles) southeast of Reno.

The *AP* reported that in Railroad Valley, satellite calculations are critical to gathering information beamed from space with widespread applications from weather forecasting to national security, agricultural outlooks and natural disasters, according to NASA, which said the satellites "provide vital and often time-critical information touching every aspect of life on Earth."

That increasingly includes certifying measurements related to climate change.

"As our nation becomes ever more impacted by an evolving and changing environment, it is critical to have reliable and accurate data and imagery of our planet," said Mark Moneza of Planet Labs, a San Francisco-based satellite imaging company that has relied on NASA's site to calibrate more than 250 of its

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A tale of three countries —
Mining law changes

by Douglas Silver

If you ever want to know where the mining industry is headed, just watch the oil industry. Decades ago, Middle East governments forced the large oil companies to exchange their vast landholdings for lucrative management contracts on the assets they previously owned. The minerals industry is starting to experience this same transition.

Three countries: Chile, Mexico and the United States are in the process of "upgrading" their mining laws. They claim these changes are to better align current practices with societal changes, but their rhetoric is questionable. This may make a nice sound bite, but these changes are of course being made solely to bring more money into the governments' coffers.

Each country appears to have a different agenda. Chile's new mining law effectively nationalizes its lithium resources. But then again, the government currently controls most of these resources and claims it will honor existing contracts. So, is this resource nationalism or simply the government's realization that it can create another governmental mining company (ala CODELCO) and reap the economic rewards? Their press release pointed out that these new rules do not apply to small miners, and that the large producers will have to give up majority control to the government when their concessions expire.

Separately, Chile is also raising its taxes on copper mines, especially the large ones. Should the operator have a foreign investment agreement in place, then this would constitute resource nationalism. For those without an agreement, your anticipated IRR just went down.

Then there is Mexico. Mexico's new law seems to focus on making sure foreign mining companies take their business elsewhere. They have shortened concession terms, thus allowing the government to put these same concessions out for bid, even after the operator has spent substantial capital to

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President's Page: Local sections key to success

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and excellence.

In May I was invited to speak to the SME Salt Lake Section. The audience was filled with members and friends as well as students. The efforts of section leaders Dr. Abani Samal, Mick McCaslin, Christy Miller, David Garbrecht and Derek Loveday were immensely appreciated. The local section presented the SME Foundation with a check for $2,000. Again, the efforts of an SME local section bears fruit and contributes to the many Foundation programs.

In addition to the section meeting, discussions were held with Rio Tinto and FLSmidth (FLS) on how SME can support their companies. We were invited to the Rio Tinto new graduate hires and summer intern orientation. The room was alive with enthusiasm and nonstop chatter and excitement by the new hires. They were welcomed by Nate Foster, general manager, Rio Tinto-Kennecott and a Montana Tech alum (Roll DIGGS).

At FLS, we were welcomed by our hosts Mick McCaslin, Wendi Cooksey, Marnus Fick and Wayne Douglas. Again, great discussions on FLS and how SME can support their efforts. Productive discussions ended with a tour of the world-class FLS facility and metallurgical testing laboratory.

Cooksey, who hosted about 40 high school students on a tour of Kennecott operations asked them, "Well, you drive up and down the interstate every day, and you never bothered to ask what went on over at the mine?"

No! The signs of activity, the buildings and openpit had all become like window dressing, and no one asked and teachers did not bother to discuss the vocational opportunities.

We can remember the subject of workforce and think about the overwhelming demand for trade skills and engineers that the mining industry is facing. The local sections have a key role, no matter their location, to engage with high schools and work with counselors and science teachers on what mining truly is all about, a high-technology business with critical skills in math and sciences. MEC recently developed a pilot program in Denver, CO where a high school was adopted, and information is provided on mining to counselors and students. The program is growing and prepared to launch in Salt Lake City. Local sections make a difference.

Meanwhile on social media, I read a post about mine tours WIM-Elko organized for elementary school kids. The "big" discovery was how little the kids knew about "what mom and dad did at the mine." A great effort by the WIM-Elko Section in outreach to students.

Think of the difference you can make by taking five minutes with a young person in speaking about mining. Life-changing opportunities can be presented, and that young person's life can be changed forever in a good way. Things happen for a reason. Heroes are around us everywhere. If you need assistance getting a program started, ask for help. We have the resources available for you.

Finally, big thanks to all the local sections and what they do for SME. The common traits that we observe are leadership, commitment, dedication and passion. The best part of our mining community is the relationships and friendships that last a lifetime. I look forward to more local section events through my President's term. ■

NASA: One of 10 largest deposits in the world

(continued from page 14)

satellites since 2016.

Republican Rep. Mark Amodei told a House subcommittee that the decision underscores the "hypocrisy" of President Joe Biden's administration.

"It is supposedly a goal of the Biden administration to boost the development of renewable energy technology and reduce carbon in our atmosphere," Amodei said. "Yet they support blocking a project to develop the lithium necessary for their clean energy objectives."

The Carson City, NV, company holding most of the mining claims, 3 Proton Lithium Inc., had not submitted any formal project plans in 2021 when NASA requested the land withdrawal. But the firm claimed to have done extensive research in anticipation of future plans to extract the brine-based lithium resource it said is one of the 10 largest deposits in the world.

Chairman Kevin Moore said the tract's withdrawal likely will prevent his energy company from pumping the "super brine" from about one-third of its claims there, including the deepest, richest deposits holding about 60 percent of the site's value. He joined Amodei in testifying before the House Resources Subcommittee on Mining and Mineral Resources.

"This project is a vital part of transitioning to a green economy, creating good-paying American jobs, combating climate change, ending America's over-reliance on foreign adversaries and securing a domestic supply chain for critical and rare earth minerals," Moore said.

Other opponents of BLM's move include James Ingraffia, founder of the energy exploration company Lithium Arrow LLC. He told the bureau in earlier public comments that by establishing obstacles to Railroad Valley lithium mining, it was undermining efforts to combat climate change. ■

Silver: Mining law to be considered

(continued from page 13)

build and develop the operation. Granted, Mexico has not issued a new concession since 2018, but this new approach will surely prove a disincentive for new investment. But this may be part of their larger agenda. After all, Mexico created a government-owned lithium company last year. We will see how that goes.

Part of the Mexican agenda may be to put more of its lands in the hands of Mexican companies. But most of these companies do not have access to capital in the way the Northerners do, so this transition will slow down exploration, discovery, development and production along with impacting jobs and tax revenues. If one is playing the long game, this may be a smart move. But for a government with the fiscal and social problems facing Mexico, this aggressive action may backfire.

The U.S. government has a very different agenda than these other countries. The current administration's efforts are designed to thwart mining. Curiously, these efforts are being spearheaded by Congressmen Raul Grijalva and Martin Heinrich, both Democrats from states with large mining operations. One would expect this from nonmining states legislators, but not from those whose states receive large economic benefit from mineral extraction. These congressmen complain that the Mining Law of 1872 is outdated, despite being amended in 1993 and followed by a slew of subsequent hardrock and reclamation acts, along with infinite new environmental laws. Their false narrative claims that the mining industry has not paid a penny in federal royalties, making our industry sound like we are dodging our fiscal responsibilities by playing accounting games. We have not paid a penny because the Mining Law of 1872 does not include a royalty provision. But they conveniently ignore the federal and state income tax, ad valorem taxes, jobs, infrastructure development and multiplier effect on contractors, local communities and state budgets that mining provides. They also ignore the states that charge their own mineral royalties to ensure the federal government does not abscond with the proceeds. The federal proposal goes further to blame mining for 40 percent of water pollution in western states (has anyone seen the data for this?) and complain about the lack of consultation with Indigenous communities.

They suggest that the mining-industry should pay a fair royalty. I doubt anyone in the industry would disagree with this position. Grijalva believes a "fair" royalty is 5 to 8 percent on gross income royalty, which is two to four times greater than the current fair-market rates of such royalties on private lands. If his real agenda here is to stop all mining on federal lands, then passage of this bill should do it.

They want more consultation with tribes even though the existing permitting process requires public hearings. If the mine is on tribal lands this makes sense, but when the tribal lands are miles away from the mine, the Indigenous people should have to follow the same process as other U.S. citizens. I do not personally know of any miner ignoring the local stakeholders, so this one is a head scratch.

They claim they want to level the playing field. Somehow taking 15 to 20 years and spending millions of dollars to address all stakeholders' concerns as part of the laborious permitting processes endured today, only to be continuously blocked by special interest groups, has not leveled the playing field enough.

Finally, they want the hardrock mining industry to fund historic reclamation sites — sites that today's miners did not create. Were these historical metals only sold to foreigners? Of course not. They were used to build the United States into the largest and most dynamic economy in the world, which benefitted all the citizenry and will for future generations. But acknowledging this would undermine their antimining agenda. I personally tried to organize an abandoned-mine reclamation effort 30 years ago but was told that if I moved one spoonful of dirt, I would become a potentially responsible party. Good Samaritan laws? We are not interested.

What I cannot figure out is why these governments do not sit down with mining companies to hear their concerns and then actually use this information to structure laws that benefit their jurisdictions and constituents. They are literally leaving billions of dollars on the table by destroying the minerals industry.

Mining provides high-paying jobs, community infrastructure and large tax revenues. These governments seem to be clueless that capital is global, fluid and dynamic. If their actions make existing and future mines uneconomic, investors and mining companies will simply take their business elsewhere. ■

Bolivia seals $1.4 billon lithium deal with CATL

BOLIVIA'S government has signed on to a $1.4 billion deal with Chinese battery giant CATL to develop that nation's lithium reserves.

Reuters reported that the partnership was originally made in January and that it connects CATL, the world's largest manufacturer of electric vehicle batteries, with Bolivia's salt flats that are home to the world's largest lithium resources.

Bolivian President Luis Arce confirmed the commitment to build two lithium plants to extract minerals from the country's Uyuni and Oruro salt flats.

"We met with Burton Roy (Yu Bo), chief executive officer of the Investment Committee of CATL to confirm the investment of $1.4 billion," the president said via Twitter, adding that as partners they would "evaluate the possibility" of increasing investments to 2028. ■

Mine water stewardship in Arizona

by Terry Braun

The Colorado River. Image from Shutterstock.

On May 6, 2022, the Central Arizona Project and the Arizona Department of Water Resources (ADWR) held a public briefing on Colorado River Shortage Preparedness. The briefing started with three observations. First, the Colorado River Basin drought has lasted more than 22 years. Second, dry soil, higher temperatures, and low precipitation represent the driest basin conditions in more than 1,200 years. Third, the Colorado River was 36 percent of Arizona's water supply in 2020. The briefing ended with the certainty of further reductions to Arizona's Colorado River allocation in 2023 — beyond the 30 percent reduction instituted in January 2022.

One full year later, the states of Arizona, California and Nevada (lower division states) agreed to conserve an additional 3 million acre-feet (MAF) of Colorado River water by the end of 2026. This agreement followed the February 2023 release of the Near-Term Colorado River Operations Draft Supplemental Environmental Impact Statement, prepared by the Bureau of Reclamation. As proposed in the agreement, up to 2.3 MAF of compensation will be federally compensated under the Inflation Reduction Act. The remainder "may be in whole or in part compensated (or be uncompensated) by state and/or local entities."

The complexity of the Colorado River legal framework and the reality of the current basin condition triggers a statewide ripple effect in terms of water supply planning and allocation in Arizona. In 2021, Arizona copper mining (for example, metal mining) accounted for 74 percent of the domestic U.S. copper production (U.S. Geological Survey, 2021). At least two Arizona copper operations import Colorado River water as a portion of freshwater supply. How do the major copper producers in Arizona navigate the sustained drought conditions, climate change forecasts and complex legal frameworks of today? The solutions lie in a collaborative strategy involving long-term conservation planning and a sustained commitment to water stewardship.

Terry Braun is president, SRK North America. Email: tbraun@srk.com.

Regulatory brief

The most recent statewide water conservation measures announced in 2022 and

2023 are the latest of a long series of forward-looking water strategies in Arizona, accelerated by the construction start of the Central Arizona Project in 1973.

Established in 1980, ADWR assumed responsibility for all groundwater planning and regulation in the state except for water quality. This legal authority included development and oversight of mandatory conservation programs for groundwater use in four areas of heaviest groundwater pumping, classified as active management areas (AMAs). ADWR's legal authority on groundwater use outside of the AMAs requires users demonstrate a reasonable and beneficial use. In this role, ADWR regulates "groundwater mining."

The act includes the provision that developers of new subdivisions within AMAs demonstrate a 100-year assured water supply. ADWR monitors and models groundwater use within each AMA. On Jan. 9, 2023, Arizona Gov. Katie Hobbs announced the ADWR cannot approve the development of subdivisions reliant on groundwater in the Phoenix AMA. This announcement was based on the ADWR finding that Phoenix's West Valley is short of its 100-year supply of water.

The Surface Water Division of ADWR administers permits, certificates of water rights and claims to the appropriation of surface water in the state. This legal authority defines beneficial use as the basis, measure and limit to the use of surface water. Mining is one beneficial use.

Established in 1987, the Arizona Department of Environmental Quality (ADEQ) assumed responsibility for surface and groundwater quality protection through various water quality programs. The aquifer protection permit requires compliance with aquifer water quality standards at the point of compliance, and operators to demonstrate best available demonstrated control technology (BADCT). The purpose of BADCT is to employ engineering controls, processes, operating methods or other alternatives to reduce the discharge of pollutants to groundwater to the greatest degree achievable.

ADWR provides specific conservation requirements for metal mining facilities in AMAs. The Fifth Management Plan (2020), published for the Tucson AMA, defined a series of water conservation-related best management practices (BMPs) for metal mining facilities. These BMPs are generally consistent with BADCT guidelines under the ADEQ aquifer protection permit program.

There are multiple water-focused public agencies, private utilities and councils involved in conservation, storage and strategic resource planning in Arizona. In terms of water stewardship and metal mining, ADWR and ADEQ are the primary agencies of interest for this article.

Metal-mining water consumption estimates

ADWR (2020) estimates industrial use accounts for 6 percent of water consumption in Arizona. Metal mining (that is, mining operations that consume more than 500 acre-feet per year) is one of several industrial uses, in addition to turf-related facilities, sand and gravel, and large-scale power plants (greater than 25 MW). At the statewide scale, metal mining consumption is about four times less than municipal use (22 percent) and at least 10 times less than agricultural use (72 percent).

ADWR manages six AMAs: Prescott, Phoenix, Pinal, Tucson, Santa Cruz and Douglas. Metal mining occurs in the Phoenix (one facility), Pinal (one facility) and Tucson (six facilities) AMAs. ADWR estimates metal mining in 2020 accounted for 39 percent (approximately 432,000 acre-feet) of AMA total groundwater use (eight facilities within the Phoenix, Pinal and Tucson AMAs). This is a partial accounting because groundwater is one of several classified water resources and metal mining also occurs outside of designated AMA boundaries.

The relevant context of water use by metal mining operations is basin specific. Water consumption at a large metal mine depends on the volume of ore mined, commodity, mineral processing methods, and availability and type of water resources.

Industry best practice

Water stewardship includes evaluating water supply and water quality impacts associated with mine operations, closure and postclosure. Best practice extends this analysis on a basin-wide basis with active collaboration toward use that is socially equitable, environmentally sustainable and economically beneficial.

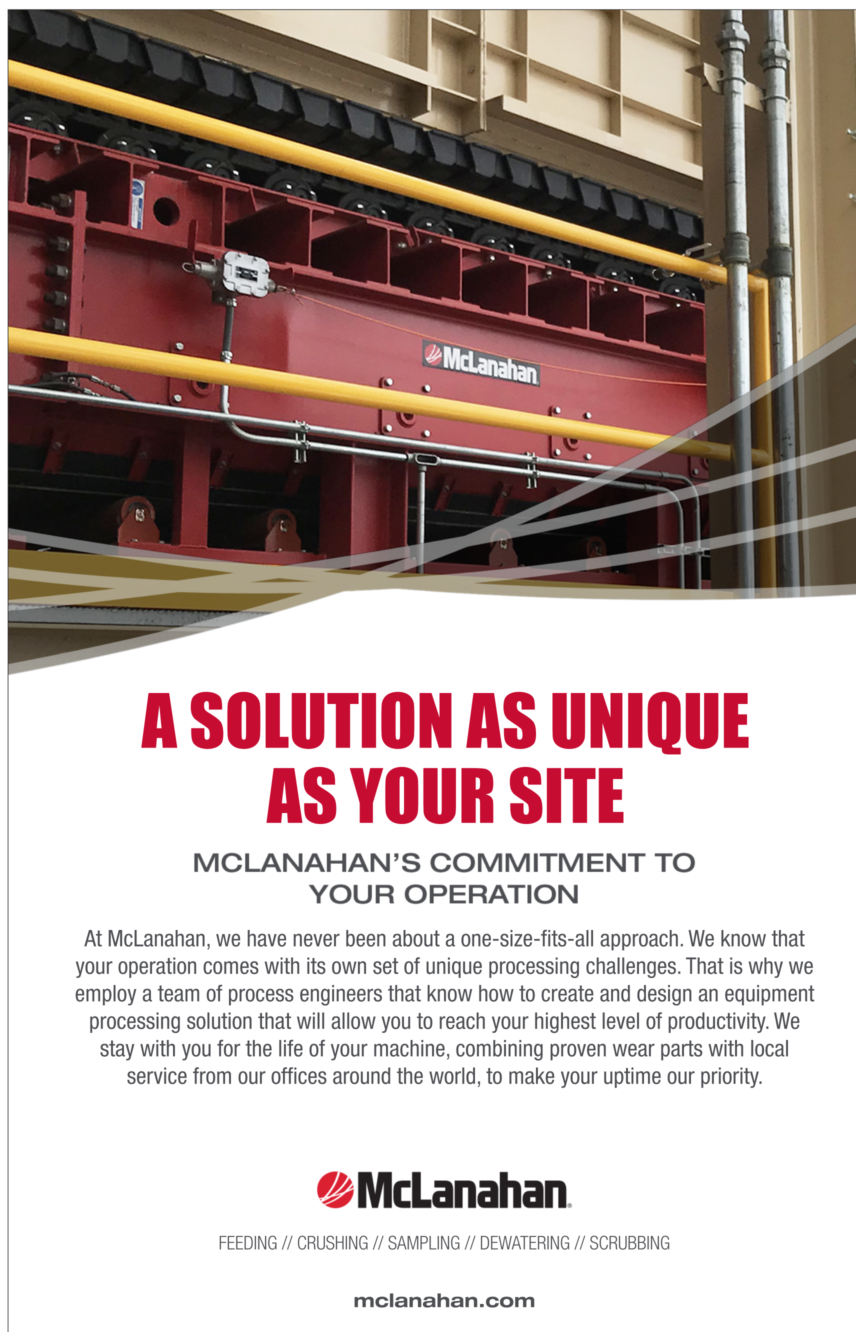
This aspect of water stewardship is an imperative for metal mine operations in the arid, semidesert climate of Arizona. Evaporation and entrainment (for example, water retained within conventional tailings storage facilities and leach stockpiles) account for a significant portion of water consumption. Large-scale metal mine operations have worked to maximize water use efficiency and promote use of recycled, reused and lower-quality resources for decades. Examples of best practices in Arizona include:

- Minimizing use of freshwater and impacts to freshwater quality.

- Modeling and planning for climate-related impacts in terms of engineering and promoting water-supply resilience.
- Continuing improvement in terms of maximizing recycled/reused water.
- Investing in research and field demonstrations of new technologies designed to reduce water consumption.
- Collaborating with other actors in the management of the water basins to manage and develop water resources in a sustainable and balanced manner, considering the social, economic and environmental interests of the actors.

The emergence of responsible production initiatives for global mining activities represents new drivers promoting water stewardship. Other trends include early experimentation with integrating natural capital (for example, water value) into business decision-making.

These water-related goals and metrics by established operators align with the long-term conservation planning required for metal mines by ADWR as well as the updated drought mitigation measures issued by ADWR and the Central Arizona Project. Plans for new metal mines include adoption of emerging technologies such as filtered tailings, reduced evaporation from water storage facilities, less water-intensive dust control, and increased water reuse overall. These plans, combined with adaptive management and stakeholder engagement, will guide metal miners through this complex landscape. ■



Rio Tinto to expand smelter;

technology slashes greenhouse-gas emissions

Saguenay-Lac-Saint-Jean in Canada, where a state-of-the-art aluminum smelter complex is being expanded with low-carbon technology. (Image from Rio Tinto.)

Rio Tinto will invest $1.1 billion (C$1.4 billion) to expand its state-of-the-art AP60 aluminum smelter equipped with low-carbon technology at Complexe Jonquière in Canada, *Business Wire* reported.

The total investment includes up to $113 million (C$150 million) of financial support from the Quebec government. The expansion, which will coincide with the gradual closure of potrooms at the Arvida smelter on the same site, will enable Rio Tinto to continue meeting customers' demand for low-carbon, high-quality aluminum for use in transportation, construction, electrical and consumer goods.

The investment will add 96 new AP60 pots, increasing capacity by approximately 160 kt/a (176,000 stpy) of primary aluminum, enough for 400,000 electric cars. As a result, there will be a total of 134 AP60 pots and a capacity of approximately 220 kt/a (242,000 stpy). Construction will occur over two and a half years with commissioning of the new pots expected to start in the first half of 2026 and the smelter fully ramped up by the end of 2026. Once completed, the expanded smelter is expected to be in the first quartile of the industry cost curve.

This new capacity will offset the 170 kt (187,000 st) of capacity lost through the gradual closure of potrooms at the Arvida smelter from 2024. In addition, Rio Tinto will add 30 kt (33,000 st) of new capacity through the commissioning of the previously announced recycling facility at Arvida in the first quarter of 2025.

The AP60 smelting technology was developed by Rio Tinto's research and development teams and is among the most efficient and lowest carbon technology currently available at a commercial scale.

When combined with the hydropower used at Rio Tinto's operations in Canada, it generates one-seventh of greenhouse gases per tonne of aluminum when compared with the industry average, and half the emissions when compared to the technology currently used at the Arvida smelter.

The project will generate up to 1,000 jobs during the peak of construction and approximately 100 permanent jobs will be maintained as a result of the expanded smelter.

Rio Tinto chief executive Jakob Stausholm said: "This investment is aligned with our strategy to decarbonize our value chains and grow in materials essential for the energy transition. Our AP60 technology is already proven and producing some of the lowest-carbon aluminum in the world, thanks to the expertise of our highly qualified workforce and access to renewable hydropower. This is the most significant investment in our aluminum business for more than a decade and it will further strengthen Rio Tinto's high-quality and low-carbon offering to our customers as they also work to reduce their own carbon footprint."

Quebec Premier François Legault said: "A great momentum is building in our regions for our green economy. The aluminum industry in Saguenay-Lac-Saint-Jean has always been a real source of pride and has created considerable wealth in the region. Today's announcement will breathe new life into this industry with greener, less polluting processes."

Rio Tinto and the Canadian government have also signed a memorandum of understanding that deepens their commitment to strengthen supply chains for low-carbon primary metals, critical minerals and other value-added products. The cooperation will also aim to support projects that have the potential to grow Rio Tinto's activities in Canada, including the current and future decarbonization of the aluminum supply chain. ■

Industrial Minerals review 2022

by Mike O'Driscoll*

Learning to be greener and smarter

Last year's introduction to the Industrial Minerals Annual Review concluded with a pointer to the challenges facing the sector in developing and employing carbon emissions reduction, energy conservation and recycling practices for a sustainable future. Throw in further critical raw material (CRM) developments, the energy transition and continuing geopolitical hotspots, and we have the chief factors that started to shape the industry in 2022 and its near- to medium-term future.

Critical raw materials up front and center

There has already been much reported on specific CRM developments, including a recent update on U.S. CRMs by Steven Fortier et al. of the U.S. Geological Survey (USGS), published in *Mining Engineering* in May 2023.

Perhaps most significant from a big-picture standpoint is the accelerating activity from government and state organizations across the world, as well as the mainstream media, as they seek to understand and compile data on their respective CRM resources and supply-chain risks.

Indeed, even the recent G7 Hiroshima Communique included reference to a "Five-Point Plan for Critical Mineral Security." Ahead of the pack here is the European Commission (EC) (representing 27 countries) and the United States, although others, notably Canada, Australia, Brazil and India are also getting their acts together, with the likes of the United Kingdom and France as latecomers to the party.

The EC had a very busy 2022 launching a revised CRM list, notably adding feldspar and manganese, and in March 2023, an ambitious Critical Raw Materials Act. The latter introduced a new category of "strategic raw materials" (SRMs), important for technologies that support the twin green and digital transitions, and defense and aerospace objectives (this includes rare earth elements and battery-grade lithium, manganese and natural graphite).

"We are experiencing a global race for the supply and recycling of critical raw materials," noted Thierry Breton, commissioner for the Internal Market, EC.

The EC's CRM Act aims to provide the European Union (EU) with tools to ensure access to a secure and sustainable supply of CRMs, stating that not more than 65 percent of the EU's annual consumption of "each SRM at any relevant stage of processing" is sourced from a single third country. Moreover, benchmarks are set for EU annual SRM consumption to be met by at least 10 percent extracted in the EU, at least 40 percent processed in the EU and at least 15 percent from EU recycling.

Most welcome to EU mineral developers will be the act's promise to reduce administrative burden, simplify permitting procedures for EU CRM projects and support access to finance. Too good to be true?… Let's see. Certainly, EC President Ursula von der Leyen laid it on the line at the World Economic Forum in Davos, Switzerland in January 2023, as she unveiled the CRM Act: "The next decades will see the greatest industrial transformation of our times — maybe of any times."

The U.S. Inflation Reduction Act (IRA), signed into law on Aug. 16, 2022, has also been instrumental in focusing minds on CRM supply, although how much it will influence upstream U.S. CRM development remains to be seen.

Certainly, downstream activity is already emerging, with the likes of Ford Motor Co. recently signing several lithium supply agreements with a focus on material that will be eligible under the IRA, securing supply from SQM and Albemarle (both in Chile) as well as three North American projects in development.

The flip side to all this is that certain CRM-rich countries may take steps to reinforce control over their supply, such as Chile in its April 2023 announcement of plans to nationalize its lithium industry.

Energy and environment top priority

The greatest impact on the future of the industrial minerals industry will be climate change and the steps taken by industry and consumers alike to mitigate against this.

There are several strands to this that certain companies in the sector have already started to address in recent years, and it would be fair to say that the pandemic lockdown periods of 2021-2022 have helped companies reassess and restrategize their "green" priorities.

"Energy transition" is the big buzz word, and it is top of the agenda for mineral companies as they strive to switch to alternative energy sources to reduce their carbon dioxide (CO_2) footprints, such as by using electrical mining equipment or considering other fuels for processing operations.

Mining and processing is an energy-intensive industry, so it will take time to develop an optimum solution. With rising petcoke costs, mineral plants using kilns for drying and in particular for widespread calcination operations, such as in bauxite, magnesia, doloma and lime production, will, or should, be evaluating alternatives to fossil fuels.

For example, in 2022 Grecian Magnesite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started using a new biomass-fed burner system, accounting for 10 percent (by energy basis) for its thermal power demand; this is set to increase to 20 percent in 2023 and 40 percent by 2024. This was part of its participation in BAMBOO, an EU-funded project developing new technologies for energy and resource efficiency.

The company is also looking to switch from using fossil fuels to liquefied natural gas (LNG), which would not only result in reducing CO_2 emissions by at least 40 percent and improving energy efficiency by at least 8 percent, but also render flue-gas desulfurization (FGD) unnecessary (posing questions on the future of FGD scrubber minerals?).

The other main energy strand in decarbonization is in carbon capture and utilization (CCU). While research on CCU has been around for some years, it is only recently that serious projects are getting off the ground and industrial mineral companies are starting to employ such technology. The added benefit, and potential market opportunity, is that certain CCU projects result in production of some very useful synthetic mineral products.

Leading Australian decarbonization technology company Calix has already been active in supplying and developing its alternative flash calciner technology to the European cement, lime, magnesite and refractory industries Earlier this year, leading global magnesia and refractories producer RHI Magnesita signed a long-term strategic cooperation agreement with another "cleantech" Australian company, MCi Carbon, "… to achieve its goal of becoming a CO_2-neutral business."

MCi Carbon has developed a mineral carbonation process that captures and converts industrial CO_2 emissions into solid bulk materials, including calcium and magnesium carbonate, which can be used in new low-carbon products for the construction, manufacturing and consumer markets. Other companies, such as Paebbl in the Netherlands, are evaluating proprietary mineral carbonation processes that essentially accelerate and scale a natural process using heat and pressure to form synthetic mineral products. Paebbl uses CO_2 emissions and ground olivine to produce mineral filler products.

Another project using olivine is being developed by Holcim and Eni, with Eni storing its CO_2 in olivine and Holcim using the carbonated olivine as a new low-emission raw material for its new "green cement" production.

Thus, we are seeing the generation of a new market outlet for olivine (and other magnesium silicate materials), and producing new mineral products and capturing CO_2 at the same time.

An EU Horizon Europe research project called Carbon4Minerals is devoted to developing innovative technologies for CO_2 capture for use in carbon-negative construction products.

We will see more such initiatives being rolled out in the near future.

Geopolitical impact on supply chains

And finally, just a reminder that unfortunately, geopolitics is never far away from negatively impacting mineral supply chains. Lessons have to be learned from the COVID-19 pandemic and the Russia-Ukraine War.

While the Russia-Ukraine War continues with seemingly no end in sight and its impact on logistics persists, in the Eastern Hemisphere there are warnings of a potentially more catastrophic impact on global shipping logistics with the simmering China-Taiwan standoff.

A "Zero China" policy regarding mineral supply by most traders and consumers, while tempting, is unlikely and economically ill-advised owing to the country's industrial mineral wealth for export markets at relatively lower prices (though often cyclical), despite ongoing supply challenges.

But a "Cold Peace" in the region endures, so companies must now surely build supply-chain resilience and reduce excessive dependency on mineral supply from China (or indeed elsewhere in East Asia): that is, they are well advised to derisk and diversify their mineral supply chains. Certainly, this is a case of hoping for the best but planning for the worst. Mineral supply is not all about "just in time" — it now needs to be about "just in case." ■

**Mike O'Driscoll is director and cofounder of IMFORMED Industrial Mineral Forums & Research Ltd, UK; organizing Fluorine Forum 2023, Cannes, Oct. 16-18 and Salt Forum 2023, Swakopmund, Namibia, Nov. 6-9; Email mike@imformed.com or visit www.imformed.com.*

Editor's note: The articles provided by the U.S. Geological Survey (USGS) in this section are based on data included in the USGS Mineral Commodity Summaries 2022 (https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries). The USGS Mineral Commodity Summaries are published on an annual basis; this report is the earliest government publication to furnish estimates covering nonfuel mineral industry data. Data sheets contain information on the domestic industry structure, government programs, tariffs and five-year salient statistics for more than 90 individual minerals and materials.

Throughout this review, measurements are expressed as metric units unless the author provided conversions.


ERIEZ MAGNETICS

ANTIMONY

by Kateryna Klochko, National Minerals Information Center, U.S. Geological Survey

Antimony is a lustrous silvery-white material. Although it is usually described as a metal, it possesses mixed metallic and nonmetallic characteristics, and is more properly described as a semimetal or metalloid. Among the elements found in the Earth's crust, antimony ranks 63rd in abundance. At an average concentration of 0.20 g/t, it is less abundant than tin, arsenic or the rare earths but more abundant than bismuth, mercury or silver. Antimony tends to concentrate in sulfide ores along with copper, lead and silver. It occurs sparingly as the free metal, usually in association with arsenic, bismuth or silver. In 2022, no marketable antimony was mined in the United States. A mine in Nevada that had extracted about 800 t of stibnite ore from 2013 through 2014 was placed on care-and-maintenance status in 2015 and had no reported production in 2022. Primary antimony metal and oxide were produced by one company in Montana using imported feedstock. Secondary antimony production was derived mostly from antimonial lead recovered from spent lead-acid batteries. The estimated value of secondary antimony produced in 2022 was about $60 million. China continued to be the leading global antimony producer in 2022 and accounted for 55 percent of global mine production. The supply of antimony raw materials and downstream production of antimony products was constrained in 2022 as a result of various temporary mine shutdowns to mitigate the spread of COVID-19.

Consumption and end uses

In 2022, apparent consumption of antimony in the United States was estimated to be 27 kt, 5 percent less than that in 2021. Recycling supplied about 15 percent of estimated domestic consumption, and the remainder came mostly from imports. In the United States, the leading uses of antimony were as follows: flame retardants, 40 percent; metal products, including antimonial lead and ammunition, 36 percent; and nonmetal products, including ceramics and glass and rubber products, 24 percent.

Imports and exports

The United States was highly reliant on imports of unwrought antimony metal and antimony trioxide to meet its domestic consumption needs. According to the U.S. Census Bureau, in 2022, imports for consumption of unwrought antimony were 8.3 kt, 11 percent more than those in 2021. Imports of antimony trioxide were 16.9 kt, 11 percent less than those in 2021. The imported unwrought antimony was principally sourced from China (29 percent), the United Kingdom (20 percent), India (14 percent) and Oman (12 percent. The imported antimony trioxide was principally sourced from China (75 percent) and Belgium (12 percent). The United States exported 1.8 kt of unwrought antimony metal in 2022, almost double from that in 2021. The United States exported 2.4 kt of antimony trioxide in 2022, a 59 percent increase from those in 2021. The unwrought antimony was principally exported to Canada (50 percent) and Mexico (31 percent). The antimony trioxide was principally exported to Japan (38 percent), Mexico (12 percent), Canada (10 percent) and Turkey (10 percent).

Prices

The antimony price reached a high of $7.03/lb in March 2022. The estimated annual average price was $6.30/lb in 2022, compared with the annual average price of $5.31/lb in 2021.

World resources

U.S. resources of antimony are mainly in Alaska, Idaho, Montana and Nevada. Principal identified world resources are in Australia, Bolivia, Burma, China, Kyrgyzstan, Mexico, Russia, South Africa, Tajikistan and Turkey. Additional antimony resources may occur in Mississippi Valley-type lead deposits in the Eastern United States.

Trends and outlook

Global consumption of antimony was expected to remain unchanged. Although electric cars will continue to have small lead-acid batteries, consumption of antimony by the lead-acid battery industry was expected to decrease as electric-vehicle market share increases in the future. This decrease would be more than offset, as the consumption of antimony for flame retardants was expected to grow. *References are available from the author.*

BALL CLAY

by Kristi J. Simmons, National Minerals Information Center, U.S. Geological Survey

Ball clays are fine-grained, sedimentary clays with high plasticity, composed primarily of kaolinite, mica and quartz. Ball clay is a rare type of clay found only in a few locations and valued for providing strength and malleability to ceramics prior to firing. Ball clays produce a cream-to-white-colored pottery once fired.

Production

During the past 30 years, U.S. ball clay production (the quantity sold or used by domestic producers) increased from a low of 854 kt in 1992 to an all-time high of 1.31 Mt in 2003. Housing construction, a leading market for ball clay-based ceramics and sanitaryware, decreased after 2005. That decrease resulted in lower sales of ball clay through the Great Recession, which lasted from late 2007 to mid-2009. Since then, ball clay production steadily increased through 2017, before decreasing in 2018 and 2019 and then slightly increasing

in 2020 and 2021. In 2022, estimated U.S. domestic production of ball clay was unchanged at 1,200 kt from that in 2021.

Six companies (Covia Holdings LLC, Gleason Clay Co., Imerys S.A., Lhoist Group, Old Hickory Clay Co. and U.S. Mine Corp.) mined ball clay in five states during 2022. Tennessee was the leading producer state of ball clay mined in the United States; the other states that produced ball clay were California, Indiana, Mississippi and Texas. Reliable data on global production of ball clay are not available because many countries combine ball clay production data with that of other clays.

Consumption

Ceramic floor and wall tile (52 percent of sales) and sanitaryware (19 percent of sales) were the leading domestic markets for ball clay in 2022. Ball clay also was sold for the manufacture of bricks, electrical porcelain, fine china, pottery, refractory products and roofing granules.

Prices

The estimated average unit value of ball clay was $58/t in 2022, unchanged from that in 2021. Prices at most of the individual U.S. ball clay operations in 2022 were estimated to range from $30/t to $110/t. According to the U.S. Census Bureau, the average unit value for exported ball clay increased by 6 percent to $237/t in 2022 compared with $224/t in 2021, and the average unit value for imported ball clay increased by 4 percent to $361/t in 2022 compared with $346/t in 2021. Average unit values for exports and imports fluctuate more than the average unit value of domestic production owing to the influence of small, high-value shipments. Widespread transportation challenges and increased costs in 2022 resulted in many producers increasing pricing for their products to offset their rising costs.

Foreign trade

According to the U.S. Census Bureau, ball clay exports increased to 165 kt valued at $25.1 million in 2022 compared with 139 kt valued at $30.8 million in 2021. Exports of ball clay in 2022 were primarily shipped to Mexico (82 percent), the Republic of Korea (4 percent) and Guatemala (3 percent). Ball clay imports decreased to 277 t valued at $100,000 in 2022 compared with 319 t valued at $110,000 in 2021. In 2022, imports originated primarily from the United Kingdom (58 percent) and Portugal (41 percent).

Outlook

Historical sales of ball clay typically correlate with construction activity. Recently, the housing market has been facing rising interest rates and interruptions in the building material supply chain that are increasing costs. The U.S. Census Bureau reported that single-family housing starts in January 2023 were 21 percent less than that of 2022 and 4.5 percent less than December 2022. The International Monetary Fund projects economic growth in the United States to slow to 1.4 percent from 2 percent in 2023. These indicators suggest a slowdown in the production of ball clay. *References are available from the author.*

BARITE

by Michele E. McRae, National Minerals Information Center, U.S. Geological Survey

Production and consumption

Because of high specific gravity (SG), barite is the weighting agent of choice in oil and natural-gas drilling fluids, used to suppress high formation pressures and to prevent blowouts. In the United States this application typically accounts for more than 90 percent of barite sales. Barite also is used in radiation-shielding concrete, as a contrast medium in medical X-rays, and as filler, extender or weighting agent in products such as paints, plastics and rubber.

Because of barite's use in drilling fluids, trends in barite consumption generally mirror trends in drilling rig counts, which in turn reflect broader trends in oil and gas consumption. In 2022, the worldwide annual average drilling rig count was 1,747, an increase of 28 percent compared with that in 2021, although it remained 20 percent below the 2019 prepandemic average of 2,177. The U.S. annual average count of rigs was 721, an increase of 52 percent compared with 2021, but still 24 percent less than the 2019 average of 944. Domestically, an estimated 2.1 Mt of barite (from domestic production and imports) was sold by crushers and grinders operating in nine states, an increase of 26 percent compared with that in 2021, but still 11 percent below the prepandemic quantity of 2.35 Mt in 2019 (Fig. 1).

Three companies mined barite in Nevada. Mine production increased, but data were withheld to avoid disclosing company proprietary data. Halliburton Co.'s Rossi Mine and Progressive Contracting Inc.'s Coyote Mine resumed production after having been idle since 2016 and 2020, respectively. All of Baker Hughes Co.'s Nevada current and former barite facilities, which included the Argenta Mine and Mill and Slaven Canyon Mine, remained idle in 2022. According to information from the state of Nevada, the Argenta Mine was mostly reclaimed in 2022, and a portion of the mill property was sold to I-80 Gold Corp. I-80 Gold intended to use the mill property for water and rail access. There was no further information available on Baker Hughes' Slaven Canyon Mine.

CS Global Group, a barite mining company based in Turkey, invested $10 million to construct a barite grinding plant in Moundsville, WV, which would be operated by its subsidiary ADO Industries. The company would initially produce barite for use in drilling fluids but planned to add a second mill to produce barite for use in filler and paint.

In December, Cimbar Performance Minerals Inc. announced that it had completed its acquisition of Excalibar Minerals LLC's barite assets. Prior to the acquisition, Cimbar owned seven grinding plants — three in Texas, two in Ohio and one each in Georgia and Indiana. The acquisition of Excalibar included four additional plants — two in Texas and one each in Louisiana and Tennessee.

World production of barite in 2022, excluding the United States, was estimated to have increased by 17 percent to 7.9 Mt. Most of the increase was from India, which surpassed China as the world's leading producer. Production in India was estimated to have increased by 63 percent to 2.6 Mt. Other leading barite producing countries were China and Morocco, with production of 1.9 Mt and 1.3 Mt, respectively.

Figure 1

Historical trends in sales of ground barite, barite mine production and annual average rig count in the United States from 1975 through 2022. *Beginning in 2020, mine production information is withheld to avoid disclosing company proprietary data. (Sources: Baker Hughes Co. and U.S. Geological Survey)

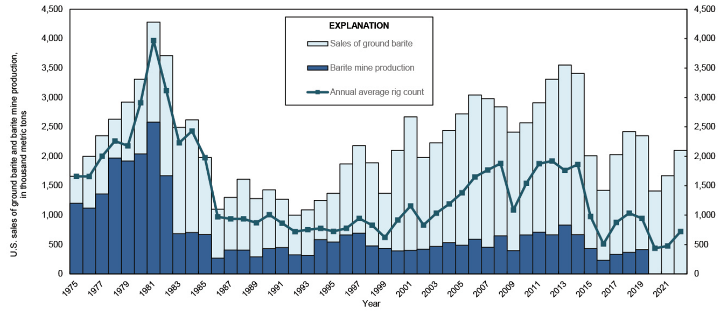


Figure 1. Historical trends in sales of ground barite, mine production of barite, and annual average rig count in the United States from 1975 through 2022. *Beginning in 2020, mine production was withheld to avoid disclosing company proprietary data. Sources: Baker Hughes Co. and U.S. Geological Survey.

Together, these three countries accounted for approximately 73 percent of world production, excluding the United States.

Domestic trade

In 2022, U.S. barite imports were 1.89 Mt, a 31 percent increase compared with those in 2021. The leading import sources, in descending order of quantity, were India (924 kt), China (434 kt), Morocco (257 kt) and Mexico (253 kt). Together, these four countries accounted for 99 percent of domestic barite imports.

Prices

Fastmarkets IM publishes annual average prices of unground lump barite meeting American Petroleum Institute specifications with SG of 4.2 from leading exporting countries. In 2022, the free-on-board (F.O.B.) annual average price from China was $110/t compared with $100/t in 2021, an increase of 10 percent. The F.O.B. annual average price from Chennai, India was $115/t, an increase of 24 percent compared with $93/t in 2021. The F.O.B. annual average price from Morocco was $107/t, an increase of 17 percent compared with $92/t in 2021.

In April 2022, India's state-owned Andhra Pradesh Mineral Development Corp. Ltd. concluded its tender for the sale of barite from its Mangampet Mine, which accounts for an estimated 90 percent of barite produced in India. During the tender, buyers compete for the company's barite production, which is offered in several grades: A-grade, with a minimum SG of 4.2; B-grade, with a minimum SG of 4.1; and C-, D- and W-grades, with no guarantee as to SG but which typically exceeded 3.9. Prices for A- and B-grades increased by about 30 to 45 percent, or approximately $25/t.

Three U.S. companies reportedly signed agreements to purchase a total of 1.6 Mt of barite over the next three years.

Outlook

Barite production and consumption generally follow broad trends in oil-gas metrics such as petroleum prices and drilling rig counts. Although the U.S. annual average rig count was higher in 2022, weekly rig counts in 2023 began to decrease. This was likely a response to crude oil prices, which were on a decreasing trend in the latter half of 2022. Despite a slight increase in the forecast crude oil price in the first quarter of 2023, the U.S. Energy Information Administration forecast that crude oil prices would continue to decline in the latter half of 2023 and into 2024. *References are available from the author.*

BAUXITE

by Adam M. Merrill, National Minerals Information Center, U.S. Geological Survey

Production

In 2022, one alumina refinery produced an estimated 1.2 Mt of alumina from imported bauxite in the United States, slightly more than the amount produced in 2021. The 1.2-Mt/a refinery in Gramercy, LA, owned by Noranda Alumina LLC, produced alumina mostly for use in aluminum smelters, but also produced specialty alumina.

The 500-kt/a refinery in Burnside, LA, owned by Arthur Metals LLC, which was temporarily shut down in August 2020, remained closed in 2022 with no announced plans for reopening.

The United States is 100 percent net import reliant for metallurgical-grade bauxite. Small amounts of bauxite and bauxitic clays are produced in Alabama, Arkansas and Georgia for nonmetallurgical uses.

Consumption and end uses

Total domestic consumption of bauxite (in crude dry equivalent) was estimated to be 2.9 Mt in 2022, 4 percent more than that in 2021. Of this total, 2.4 Mt (approximately 82 percent) was used to produce alumina, 9 percent less than in the prior year. Other uses of bauxite included abrasives, cement, chemicals and refractories, as well as uses in the petroleum industry, steel production and water treatment.

Total domestic consumption of alumina by the aluminum industry was 1.72 Mt in 2022, 3 percent less than that in 2021. Approximately 940 kt of alumina was consumed by other industries in the United States in 2022, 17 percent more than the amount in 2021. Other uses of alumina included abrasives, cement, ceramics and chemicals.

Foreign trade

Bauxite. According to the U.S. Census Bureau, metallurgical-grade bauxite (crude dry) imports totaled 2.8 Mt in 2022, 9 percent less than the quantity imported in 2021.

In 2022, the leading suppliers were Jamaica (84 percent) and Turkey (14 percent). Imports from Jamaica and Turkey decreased by 248 kt (10 percent) and 53 kt (12 percent), respectively. The bauxite from Turkey is believed to have been used for nonmetallurgical uses based on the destination ports.

Imports of refractory-grade calcined bauxite in

2022 totaled 108 kt, 22 percent less than those in 2021. Guyana (62 percent) and China (36 percent) were the principal sources of refractory-grade calcined bauxite imports. Imports of refractory-grade calcined bauxite from Guyana increased by 10.7 kt (19 percent) while those from China decreased by 40.1 kt (51 percent).

Imports of nonrefractory-grade calcined bauxite in 2022 totaled 371 kt, 17 percent more than those imported in 2021. Guyana (37 percent), the Dominican Republic (25 percent), Australia (22 percent) and Brazil (12 percent) were the leading sources. Imports of nonrefractory-grade calcined bauxite from Guyana and Australia decreased by 4.8 kt (3 percent) and 17.4 kt (18 percent), respectively, while those from Brazil and the Dominican Republic increased by 43.5 kt (no imports in 2021) and 38.6 kt (73 percent), respectively.

Alumina. Imports of alumina in 2022 totaled 1.89 Mt, 21 percent more than those in 2021. Brazil (62 percent) and Australia (13 percent) were the leading sources of imported alumina.

Exports of alumina in 2022 totaled 174 kt, 4 percent less than those in 2021, with Mexico (37 percent), Canada (13 percent) and China including Hong Kong (8 percent) as the leading destinations.

Prices

According to the U.S. Census Bureau, prices for imported bauxite varied depending on the source and grade. Average unit values (free alongside ship, or f.a.s.) for imported crude dry bauxite from major suppliers in 2022 were $25/t from Jamaica (unchanged) and $52/t from Turkey (29 percent increase). Average unit values (f.a.s.) for imported refractory-grade calcined bauxite in 2022 were $497/t from China (10 percent increase) and $239/t from Guyana (11 percent decrease). Average unit values (f.a.s.) for imported nonrefractory-grade calcined bauxite in 2022 were $34/t from Australia (8 percent increase), $54/t from the Dominican Republic (21 percent increase) and $195/t from Guyana (31 percent increase).

The average unit value (f.a.s.) for imported alumina in 2022 was $518/t, 12 percent more than that in 2021.

The average unit value (f.a.s.) for alumina exported from the United States increased to $2,920/t, a 10 percent increase compared with the price in 2021. Based on cargo sizes, export destinations and prices, it is assumed that most of the alumina exports in 2021 and 2022 were specialty grade alumina instead of smelter-grade alumina.

Outlook

Consumption of bauxite and alumina for nonmetallurgical uses will likely follow the progress of domestic economic activity combined with the influences of global supply-chain issues, higher oil prices and the possibility of interest-rate increases.

Metallurgical-grade bauxite consumption is expected to remain stable after recovering in 2021 from pandemic-related disruptions in 2020. The refinery in Gramercy, LA, was thought to be producing near its full capacity and is expected to continue to do so, while a restart of the refinery in Burnside, LA, is not expected this year.

Consumption of metallurgical-grade alumina in the United States was expected to remain flat as no primary aluminum smelter restarts have been announced for 2023. Production of alumina for specialty markets will depend on the recovery of economic activity.

Consumption of refractory-grade calcined bauxite is largely dependent upon steel production. The World Steel Association's short-term outlook anticipates domestic steel demand to increase by 1.6 percent in 2023, and it is expected that consumption of refractory-grade calcined bauxite will follow this trend.

Consumption of alumina and nonrefractory-grade calcined bauxite is expected to follow the general growth of the construction, chemical, manufacturing and petroleum industries, which is projected to increase by 1 percent in 2023. *References are available from the author.*

BENTONITE

by Kristi J. Simmons, National Minerals Information Center, U.S. Geological Survey

Bentonites primarily consist of smectite minerals (usually montmorillonite) with minor amounts of feldspar, biotite and quartz. The bentonites used for industrial purposes are predominantly composed of sodium montmorillonite or calcium montmorillonite. Sodium montmorillonite, also referred to as swelling bentonite, is mainly produced in western states and has a higher swelling capacity than calcium montmorillonite, also referred to as nonswelling bentonite. Nonswelling bentonite is mostly produced in southern states. Bentonite is found in a variety of colors including tan, gray-blue, olive, brown and white.

Production

Domestic bentonite production (the quantity sold or used by producers) was estimated to have slightly decreased to 4.5 Mt in 2022 compared with 4.59 Mt in 2021. During the past 25 years, U.S. bentonite production fluctuated between a low of 3.65 Mt in 2009 to an all-time high of 4.99 Mt in 2011. In 2022, nonswelling and (or) swelling bentonite were produced in the following states, in alphabetical order: Alabama, Arizona, California, Mississippi, Montana, Nevada, Oregon, Texas, Utah and Wyoming.

Swelling bentonite constituted an estimated 97 percent of all domestically produced bentonite. An estimated 95 percent of swelling bentonite was produced in Wyoming, while Alabama and Mississippi led in the production of domestic nonswelling bentonite. Swelling bentonite was thought to have been produced by 15 companies, and nonswelling bentonite was produced by five companies.

The United States continues to be the global leader in the production of bentonite, followed, in descending order, by India (3 Mt), China (2.1 Mt) and Turkey (2 Mt). World production of bentonite was estimated to be 19 Mt in 2022, unchanged from that in 2021.

Consumption

Pet-waste absorbents (49 percent of sales) and drilling mud (23 percent) were estimated to be the leading domestic markets for bentonite in 2022. Bentonite also was sold for the manufacturing of adhesives, animal food, filler and extender applications, foundry sand, miscellaneous civil-engineering applications, pelletizing (iron ore) and waterproofing. Exported bentonite had similar uses.

Prices

The average unit value of bentonite in 2022 was estimated to be $97/t, compared to $100/t in 2021. The average unit value for exported bentonite increased to $299/t in 2022 compared with $252/t in 2021, and the average unit value for imported bentonite increased to $635/t in 2022 compared with $407/t in 2021. Average unit values for exports and imports fluctuate more than the average unit value of domestic production owing to the influence of small, high-value shipments.

Foreign trade

According to the U.S. Census Bureau, bentonite exports decreased to 831 kt valued at $197 million in 2022 compared with 862 kt valued at $193 million in 2021. Exports of bentonite in 2022 were primarily shipped to Canada (51 percent), Japan (15 percent) and Mexico (7 percent). Bentonite imports also decreased to 18 kt valued at $11.2 million in 2022 compared with 27 kt valued at $11 million in 2021. Mexico (44 percent), China (21 percent) and Turkey (9 percent) were the leading sources of bentonite imports in 2022.

Outlook

Bentonite has various diverse uses, which enables it to remain a mature and stable industry. Pet-waste absorbents and drilling muds are likely to remain the leading uses of bentonite and may influence the demand for bentonite. The pet industry continues to grow, which may result in increased consumption of bentonite for pet-waste absorbents.

Bentonite production will also be determined by the natural-gas and petroleum well-drilling industries, which have a greater level of uncertainty compared to the pet industry. During the first two months of 2023, the Baker Hughes U.S. rig count had declined each month but remained higher compared with the same period of 2022.

BISMUTH

by Amy C. Tolcin, National Minerals Information Center, U.S. Geological Survey

Bismuth, one of the rarest elements on Earth, is concentrated in base metal ores and is typically extracted as a byproduct of metal refining, particularly lead. In the United States, bismuth was last produced as a byproduct of lead refining in 1997. An estimated 80 t of bismuth contained in alloys were recycled in the United States annually. In 2022, world refinery production of bismuth was estimated to be 20 kt, unchanged from that in 2021 but 4 percent more than production in 2019, before the onset of the COVID-19 pandemic. China was the world’s leading producer of refined bismuth as a byproduct of lead, tin and tungsten ore processing, accounting for 80 percent of the estimated world total, followed by Laos (10 percent) and the Republic of Korea (5 percent).

Consumption and end uses

In 2022, apparent consumption of bismuth in the

United States was estimated to be 2.47 kt, 2.4 times more than that in 2021. More than 60 percent of domestic bismuth consumption was for chemicals used in cosmetic, industrial, laboratory and pharmaceutical applications. It is used in the manufacture of ceramic glazes, crystal glassware and pearlescent pigments, and is included in bismuth salicylate (the active ingredient in over-the-counter stomach remedies) and other compounds used to treat burns, intestinal disorders and stomach ulcers.

Most of the remaining domestic bismuth consumption was used in a variety of metallurgical applications including as an additive to enhance metallurgical quality in the foundry industry and as a nontoxic replacement for lead in ballistics, brass, free-machining steels, pipe fittings and fixtures, solders, water meters and weight applications such as fishing weights and sinkers. Bismuth also is used as a triggering mechanism for fire sprinklers and in holding devices for grinding optical lenses, and bismuth-tellurium oxide alloy film paste is used in the manufacture of semiconductor devices.

Imports and exports

The United States was highly reliant on imports of bismuth metal to meet its domestic consumption needs. According to the U.S. Census Bureau, in 2022, imports for consumption of bismuth metal, alloys and scrap were 3.09 kt, a 56 percent increase from those in 2021 and the highest annual quantity of bismuth metal imported since 2007. The imported bismuth was principally sourced from China (74 percent), followed by the Republic of Korea (16 percent). The United States exported 0.502 kt of bismuth metal, alloys and waste and scrap in 2022, a 50 percent decrease from those in 2021. The bismuth was principally exported to Canada, Mexico and Vietnam (19 percent each).

Prices

In 2022, the daily average free market price for 99.99 percent-pure bismuth was $3.90/lb, a 4 percent increase from that in 2021 and the highest annual price since 2018. Globally, excess stocks continued to keep prices low compared with those in 2007 through 2014, when the average annual dealer prices ranged between $7.84/lb and $14.06/lb.

Trends and outlook

Globally, bismuth is used primarily in industrial sectors, mostly as a metallurgical additive in steel and aluminum alloys. Emerging and growing nations may drive bismuth consumption in buildings and infrastructure if used as a substitute for lead. With more legislation restricting the use of lead throughout the world, bismuth will likely be part of a growing market of lead replacements.

BORON

by A.S. Brioche, National Minerals Information Center, U.S. Geological Survey

Four minerals account for 90 percent of natural borates used throughout the world — the sodium borates, tincal and kernite; the calcium borate, colemanite; and the sodium-calcium borate, ulexite. Deposits of borates are associated with paleo-volcanic activity coupled with modern arid climates. The largest economically viable deposits are located in the Mojave Desert near Boron and Trona, CA, the Alpide belt in southern Asia, and the Andean belt of South America. Borax, a white crystalline substance chemically known as sodium tetraborate decahydrate, is found as the mineral tincal. Boric acid (hydrogen borate) is a colorless crystalline solid sold in technical, national formulary and special quality grades as granules or powder and marketed most often as anhydrous boric acid. Ore quality is typically measured as a function of its diboron trioxide (B_2O_3) equivalent content. Major end-use industries for boron include glass, ceramics, detergents and fertilizers.

Production

U.S. production of boron minerals and compounds increased in 2022 from that of 2021; production data were withheld to avoid disclosing proprietary company data. Two companies in southern California produced boron minerals, primarily sodium borates. U.S. Borax Inc., a wholly owned subsidiary of United Kingdom-based Rio Tinto Minerals plc, extracted kernite and tincal by openpit methods at its operation in Boron, CA. The minerals were processed into boric acid and sodium borate products in a refinery adjacent to the mine and shipped by railcar or truck to North American customers or distributed internationally through the Port of Los Angeles. Specialty borates, such as agricultural, flame-retardant and wood-preservative products, are made at U.S. Borax's Wilmington, CA, plant. Searles Valley Minerals Inc. (SVM), headquartered in Overland Park, KS, produced borax and boric acid from potassium and sodium borate brines at its Searles Lake operation near Trona, CA. The brines were refined into anhydrous, decahydrate and pentahydrous borax in SVM's Trona and Westend plants.

Consumption

The glass and ceramics industries remained the leading domestic users of boron products in 2022, consuming an estimated 65 percent of total borate consumption. Boron also was used as a component in abrasives, cleaning products, fertilizers, insecticides, various military applications and in the production of semiconductors. Boron was the most widely used micronutrient in agriculture, applied primarily to promote seed production. Boron fertilizers were mostly sourced from borax and colemanite owing to their high solubility in water, allowing boron fertilizers to be delivered through sprays or irrigation water.

Foreign trade

According to the U.S. Census Bureau, U.S. exports of refined borax were 650 kt in 2022, a 7 percent increase from 607 kt in 2021. China, Indonesia, Malaysia, Canada, Mexico, India, the Netherlands and Japan imported the largest quantities of refined borates from the United States, comprising 92 percent of total refined borate exports. The average unit value for refined borate exports was $565/t in 2022, a 19 percent increase from $474/t reported in 2021. Boric acid exports were 247 kt with a value of $826/t in 2022, a 12 percent decrease in tonnage from 280 kt in 2021 but a 14 percent increase in total sales value. Imports of boric acid in 2022 were 48 kt, about 11 percent less than those of 2021. Approximately 81 percent of imported boric acid came from Turkey in 2022. The average unit value for boric acid imports was $838/t in 2022, a 38 percent increase from $607/t reported in 2021. The average unit value for refined borate imports was $397/t in 2022, a 9 percent increase from $364/t reported in 2021.

International

Chile, China, Turkey and the United States (in alphabetical order) led the world in the production of borates in 2022. Chile was the leading borate producer in South America. China mined more than 100 borate deposits in 14 provinces. Boron resources in China, however, are of low quality, averaging around 8.4 percent B_2O_3. By comparison, reserves in Turkey and the United States have grades ranging from 26 to 31 percent and 25 to 32 percent B_2O_3, respectively. China has become more import reliant on borate products from South America, Turkey and the United States. Turkey's boron products reached a record $1.3 billion in sales from approximately 2.65 Mt produced in 2022, most of which were exported. Over 95 percent of sales were of refined boron products.

Outlook

Consumption of borates is expected to increase as a result of strong demand in the agriculture, ceramic and glass markets in Asia and South America. Demand for fertilizers containing boron is expected to rise as a result of an increase in demand for food and biofuel crops. Higher crop prices have enabled farmers to invest more capital in advanced farming techniques and higher-grade fertilizers.

The expectation of increased boron demand prompted a few companies to continue investment efforts in new borate refineries in the United States. Two Australian-based mine developers previously confirmed that production of high-quality boron products would be possible from their projects in California and Nevada, respectively. These companies worked on acquiring some of the permits and funding necessary to begin and continue construction in 2022. Construction on the California project began in April 2022 and was expected to have a focus on specialty boron products for industries related to global decarbonization and food security once production starts. The Nevada project was expected to begin production by 2025. *References are available from the author.*

BROMINE

by Emily K. Schnebele, National Minerals Information Center, U.S. Geological Survey

Production

The United States was one of four leading bromine producers in the world; the other three leading producers were China, Israel and Jordan. Two companies in Arkansas accounted for all the U.S. production of bromine in 2022. The two bromine companies in the United States accounted for a large percentage of world production capacity. Bromine is one of the leading mineral commodities, in terms of value, produced in Arkansas. Domestic production data for elemental bromine were withheld to avoid disclosing company proprietary data. World production of bromine in 2022, excluding U.S. production, was estimated to be 390 kt, unchanged from that in 2021.

Consumption

The leading global applications of bromine are for the production of brominated flame retardants and clear brine drilling fluids. Bromine compounds are also used in a variety of other applications, including industrial uses, as intermediates, and for water treatment.

Foreign trade

According to the U.S. Census Bureau, U.S. imports of bromine and bromine compounds were 46 kt on a gross weight basis in 2022, 35 percent more than the 34.1 kt imported in 2021. The average cost, insurance and freight (c.i.f.) unit value of elemental bromine imports in 2022 was $7.35/kg, 63 percent more than the average unit value of $4.50/kg in 2021. Israel was the leading source of bromine imports into the United States, accounting for 83 percent of the total quantity imported on a gross weight basis. Exports of bromine and bromine compounds in 2022 were 24.5 kt on a gross weight basis, a 29 percent decrease from 34.5 kt on a gross weight basis in 2021.

The average unit value of exported elemental bromine in 2022 was $3.56/kg, slightly more than the average unit value of $3.50/kg in 2021. Guyana (22 percent) was the leading destination of bromine exports from the United States followed by Saudi Arabia (19 percent), Canada (14 percent) and United Arab Emirates (10 percent), which together accounted for 65 percent of the total quantity exported on a gross weight basis.

Outlook

Consumption of bromine will primarily be driven by demand for brominated flame retardants from the appliance, automotive, construction and electronic industries. The amount of clear brine fluids consumed in the oil and natural-gas drilling industry is expected to mirror global changes in oil and natural-gas prices and the number of active drilling rigs.

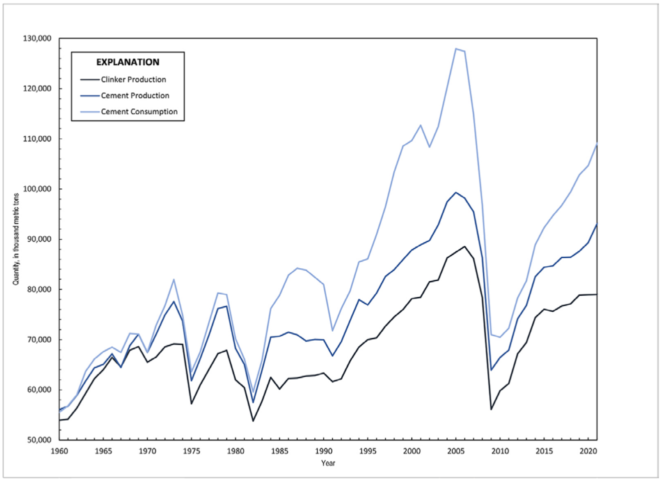
CEMENT

by A.K. Hatfield, National Minerals Information Center, U.S. Geological Survey

Portland, blended and masonry cement (cement) are construction materials that, when mixed with water, serve as the binder in concrete and most mortars. Cement contributes all of concrete's compressional strength, despite only comprising about 13 percent of its content by weight. Cements are made from a material called clinker, which is finely ground into a powder and mixed with a small amount of gypsum and potentially supplementary cementitious materials to make cement. Clinker is produced from a precise combination of calcareous, aluminous, ferrous and siliceous materials, which are transformed through pyroprocessing of the requisite materials in a rotary kiln.

Figure 1

U.S. clinker production, cement production and cement consumption, 1960–2022.



Production and consumption

In 2022, production of portland (including blended) and masonry cement in the United States, excluding Puerto Rico, was estimated to be 95 Mt, a slight increase in quantity from 93 Mt in 2021. Production in 2022 was 4 percent lower than the record of 99.3 Mt set in 2005 (Fig. 1). Total world cement production in 2022 was estimated to be about 4.1 Gt, a decrease from 4.4 Gt in 2021. China (2,100 Mt), India (370 Mt), Vietnam (120 Mt), the United States (95 Mt) and Turkey (85 Mt) were the leading producers in 2022. The United States manufactured about 2 percent of cement produced worldwide.

Domestic cement consumption in 2022, as measured by sales to final customers, was estimated to have increased by about 3 percent to 112 Mt from 109 Mt in 2021 but was 12 percent lower than the 2005 record consumption of 127.9 Mt. The difference between consumption and domestic production in 2022 was met, in part, by a 20 percent increase in imports. Over the past 10 years, imports have increased from 7.1 Mt in 2012 to 26.6 Mt in 2022, but imports in 2022 were still well below the record of 35.9 Mt set in 2006. The leading cement-consuming states continued to be Texas, California and Florida, in descending order by tonnage. The major end uses for cement in the United States are, in descending order by estimated market share, ready-mixed concrete, concrete product manufacturers, contractors and other customer types (such as building material dealers, government, mining, oil well drilling, waste stabilization and(or) unspecified uses).

Foreign trade

According to the U.S. Census Bureau, U.S. imports of cement and clinker, including Puerto Rico, in 2022 were 26.6 Mt, an increase of 20 percent from 22.2 Mt in 2021. In 2022, Turkey (36 percent), Canada (18 percent), Mexico (10 percent), Greece (9 percent) and Vietnam (9 percent) supplied the majority of U.S. cement imports, with the remainder coming from several other countries. Exports of cement were 906 kt, a decrease of 6 percent compared with 961 kt in 2021. Canada (85 percent), the Bahamas (5 percent) and Mexico (4 percent) received the majority of U.S. cement exports, with the remainder going to several other countries and localities.

Prices

The average mill net value (price) of cement depends on application, quality, quantity purchased, source and type, and therefore encompasses a wide range of prices. During 2022, the overall estimated value of sales increased to a record-high $14.6 billion ($130/t). In recent years, increased prices have been partially attributed to increased costs of production.

Environmental issues

Large quantities of raw materials (mainly carbonate rocks, especially limestone) and fuels are burned at high temperatures to make clinker, resulting in emissions of large quantities of carbon dioxide (CO_2) and potentially significant emissions of nitrogen oxides, sulfur oxides, mercury and some other metals, volatile organic carbon compounds and particulates. Increasingly, these emissions are being stringently regulated. The cement industry is one of the leading industrial emitters of CO_2, an important greenhouse gas.

Outlook

The increase in apparent consumption of cement in 2022 resulted from continued economic recovery from the effects of the COVID-19 pandemic. The passage of the U.S. Bipartisan Infrastructure Law in November 2021 was projected to support increased cement consumption over the next five years. In 2022, regulators implemented new measures designed to aid industry decarbonization efforts, including green procurement strategies and research investments. Following widespread acceptance of portland-limestone cement (PLC) blended cement by various authorities, several cement plants announced their transition to PLC (Type IL). However, cement industry growth continued to be constrained by increased costs for energy, material and service inputs; labor and production shortages; and ongoing supply chain disruptions. Imports are likely to continue to increase as cement manufacturers augment their cement supply to counteract reduced domestic production capacity resulting from kilns being idled owing to environmental concerns. In 2022, upgrades at a cement plant in Alabama were completed and an upgrade of a cement plant in Indiana progressed toward its expected completion date in early 2023. Cement plant closures were announced at cement plants in California and New York. *References are available from the author.*

CHROMIUM

by Ruth F. Schulte, National Minerals Information Center, U.S. Geological Survey

Chromium is found in many minerals, but the only economically significant chromium-bearing mineral is chromite. Chromite has been mined from four different deposit types: stratiform chromite, podiform chromite, placer chromite and laterite deposits. Most of the world's resources, however, are located in stratiform chromite deposits, such as the Bushveld Complex in South Africa. The economic potential of chromite resources depends on the deposit thickness, continuity, and the grade of ore. Many of the major stratiform chromite deposits also contain economic levels of platinum, palladium, rhodium, osmium, iridium and ruthenium.

The major markets for chromium materials are chromium chemicals, ferroalloys and metal. Stainless steels and superalloys require the addition of chromium via ferrochromium or chromium-containing scrap. In 2022, stainless-steel and heat-resisting-steel producers were the leading consumers of ferrochromium. Chromite ore can also be roasted to make sodium dichromate, which is subsequently converted to chromium chemicals used in pigments and metal coatings. Chromium is also an important component in refractories, foundry applications and as a nutrient.

Table 1

World production of chromium ores and concentrates, by country (kt, gross weight). (Source: U.S. Geological Survey)

	2021	2022[e]
United States	—	—
Finland	2,270	2,200
India	4,250	4,200
Kazakhstan[e]	6,500	6,500
South Africa	18,600	18,000
Turkey	6,960	6,900
Other countries	3,620	3,500
Total (rounded)	42,200	41,000

[e] Estimated production
— Zero

Production

The United States did not produce chromite ore in 2022. Global production of chromite ore, on a gross weight basis, was an estimated 41 Mt in 2022, compared with 42.2 Mt in 2021. South Africa was the leading chromite ore producer in 2022 and accounted for 44 percent of global production. The next leading producing countries were Turkey and Kazakhstan, with 17 percent and 16 percent of global production, respectively (Table 1).

Trade

The United States continued to be a net importer of many chromium materials in 2022. According to the U.S. Census Bureau, total imports for consumption of all chromium-bearing materials, including chromium chemicals, chromium metal, chromite ores, ferrochromium, and stainless-steel products and scrap, was 608 kt of contained chromium in 2022, unchanged from 607 kt of contained chromium in 2021. In 2022, total exports of all chromium-bearing materials from the United States was 132 kt of contained chromium, a 16 percent increase from 114 kt of contained chromium in 2021.

Prices

In 2022, the annual average U.S. ferrochromium price for high-carbon ferrochromium with 62 to 70 percent chromium content more than doubled to 320.67 cents per pound in 2022 from an annual average price of 155.81 cents per pound in 2021. The annual average U.S. price for chromium metal was $7.12/lb in 2022, a 64 percent increase compared with $4.35/lb in 2021.

Outlook

Domestic and global consumption of chromium is expected to follow closely the trend in stainless steel production. Operational challenges in some countries, such as electrical supply constraints, slow global economic growth, and increasing labor costs could affect ferrochromium and stainless-steel production as well as chromite mine production.

CONSTRUCTION AGGREGATES

by Mark J. Zdunczyk, National Minerals Information Center, U.S. Geological Survey

Construction aggregates is a general term that includes crushed stone, sand, gravel, iron or steel slag, recycled asphalt pavement (RAP) or recycled concrete used to make portland concrete (PCC), bituminous concrete (asphalt), road base, railroad ballast, armor stone, concrete block/pavers, filter stone/gravel/sand, bedding sand and other construction materials. Most construction aggregates are consumed by the concrete and asphalt industry.

Crushed stone is mined from many rock types. The U.S. Geological Survey (USGS) lists the types of rock sold for construction aggregates as limestone, dolomite, marble, calcareous marl, shell, granite (granite gneiss, granitic type rocks), traprock (basalt, diorite, diabase), sandstone/quartzite, slate, volcanic cinder, scoria and miscellaneous materials. Some rock types such as shell, slate, calcareous marl, volcanic cinder and scoria generally cannot meet the specifications required in most states to be used in PCC and asphalt mixtures. Volcanic cinder and scoria may be used as lightweight aggregate sources or in concrete blocks if the material meets the specifications set forth by that industry.

The aggregate mining industry remains the largest mining sector in the United States in terms of production by weight, volume and number of active operations. In 2022, the USGS reported aggregate production from 3,290 rock quarries and 6,200 sand and gravel pits. The leading states in crushed-stone production were Texas, Florida, Missouri, Pennsylvania, Ohio, Georgia, North Carolina, Tennessee, Kentucky and Indiana. In 2022, the USGS estimated that 1.5 Gt of crushed stone was produced and valued at more than $21 billion.

Specifications and markets

Construction aggregate must meet the specifications of various state, federal and sometimes local public works departments or municipalities and public health departments for septic sand filtration to be used for projects by these agencies. Many of the physical testing required is set forth by ASTM and the American Association of State Highway Officials (AASHTO). Most state agencies base their specifications on ASTM and AASHTO. The Federal Aviation Administration (FAA) and the U.S. Army Corp of Engineers (USACE) have their own specifications for airport runways and taxiways, or armor stone. One test for armor stone used by the USACE is the so called “drop test.” This test requires one 3- to 5-t stone to be dropped about 9 m onto another 3- to 5-t stone. After the drop, the stones are inspected for open fractures and large losses due to breakage. Generally, it is a judgement call by the engineers or geologists whether the armor will be rejected or approved. Railroads have specifications for ballast stone and traction sand. Traction sand must be dried so it is supplied by the industrial silica sand industry. A physical test required by state, federal and local regulators is the Los Angeles Abrasion (LA). The LA method covers the procedure for testing coarse aggregate for resistance to degradation. The five-cycle magnesium or sodium sulfate soundness tests determine an aggregate’s resistance to disintegration by weathering, particularly freezing and thawing cycles. The LA and soundness tests are perhaps the tests that should be performed on coarse aggregate to determine suitability of the rock to meet specification before the many other tests that are needed are performed. Additional tests include deleterious material, particle size and shape, mineral contaminants especially iron sulfide minerals, and asbestiform/nonasbestiform minerals, specific gravity and absorption, acid-insoluble residue for skid-resistant (friction) aggregate, hardness and freeze-thaw, alkali silica or carbonate reactivity, and petrographic analysis. Skid-resistant or friction aggregate generally requires all rock that passes physical specifications set forth by the agency to be noncarbonate. Therefore, limestone or dolomite cannot be used on the top course of most roads. Some states have a specification on the residue left after a certain-size carbonate aggregate is placed in concentrated hydrochloric acid and dissolved. The residue left, if significant enough, may be used on the top course of less traveled roads. In recent years, the microdeval test has become popular in some states, especially for testing aggregate for the asphalt industry. Officials report that it is a more accurate test for aggregate quality and durability than the LA abrasion test.

States require different tests or limits on some tests to accommodate the rock, or sand and gravel, in their area. For example, the Texas Department of Transportation (TXDOT) allows the individual TXDOT regional engineer to decide whether to require a five-cycle sodium sulfate test or a five-cycle magnesium sulfate test on coarse aggregate. Magnesium sulfate is harsher on aggregate. In Oregon, a dimethyl sulfoxide (DSMO) test is used to test some aggregate, South Carolina has higher loss limits on the LA abrasion than most surrounding states, and the New York State Department of Transportation (NYDOT) Bureau of Materials requires a 10-cycle magnesium sulfate test on coarse aggregates.

Construction aggregates’ markets can range from low-grade material such as fill, road base and miscellaneous products to washed and sized aggregate sold to the ready-mix concrete and asphalt producers. The market area is generally within trucking distances as trucks transport about 85 percent of aggregate in the United States. Rail and barge or ship together total about 15 percent. As an industry “rule of thumb,” trucks can generally travel 56 to 64 km before transportation costs increase significantly. These costs depend on many factors such as road conditions, traffic, tolls, bridges, back hauls and weight laws. For example, relatively straight roads with limited traffic signals can allow trucks to carry material much farther than 64 km at low rates. Conversely, in areas near New York City, Atlanta, Dallas/Forth Worth, Los Angeles and other major cities, trucks are slowed by traffic congestion, traffic signals and tolls. Thus, freight rates are much higher. In these cases, many of the trucks charge an hourly rate. Most aggregate producers do not own their own trucks for delivery — many use contract trucking companies. In recent years, the "rule of thumb" has changed as quarries and sand and gravel pits are being permitted farther from urban areas where most of the material is consumed. Truck rates affect many operations on pricing and bidding projects.

Rail rates are lower than trucking rates, but have limited areas of service. The producer using rail generally owns or leases a siding on both production and a distribution end. Once the product is stockpiled in the distribution yard, extra costs include storage, loading and unloading. Those producers who have rail access generally serve the railroad ballast stone market as rail companies send their own rail cars to be loaded at that quarry.

Barge and ship rates are generally lower than rail, and similar to rail service, the producer is generally on or near navigable water. A small river barge can carry approximately 1.4 kt to about 2.9 kt of aggregate. Larger barges can carry about 6,350 t. Generally, several river barges are grouped (tied) together and pushed by one tugboat. Producers on or near the Mississippi, Missouri, Ohio, Delaware, Potomac, Hudson and Columbia rivers use river barges to deliver aggregates to markets in need of crushed stone and sand and gravel. The American Bureau of Shipping (ABS) barges or ocean-going barges carry approximately 8.2 kt. Some of these barges deliver aggregate through the intercoastal waterways and the great lakes. Ocean-going vessels (ships) can carry approximately 32.6 kt and the larger Panamex ships can carry upward of approximately 54.4 kt of aggregate. The time it takes to unload or load the material (demurrage) and all other handling of material increase final costs at the dock.

Construction aggregates are sold free on board (F.O.B.) quarry or sand and gravel pit. F.O.B. prices are listed at the scale house and provided by sales people. The F.O.B. prices do not reflect lower prices negotiated with contractors on a project, bid work, or those companies that buy in large volumes. When a producer is vertically integrated, its price for material to its asphalt plant, concrete batch plant or construction group may be the exact F.O.B. price or discounted. Where aggregate is needed, F.O.B. prices are generally higher than in areas where aggregate is abundant. For example, in intercoastal and coastal areas of the United States, prices for crushed coarse aggregate of any type are generally higher as these areas are devoid of quality or friction aggregate. Inland, where many quarries are located, prices tend to be lower because of competition.

Quality aggregates are railed from the southeast Piedmont area to rail yards on the East Coast or shipped from the Bahamas, Nova Scotia and New Brunswick, Canada. In late 2022, 36 kt of construction-grade limestone was shipped from Jamaica to Savannah, GA. Quarries along the Mississippi barge both crushed stone and slag to ports along the southern Mississippi to the Gulf Coast along the intercoastal waterway. Aggregate is shipped from Mexico to the Houston, TX market. Rail shipments from Oklahoma also supplies the Houston and Dallas, TX market. Sand and gravel aggregates are shipped from Vancouver Island, Canada to the West Coast cities, especially to San Francisco, CA. In much of the Western United States, rail is used to supply distant markets.

The results of some or all physical tests determine the marketability of the product. Aggregate that does not meet certain specifications is sold for low-grade construction products or nonstate specification aggregate. Being an approved aggregate source by the state, federal or other approval agencies is an advantage in the marketplace.

Sand and gravel as construction aggregate is used for many of the same purposes as crushed stone. Geology plays a significant role in determining the use of crushed stone or sand and gravel in geographic regions. In California, where large alluvial fan deposits are located, sand and gravel is widely used. Glacial deposits are generally mined in the Northeast and North Central states. Colluvium and river deposits in the Western states, and river deposits in the Mid-South are utilized. Where there are large deposits of rock, crushed stone is generally used. There are two exceptions, natural sand is generally preferred over manufactured sand (stone crushed to sand size) by most ready-mix concrete and asphalt producers. Crushed stone is preferred over crushed gravel for the same use, if available. In both PCC and asphalt, crushed stone consists generally of one rock type while crushed gravel may contain several lithologies or rock types. In ready-mix concrete and asphalt, each different lithology may absorb more/less water or react differently to the cement or cement additives. In addition, liquid asphalt added to the asphalt mix may not adhere (strip) to certain aggregate types, such as quartzite, and large mineral crystals in the rock matrix having a vitreous or glassy luster. The producer may have to add antistripping chemicals, thus increasing costs. Sand for use in PCC has been increasingly difficult to find.

Sand may seem ubiquitous, but many deposits of natural sand are too fine-grained to meet ASTM

C-33 gradation specifications.

In 2022, the USGS estimates 960 Mt of sand and gravel were produced in the United States valued at $10 billion. The 10 leading producing states were California, Texas, Arizona Minnesota, Washington, Utah, Michigan, Colorado, Ohio and New York. Most of the sand and gravel production in 2022 was used by PCC aggregates. These leading states have an abundance of mines in the alluvial fans, colluvium, river deposits and glacial deposits. Most specifications required by states for crushed stone are the same for sand and gravel aggregates with a few exceptions. One of these is that natural gravel must be crushed to meet PCC and asphalt specifications. Natural gravel or gravel that is not crushed is generally used for landscape products, flat commercial roofing material and filtration media. This is generally low-volume, high-price material.

Recycling

RAP and recycled concrete usage are becoming more prevalent in the industry. This material is generally crushed and sized for use as base materials and other low-grade construction aggregate. The material does not meet state specifications for approved PCC or asphalt aggregate. The USGS reports that recycling is a small percentage of aggregate consumption. Substitutes for natural aggregates such as iron or steel slag have quality and environmental issues. Steel slag can cause expansion cracks in concrete and the stockpiling of slag may release pollutants over time. Some asphalt producers are recycling asphalt roofing shingles to limit or replace buying liquid asphalt for the mix. The oil from the shingles is extracted during the heating process at the plant and added to the mix. Sand was used as a filler in asphalt. The specifications are less rigid than sand used for PCC. One major difference is that asphalt sand is not washed. Many asphalt producers have stockpiles of RAP on their site and are blending washed concrete grade sand with RAP for filler material. RAP has an abundance of fine material and therefore the producer uses washed concrete sand to meet specifications on the finer sieves. In some areas of the country, concrete sand producers are providing washed sand to both ready-mix concrete and asphalt producers creating a shortage of specification concrete sand. Crushed glass in asphalt (glassphalt) replacing some aggregate has gained acceptance as a substitute with some producers. Recycled tire rubber and cellulose fiber are also used in asphalt. The main issue with recycled materials in asphalt is implementing a proper and acceptable mix design to the customer.

Issues

Construction aggregates have many issues facing the industry. Since the aggregate industry is the largest mining sector in the United States, the general public is exposed to their operations more than any other mining industry.

Although the industry has come a long way in mitigating many environmental concerns of local citizens, the fact remains that opposition from not-in-my-backyard (NIMBY) citizens deny or slow the process of permitting or expanding aggregate mines. In 2022, denials of permits continue in several U.S. states. All the major companies and most of the other aggregate producing companies have environmental/compliance managers who handle all environmental issues and permitting. Many use open houses or environmental days at their mine sites to educate the general public and school children about the importance of construction aggregates in everyday lives. Because about 85 percent of aggregate production is transported by truck, truck traffic remains a concern to local citizens and is difficult to mitigate. Dust, noise, blasting, wetlands issues and safety issues have through the years been largely mitigated in most operations.

In 2022, Heidelberg Materials (formerly Leigh Hanson) acquired JEV Recycling, a concrete and asphalt recycler in Woodinville, WA. Vulcan Materials Co. purchased Syar Industries of Northern California, a recycler, aggregates, asphalt and ready-mix producer. Blue Ridge Construction Capital purchased Mathews Sand and Gravel and Edge Materials in North Carolina. York Building Products acquired Union Quarries in Carlisle, PA and Martin Marietta opened a new quarry in Virginia.

The Mine Safety and Health Administration (MSHA) is continuing its inspections and enforcement of safety of the industry. Most large aggregate operations have health and safety managers on staff to help comply with MSHA regulations and welcome practical inspections. However, MSHA inspectors often "write up" a violation based on rule with little flexibility. Each aggregate mine is different, and a one-size-fits-all approach to safety does not always work.

MSHA continues to draft rules on respiratory crystalline silica. This issue is of great concern to producers because most igneous, metamorphic and sedimentary rocks mined for aggregate contain some coarsely crystalline or cryptocrystalline varieties of quartz (SiO_2), and since quartz is extremely resistant to both mechanical and chemical weathering, it is found in most unconsolidated sand deposits and gravel deposits.

Outlook

The industry and its outside prognosticators seem reluctant to speculate on aggregate market growth in 2023. Most report that it will be a good year. The large urban areas such as Atlanta, GA, Dallas/Fort Worth, TX, New York City, Los Angeles and San Francisco, CA, Miami, FL and other large cities always need large amounts of construction aggregates that drive the market. *References are available from the author.*

DIATOMITE

by R.D. Crangle, Jr., National Minerals Information Center, U.S. Geological Survey

Diatomite is a chalk-like, soft, friable, very fine-grained, siliceous sedimentary rock. Typically light in color (white if pure, commonly buff to gray in situ), diatomite is also very finely porous, very low in density and essentially chemically inert. Diatomaceous earth (D.E.) is a common alternate name, but the term is more appropriate for unconsolidated or less lithified rock of the same origin.

Production

Diatomite deposits are usually mined from openpit operations. If necessary, the mined crude ore is dried and crushed. Dried diatomite is collected in cyclones and fed through air separators to remove coarse material and impurities. Calcination and flux calcination are used to thermally volatize organic material and oxidize iron. Calcination also is used to increase diatomite hardness, specific gravity and refractive index. The fusing of small diatomite particles into clusters can also be accomplished through calcination, which results in increased pore size and volume. Diatomite products are sold as various grades of calcined powders.

The United States continues to be the world's leading producer and consumer of diatomite. Production of diatomite in the United States during 2022 was estimated to be 1.1 Mt, 10 percent more than the 998 kt in 2021. Six companies operated 12 mines and nine processing facilities in California, Nevada, Oregon and Washington. According to the U.S. Census Bureau, U.S. diatomite exports were 63.4 kt. Imports were lower at 13.6 kt. Total world production of diatomite was an estimated 2.5 Mt in 2022. Following the United States in diatomite production, other significant producers in 2022 were Denmark (400 kt), China (140 kt), and Argentina, Mexico and Turkey (each with 100 kt). World resources of crude diatomite appear to be adequate for the foreseeable future. However, increased transportation costs may encourage development of sources of material closer to markets.

Diatomite deposits accumulate in oceans or fresh waters from the cell walls of diatoms, composed of amorphous hydrous silica. Diatoms are microscopic, single-celled organisms, often appearing as colonial aquatic plants (algae). Diatom cells contain an elaborate internal siliceous skeleton. More than 10,000 living diatom species have been identified, in addition to another 10,000 known diatom fossil forms.

Prices

The unit value of diatomite varied widely by end use in 2022. The estimated annual average unit value of diatomite in 2022 was $430/t, 4 percent more than that in 2021. Diatomite used as an absorbent was priced at approximately $10/t, but specialty grade diatomite, used in art supplies, cosmetics or biomedical applications, was priced as high as $1,000/t.

Consumption

Domestic apparent consumption in 2022 was estimated to be 1.05 Mt. The internal structure and inert chemical composition of diatomite make it an excellent raw material for filtration, absorbent and filler applications. Filtration, especially the purification of beer, liquors and wine, and the cleansing of greases and oils continued to be the largest end use for diatomite. Other applications included the removal of microbial contaminants, such as bacteria, protozoa and viruses, from public water systems. The use of diatomite as a filler, which serves to displace higher-cost raw materials, and in pharmaceutical applications, including the filtration of human blood plasma, continues to increase, as has its use as an insecticide base and in cement and concrete pozzolan. In 2022, approximately 55 percent of diatomite-derived products were utilized in filter aids. The remaining 45 percent was used in absorbents, fillers, lightweight aggregates and other applications. A small amount, less than 1 percent, was used for specialized biomedical and pharmaceutical purposes.

Substitutes

Many materials can be substituted for diatomite, especially for lightweight aggregate purposes, such as expanded perlite and silica sand. Synthetic filters, including ceramic, polymeric or carbon membrane, and cellulose fibers offer competition as filter media. Alternate filler materials include clay, ground limestone, mica, perlite, silica sand, talc and vermiculite. For thermal insulation purposes, materials such as specialty brick, various clays, mineral wool, expanded perlite and exfoliated vermiculite may be used.

Many alternatives exist for diatomite as a pozzolan, but its use as an ingredient of portland cement has increased in recent years. The encroachment of natural and synthetic substitute materials into diatomite markets has not been significant.

Outlook

Adequate supplies of diatomite are likely to remain available for the foreseeable future. The economic stability of the diatomite industry was largely owing to its use as a filtration medium, where demand remains strong. This is particularly so in the filtration of spirits, as well as human blood plasma and other biotechnical applications.

Likewise, the substitution for diatomite by more advanced filtration products, including carbon membranes, ceramics and polymers, was not a concern in 2022. The high costs associated with these alternatives and a cultural preference toward the use of diatomite in the brewing and wine industries indicate a strong likelihood for the continued widespread use of diatomite in filtration.

DIMENSION STONE

by Jason Williams, National Minerals Information Center, U.S. Geological Survey

Dimension stone is natural rock material quarried for the purpose of obtaining blocks or slabs that meet specifications as to size (width, length and thickness) and shape. Color, grain texture and pattern, and surface finish of the stone also are normal requirements from customers and the stone industry. Although various igneous, metamorphic and sedimentary rocks are used as dimension stone, the principal rock types are granite, limestone, marble, sandstone and slate.

Production

Approximately 2.5 Mt of dimension stone, valued at $520 million, was sold or used by U.S. producers in 2022. Dimension stone was produced by approximately 200 companies conducting mining operations at 231 sites in 34 states. Leading producing states were Texas, Wisconsin, Indiana and Vermont (in descending order by tonnage). These four states accounted for about 68 percent of the production quantity and contributed about 58 percent of the value of domestic production.

Approximately 49 percent, by tonnage, of dimension stone sold or used was limestone, followed by granite (19 percent), sandstone (18 percent), dolomite and slate (4 percent each), and the remaining 6 percent was divided, in descending order of tonnage, among marble, traprock, miscellaneous stone and quartzite.

Consumption and pricing

Rough stone represented 59 percent of the tonnage and 56 percent of the value of all the dimension stone sold or used by domestic producers, including exports in 2022.

The leading uses and distribution of rough stone, by tonnage, were in building and construction (66 percent) and in irregular-shaped stone (26 percent). The leading uses and distribution of dressed stone, by tonnage, were in ashlars and partially squared pieces (43 percent), curbing (13 percent), slabs and blocks for building and construction (10 percent) and flagging (9 percent).

The average price per ton as reported by domestic producers for dimension stone was $208/t. By value, the leading sales or uses were for limestone (47 percent), followed by granite (26 percent), sandstone (10 percent), and marble and slate (5 percent each); the remaining 7 percent was divided, in descending order of total value, among dolomite, traprock, quartzite and miscellaneous stone. Prices are substantially different not only for the type of stone but also for the appearance of the same type of stone. Color, grain structure and finish contribute significantly to price and marketability.

Foreign trade

In 2022, Brazil, China, Italy and India were the leading sources in terms of value and weight of dimension stone imports into the United States, according to the U.S. Census Bureau. Nearly 73 percent of the total value (and 68 percent of the total tonnage) of U.S. dimension stone imports came from those four countries in 2022.

Canada was the leading export destination, with approximately 56 percent of the total value (and 94 percent of the tonnage) of U.S. dimension stone exports being attributed to this single country. Italy, the Bahamas, China and Mexico were also other significant destinations, together accounting for 30 percent of the total value of U.S. dimension stone exports.

These four countries accounted for most of the remaining 6 percent of the tonnage of dimension stone exports, although 67 other countries received relatively smaller volumes of dimension stone, which accounted for the remaining 14 percent of the value of dimension stone exports in the United States in 2022.

Outlook

The United States remained one of the world's leading markets for dimension stone. In 2022, total imports of dimension stone increased in value by about 9 percent compared with those in 2021. In 2022, the value of dimension stone exports increased by 3 percent to about $48 million. Apparent consumption, by value, was estimated to be $2.9 billion in 2022 — an 11 percent increase compared with that in 2021. Dimension stone production trends similarly to economic indicators for the construction industry in the United States.

According to the U.S. Bureau of Economic Analysis, most economic indicators for construction have shown slight to moderate growth in 2022. At a national level, the price index for multifamily homes increased by 6 percent, the average producer price index for construction materials increased by 13 percent from what was reported in 2021, and the total amount spent on construction increased by 29 percent. At a state level, all four of the leading dimension stone producing states saw increases in total construction earnings and number of construction employees.

The dimension stone industry continued to be concerned with safety and health regulations and environmental restrictions in 2022, especially those concerning crystalline silica exposure.

In 2016, the Occupational Safety and Health Administration finalized new regulations to further restrict exposure to crystalline silica at quarry sites and other industrial operations that use materials containing it. Final implementation of the new regulations took effect in 2021, affecting various industries that use materials containing silica. Most provisions of the new regulations became enforceable on June 23, 2018, for general industry and maritime operations.

FIRE CLAY

by Kristi J. Simmons, National Minerals Information Center, U.S. Geological Survey

Fire clay is a detrital material, either plastic or rocklike, that is often found below coal beds. Within the United States, most fire clay is of Pennsylvanian Age, scattered from Virginia to Missouri. Fire clay contains high percentages of alumina and silica. Low concentrations of iron oxide, lime, magnesia and alkalies enable the material to withstand high temperatures. Fire clay is composed mainly of kaolinite and most often is mined by openpit methods. Once kiln-processed, fire clay ranges from buffs to grays in color.

Production

Fire clay was the dominant clay type mined in the United States prior to the 1940s and accounted for nearly 70 percent of the total clay tonnage produced from 1900 through 1939. Domestic production of fire clay (the quantity sold or used by producers) increased sharply from the beginning of U.S. involvement in World War II through the immediate post-war period, peaking at 10.8 Mt in 1951. The trend reversed in 1956 and was followed by several years of decreasing rates of production. In every year since 1986, fire clay production has been lower than that in 1900 and reached a low of 183 kt in 2012. During the past five years, fire clay production gradually increased from 567 kt in 2018 to an estimated 720 kt in 2022. In 2022, fire clay production accounted for about 3 percent of total clay produced domestically.

In 2022, six companies (The Belden Brick Co., Christy Minerals Co., General Shale Brick Inc., Harbison Walker International, Resco Products Inc. and Triangle Brick Co.) were thought to mine fire clay in four states (Colorado, Missouri, North Carolina and Ohio). Other companies may or may not have produced fire clay as year-to-year output recently became variable as common clay producers entered and exited the marketplace in response to short-term demands. Fire clay production was estimated to have increased by 7 percent to 720 kt in 2022 compared with 675 kt in 2021. Reliable data on global output of fire clay are not available because many countries either do not report clay production or do not distinguish between fire clay and other clay types.

Consumption

Structural concrete was estimated to be the leading market of fire clay in 2022. Other markets for fire clay included common brick, fire brick, floor and wall tile, portland cement, refractory grogs and calcines, and miscellaneous uses. The U.S. Geological Survey withholds data related to specific market consumption of fire clay to avoid disclosing company proprietary data.

Prices

The average unit value of fire clay was estimated to be unchanged at \$12/t in 2022 from that of 2021. Fire clay prices have trended downward since 2007, when the average unit value was \$42/t. Over the past five years (2018-2022) the average unit value of fire clay was estimated to be \$12/t. According to the U.S. Census Bureau, the average unit value of imported fire clay in 2022 was \$206/t, compared with \$459/t in 2021. The average unit value of exported fire clay was \$504/t in 2022, compared with \$463/t in 2021. Average unit values for imports typically fluctuate more than the average unit values for exports owing to smaller, high-value shipments.

Foreign trade

According to the U.S. Census Bureau, fire clay exports decreased in 2022 to 158 kt valued at \$47.4 million from 210 kt valued at \$52.9 million in 2021. The principal destinations for U.S. exports of fire clay in 2022 were the Netherlands (34 percent), Taiwan (15 percent), Mexico (13 percent), Germany (8 percent) and Japan (6 percent). Imports of fire clay increased in 2022 to 14 kt valued at \$2.9 million compared with 6 kt valued at \$2.8 million in 2021. China (62 percent) and Spain (32 percent) were the leading sources of fire clay imports in 2022.

Outlook

The fire clay industry is mature and is not expected to experience large changes. Fire clay production is expected to remain relatively stable over the next several years supported by applications that use refractory brick, such as the aluminum, cement, glass, heavy-clay products, lime and steel industries.

FLUORSPAR

by Michele E. McRae, National Minerals Information Center, U.S. Geological Survey

Fluorspar is used for its fluorine content. Because of technical and practical considerations, fluorine is seldom consumed in elemental form but rather as fluorspar, which is the commercial name that refers to crude or beneficiated material that is mined and (or) milled from the mineral fluorite (calcium fluoride, CaF_2). Fluorspar with a minimum CaF_2 content of more than 97 percent has historically been referred to as acid grade, and anything with content less than or equal to 97 percent has been referred to as metallurgical grade. Globally, there are three leading fluorspar-consuming industries: aluminum production, the chemical industry and steelmaking. The manufacture of hydrofluoric acid (HF), the leading source of fluorine in industrial applications and a precursor in the production of most other fluorine-containing chemicals, and the manufacture of aluminum fluoride (AlF_3) and cryolite (Na_3AlF_6), essential for primary aluminum smelting, typically require acid-grade fluorspar, although fluorosilicic acid (FSA) can also be used. Fluorspar used as a steelmaking flux historically consisted of metallurgical-grade fluorspar, although acid-grade has also been used. Other applications of fluorspar include use in the manufacture of cement, ceramics, enamel, glass and welding rod coatings.

Legislation and government programs

In September, the United States became the 137th country to ratify the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer. The goal of the amendment is to reduce production and consumption of hydrofluorocarbon (HFC) gases, commonly used as aerosols, refrigerants and solvents, by 80 percent over the next 30 years. This is expected to reduce projected global warming by as much as 0.5 °C by the end of the century. The American Innovation and Manufacturing Act of 2020 established all the HFC phasedown provisions and enforcement mechanisms needed to comply with the Kigali Amendment.

Production

Minimal fluorspar was produced in the United States in 2022. Hastie Mining & Trucking Co. sold metallurgical-grade fluorspar from stockpiles produced as a byproduct of its limestone quarrying operation in Cave-in-Rock, IL. A second company, Ares Strategic Mining Inc. (Canada), received a nearly $5 million loan from the U.S. Department of Agriculture's Business and Industry Guaranteed Loan Program, which it expected to use to finish construction of a metallurgical-grade fluorspar processing plant, rail spur and tailings dam in Utah.

An estimated 40 kt of FSA, equivalent to about 65 kt of fluorspar grading 100 percent, was recovered in 2022 from three phosphoric acid plants processing phosphate rock, which was primarily used in water fluoridation. In 2022, Nutrien Ltd. (Canada), in partnership with Arkema SA (France), continued development on a 40-kt/a anhydrous HF plant in Aurora, NC, using FSA feedstock. The new plant, expected to begin production in 2023, would be the first plant of its kind outside of China, although similar projects were reportedly being evaluated in other countries.

World production of fluorspar was estimated to have decreased by 4 percent to 8.3 Mt in 2022. Global fluorspar supply, which is highly concentrated, was constrained by the bankruptcy and subsequent idling of a fluorspar mine in Canada and the declaration of force majeure for supply contracts by the world's leading exporting mine in Mexico. However, overall adverse impacts to supply appear to have been offset by decreased consumption in China. Production of fluorspar in China, the world's leading producer, was estimated to have remained unchanged at 5.7 Mt. Mexico's fluorspar mine production was 990 kt, a slight decrease compared with 1.01 Mt in 2021. Production in South Africa was estimated to have increased by 4 percent to 420 kt; Vietnam's production was reported to have increased slightly to 218 kt. Production in Mongolia was estimated to have decreased by 46 percent, to 350 kt, which was primarily attributed to decreased exports to China, the country's main fluorspar trading partner.

In February, the mine and processing operations of Canada Fluorspar (NL) Inc. (CFI) were idled and placed on care-and-maintenance status after the Supreme Court of Newfoundland and Labrador (Canada) appointed a monitor for the operation. The initial agreement to sell CFI's assets was canceled in October after the selected bidder failed to deliver the agreed-upon deposit. The bidding process was subsequently reopened, and actions were taken to move the facility from care-and-maintenance status to cold idle, which included reducing the number of total employees to 11; allowing the open pits to flood in accordance with the mine closure and rehabilitation plan; shutting off power and water to almost all facilities, except for those being used by remaining staff; and terminating payments on leasing and financing agreements and arranging to return leased equipment.

Domestic consumption and trade

Domestically, production of HF at plants in Louisiana and Texas was by far the leading use for fluorspar. As of 2020, total domestic HF capacity was 220 kt/a, second only to China. Although some HF was consumed directly in various manufacturing processes, most was used to produce a diverse variety of organic fluorochemicals, including primarily fluorocarbon gases used as aerosols, propellants and refrigerant gases, or fluoropolymers. There was little domestic production of inorganic fluorochemicals. Apparent consumption of acid-grade fluorspar in 2022 was estimated to be 410 kt, an increase of 6 percent compared with 388 kt in 2021.

The use of fluorspar as a steelmaking flux, primarily metallurgical-grade fluorspar, was the second leading domestic use of fluorspar. Apparent consumption of metallurgical-grade fluorspar was 78.8 kt, a 63 percent increase compared with 48.3 kt in 2021.

In 2022, acid-grade imports were 425 kt compared with 391 kt in 2021, an increase of 8 percent. The leading acid-grade import sources in 2022, based on quantity, were Mexico (53 percent), China (22 percent), Vietnam (16 percent) and South Africa (8 percent). Metallurgical-grade imports in 2022 were 87.8 kt, a 48 percent increase compared with those in 2021. The leading sources of metallurgical-grade fluorspar, in terms of quantity, were Mexico (76 percent), China (15 percent), South Africa (5 percent) and Pakistan (4 percent). Decreased imports from Mexico and increased imports from China were likely the consequence of North American supply disruptions in Canada and Mexico.

Prices

According to Fastmarkets IM, the average annual midpoint price of fluorspar from all leading exporting countries increased in 2022 compared with those in 2021. The average midpoint price of acid-grade fluorspar from China was $479/t, an increase of 16 percent; the average midpoint price from Mexico was $367/t, an increase of 14 percent; and the average midpoint price from South Africa was $523/t, an increase of 47 percent. The average annual midpoint price of metallurgical-grade fluorspar from Mexico, with a minimum CaF_2 content of 85 percent, was $345/t, an increase of 17 percent compared with that in 2021.

Outlook

Fluorocarbon gases, used as aerosols, propellants, and refrigerants, are the single largest end use for fluorspar. Although HFC phasedowns are already underway in a number of countries, alternatives are often other fluorocarbon gases so that the overall volume required is not expected to decrease. In addition, the U.S. Department of Energy identified chemicals derived from fluorspar as important in nine out of 11 emerging technologies (including those on carbon capture;electric grid transformers and high-voltage, direct-current transmission; energy storage; fuel cells and electrolyzers; hydropower; neodymium magnets; nuclear energy; semiconductors; and solar photovoltaics).

Over the next five years, fluorspar consumption is expected to increase, particularly in fluorocarbon manufacturing; in the production of lithium hexafluorophosphate, the main electrolyte salt used in lithium-ion batteries; and in semiconductor manufacturing, both in cleaning and etching processes and in the manufacture of electronic specialty gases.

References are available from the author.

FRAC SANDS

by Jack Sackrider, Westward Environmental, Inc.

In 2022, the hydraulic fracturing sand (commonly known as frac sand) market was valued at around $7 billion globally. The domestic market again experienced increases in both demand and spot pricing, with Permian Basin sand accounting for roughly half of the market.

Frac sand is a high-purity silica sand with specific physical and chemical properties. In the fracking process, a mixture of sand, water and other compounds are pumped down a well at high velocities into very small, induced fractures. The frac sand particles become lodged in the fractures, "propping" them open to allow increased flow of oil and natural gas from the well. A range of particle sizes is typically used during the fracking process. These size ranges are often referred to as the mesh and are based on the ASTM International test sieve sizes. Product mesh sizes include: 20/40-mesh, 30/50-mesh, 40/70-mesh, and 100-mesh, which is sometimes referred to as 70/140-mesh. The name defines the particle size range, and the two numbers separated by a slash indicate sieve size. By convention, the size range includes particles small enough to pass a sieve indicated by the first number, but are retained on the sieve of the second number.

The American Petroleum Institute (API) and the International Organization for Standardization (ISO) have published testing procedures and standards for frac sand, which are defined in API RP 19C/ISO 13503-2, "Recommended Practice for Measurement of Properties of Proppants Used in Hydraulic Fracturing and Gravel-packing Operations." Beyond size, ideal frac sand material will exhibit the following:

- High silica content: Mineralogical purity is indicative of a mature deposit that has endured physical and chemical weathering, reducing impurities that are physically weaker or that may negatively interact chemically with other fracking fluids.
- Homogeneous grain size: Individual well conditions drive completion design and desired grain sizes, and mixtures are designed to optimize recovery. In general, larger grains increase permeability but are less durable, while smaller grains are stronger, and result in less permeable conditions.
- High sphericity and roundness: Sometimes referred to as the Krumbein shape factor, sphericity and roundness primarily impact grain strength and completed porosity. More rounded and spherical grains are generally stronger and result in an increased flow of oil and natural gas during extraction.
- High crush resistance: In order to be effective, individual grains must be able to withstand pressures of 2,000 to 10,000 lb/in.^{2} (psi) or more. Crush resistance is measured as a percentage of fines generated when a sample is exposed to increasing pressures. A k-value is assigned, indicating the greatest pressure withstood while generating not more than 10 percent fines by weight. For example, a k-value of nine indicates a sample generating no more than 10 percent fines by weight when subjected to 9,000 psi, but more than 10 percent fines when subjected to 10,000 psi.
- Low solubility: Solubility tests provide an indication of the amount of undesirable contaminants. Exposing a proppant to a 15 percent solution of hydrochloric-hydrofluoric acid (HCl-HF) may result in the dissolution of part of the proppant, which can reduce fracture conductivity.
- Low turbidity: Turbidity is a measure of clays, silts and other fine-grained impurities that can negatively impact the fracking fluid.

These API standards represent ideal proppant material. However, in recent years, operators have made compromises in proppant quality to drastically reduce well completion costs.

Uses

While there are very few alternate uses for frac sand, geologic deposits yielding frac sand material can produce glass, foundry, recreational and construction sand, as well as high-purity ground silica products used in coatings, epoxies and ceramics.

Production

U.S. frac sand demand increased by 27 percent year over year in 2022 to reach an all-time high of 113 Mt, according to data prepared by Lium Research, an energy market research firm. The Permian Basin continues to be the sand consumption geomarket leader and demand there of 58 Mt comprised approximately half the U.S. total, more than four times greater than the next largest shale basin (Eagle Ford).

With demand for frac sand linked to oil and natural-gas drilling, the increased demand was mirrored by a rising rig count in North America. Based on data from Baker Hughes, the total rig count in the the United States increased by about 191 rigs in 2022 (Fig. 1). A majority of the increase was seen in the first half of the year with the second half seeing only a 50-rig increase.

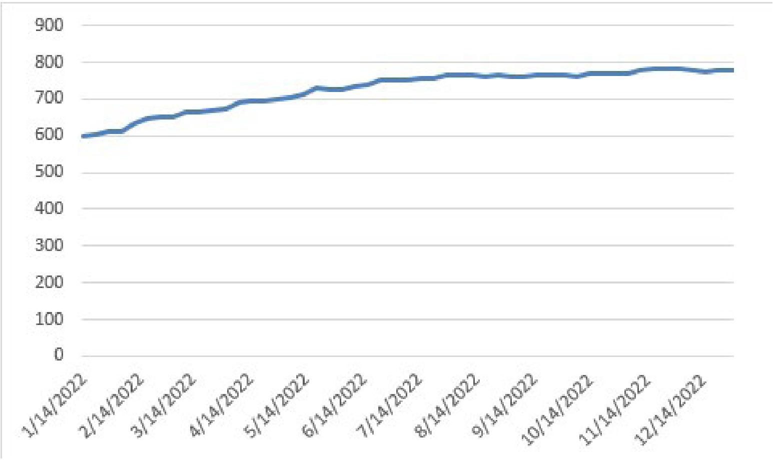
West Texas Intermediate (WTI) crude-oil prices in early 2022 increased to a mid-year high of just above $122 per barrel, at which point they began to fall, finishing the year at $80.51 per barrel, according to www.macrotrends.net.

Pricing

Spot prices for local sand in the Permian more than doubled in 2022, according to Lium Research estimates, as demand surpassed local sand mine capacity in the first quarter and the supply base raced

Figure 1

Total U.S. rig count 2022.



to keep up for the rest of the year. It is important to note that pricing was still cyclically depressed in 2021, so even after the big upward move in 2022, prices still averaged below the prior cyclical highs set in the first half of 2018. Also of note, all the inflation occurred in the first half of 2022 with prices plateauing in the second half of 2022 and not budging much since then.

Trends and outlook

IMARC group projects a frac sand market compound annual growth rate of nearly 8.5 percent during 2022-2028, bringing the market to an estimated $11.4 billion by 2028. A thriving oil and natural-gas industry is cited as the key factor driving global frac sand demand. Additionally, there is an increased interest in fine-mesh frac sand, which can increase natural-gas flow in tight shale plays.

Lastly, the mini-mine for on or near-site production of proppant continued to gain popularity in 2022, primarily driven by freight and fuel costs.

References are available from the author.

GEMSTONES

by Donald W. Olson, National Minerals Information Center, U.S. Geological Survey

Production

The value of natural gemstones produced from U.S. deposits during 2022 was estimated to be $9.5 million, essentially unchanged from that in 2021. U.S. natural gemstone production included agate, beryl, coral, diamond, garnet, jade, jasper, opal, pearl, quartz, sapphire, shell, topaz, tourmaline, turquoise and many other gem materials.

More than 60 varieties of gemstones have been produced from U.S. mines, but commercial mining of gemstones has never been extensively undertaken in the United States. Most U.S. gemstone production has been from relatively small mining operations, or production has been as a byproduct of the mining of other mineral commodities. In the United States, much of the current gemstone mining is conducted by collectors, gem clubs and hobbyists, rather than commercial organizations.

The commercial gemstone industry in the United States consists of individuals and companies that mine gemstones or harvest shell and pearl, firms that manufacture synthetic gemstones, and individuals and companies that cut natural and synthetic gemstones. The U.S. gemstone industry is focused on the production of colored gemstones and on the cutting of large diamonds.

During 2022, each of the 50 states produced at least $1,720 worth of natural gem materials. Twelve states accounted for 93 percent of the total value, as voluntarily reported to the U.S. Geological Survey (USGS) by survey respondents. These states (listed in alphabetical order) were Arizona, Arkansas, California, Colorado, Idaho, Maine, Montana, Nevada, North Carolina, Oregon, Tennessee and Utah.

Some states are known for the production of a single gem material, such as Tennessee for freshwater pearls. Other states, including Arizona, California, Colorado, Idaho, Montana, Nevada and North Carolina, are known for producing a variety of gemstones. California and North Carolina have identified deposits of three of the most popular precious gemstones: emerald, ruby and sapphire. Both states reported production of emerald, ruby and sapphire during 2022, and diamonds have been found in both states in the past.

The USGS estimated the value of U.S. synthetic or manufactured gemstone production was $85 million in 2022. Reported output of synthetic gemstones was from eight companies in Arizona, California, Maryland, New York, North Carolina, Oregon, South Carolina and Wisconsin. Production included the manufacture of azurite, malachite, diamond, moissanite and turquoise.

Consumption and uses

Although the United States accounts for only a small portion of the total global gemstone production, it is the world's leading gemstone market. The U.S. gemstone market was estimated to account for more than 35 percent of world gemstone consumption in 2022.

U.S. apparent consumption of unset gemstones in 2022 increased by 18 percent over the previous year to an estimated $28 billion. The U.S. apparent consumption of unset gem-quality diamond during 2022 was estimated to be about $24 billion. U.S. apparent consumption of unset nondiamond gemstones totaled about $3.8 billion. The major uses for gemstones in the United States were in jewelry, for carvings, and in gem and mineral collections.

Prices

Gemstone prices are governed by many factors and qualitative characteristics, including beauty, clarity, demand, durability, freedom from defects, perfection of cutting and rarity.

Colored gemstone prices are generally influenced by market supply-and-demand considerations, and diamond prices are supported by producer controls on the quantity and quality of supply. Diamond pricing in particular is complex; values can vary significantly depending on time, place and the subjective evaluations of buyers and sellers.

Imports and exports

Trade data in this report are from the U.S. Census Bureau and were adjusted by the USGS. During 2022, total U.S. gemstone trade with all countries and territories was about $29.6 billion ($28.0 billion in imports plus $1.57 billion in domestic exports). In 2022, U.S. domestic exports of diamond were valued at $1.12 billion.

U.S. domestic exports of gemstones other than diamond were valued at $447 million. U.S. imports of diamond were valued at $24 billion, and U.S. imports of gemstones other than diamond were valued at $3.97 billion.

The United States is a significant international diamond transit center as well as one of the world's leading gem diamond markets. The large volume of reexports shipped to other centers is one measure of the significance of the United States in the worldwide diamond supply network.

New sales platforms were established during 2020 and remained in place during 2021 and 2022 in the rough diamond market to overcome travel constraints and streamline the journey from the mine to the jeweler. Online auctions gained a higher share of rough diamond sales and offset deficits in traditional sales channels.

In a four-year (2018-2021) average of U.S. import sources by value, the leading gemstone sources were India (45 percent), Israel (28 percent), Belgium (11 percent) and South Africa (5 percent). Typically, diamond imports accounted for 86 to 95 percent of the total value of gemstone imports.

Outlook

During 2022, the U.S. and global gemstone and jewelry industries continued recovering from the effects of the global COVID-19 pandemic.

Jewelers maintained their online business and sales from their websites throughout the pandemic. Many reopened stores, but they still maintained their online presence during 2022. U.S. apparent consumption of gemstones increased in 2022 and exceeded prepandemic levels of 2018 by about 8 percent. Most major U.S. gemstone trade shows were held again.

During 2022, world gem-quality diamond production increased by about 3 percent from 2021 levels and was driven by the reopening of profitable mines that were suspended in 2020 and the addition of new mines.

By 2025, several large mines will reach the end of their mine life, while only a few new projects are currently being developed.

As domestic and global luxury spending recovers from the effects of the pandemic, sales of gemstones and jewelry are also expected to increase. Internet sales of diamonds, other gemstones and jewelry are expected to continue at a high level and to increase in acceptance, along with other forms of electronic commerce (e-commerce) that emerge to serve the diamond and gemstone industries, partially replacing "brick-and-mortar" store sales.

More synthetic gemstones, simulants and treated gemstones are likely to enter the marketplace and necessitate more transparency in the industry trade standards to maintain customer confidence.

GRAPHITE

by Andrew Stewart, National Minerals Information Center, U.S. Geological Survey

Natural graphite is classified into three types — amorphous, crystalline flake and vein. Amorphous graphite is the lowest quality and most abundant. Amorphous refers to its very small crystal size and not to a lack of crystal structure. Crystalline flake graphite is less common and higher quality than amorphous graphite. Flake graphite occurs as separate flakes that crystallized in metamorphic rock, and high-quality flake graphite can be four times the price of amorphous graphite. Vein graphite is the rarest, most valuable and highest quality type of natural graphite. It occurs in veins along intrusive contacts and it is only commercially mined in Sri Lanka.

Graphite has metallic and nonmetallic properties, which make it suitable for many applications. The metallic properties include electrical and thermal conductivity. The nonmetallic properties include high thermal resistance, inertness and lubricity. The combination of conductivity and high thermal stability allows graphite to be used in many applications such as batteries, electrodes, fuel cells and refractories. Graphite's lubricity and thermal conductivity make it an excellent material for high-temperature applications because it provides effective lubrication at a friction interface while furnishing a thermally conductive matrix to remove heat from the same interface.

High-purity natural and synthetic graphite have played an important role in the emerging nonhydrocarbon energy sector and have been used in several new energy applications. In energy production applications, graphite is used as pebbles for modular nuclear reactors and in high-strength composites for wind, tide and wave turbines. In energy storage applications, graphite is used in bipolar plates for fuel cells and flow batteries, anodes for lithium-ion batteries, electrodes for supercapacitors, high-strength composites for fly wheels, phase-change heat storage and solar boilers. In energy management applications, graphite is used in high-performance polystyrene thermal insulation and for silicon chip heat dissipation. These new energy applications use value-added graphite products such as spherical graphite, expanded graphite and graphene.

Production

No natural graphite is mined in the United States, but four natural graphite projects were under development in 2022. Graphite One Inc. was developing the Graphite Creek project in Alaska, South Star Battery Metals Corp. was developing the BamaStar project in Alabama, and Westwater Resources Inc. was developing the Coosa project in Alabama. An additional project was under early development in Montana.

World production of natural graphite in 2022 was an estimated 1.30 Mt compared with 1.13 Mt in 2021. The leading producers of natural graphite in 2022 were China, 850 kt; Mozambique, 170 kt; Madagascar, 110 kt; and Brazil, 87 kt. These four countries contributed approximately 94 percent of the global natural graphite production.

Consumption

U.S. consumption of natural graphite increased by an estimated 62 percent to 72 kt in 2022 from 44.4 kt in 2021. The major uses of natural graphite in 2022 were batteries, brake linings, lubricants, powdered metals, refractory applications and steelmaking.

A recent and growing source of graphite consumption is that of lithium-ion batteries, owing to increased demand for electric vehicles (EV) and portable electronic devices. Graphite is an essential component of many types of batteries, making up the majority of the material contained in the anode. Spherical purified graphite (SPG) is the specialized form of graphite used as battery anode material. SPG is produced from natural flake graphite concentrate, which has been rounded, micronized, purified to 99.95 percent and coated. Most SPG is produced in China. Anode material can be made with natural or synthetic graphite. Some companies combine natural and synthetic to utilize the strengths of each, especially in the EV market.

Prices

Prices for natural graphite largely depend on flake size, size distribution and carbon content. Prices for individual flake mesh sizes were unavailable. The estimated unit values of imports in 2022 were $560/t for amorphous, $1,300/t for flake and $2,500/t for vein graphite from Sri Lanka. According to China customs data, prices for uncoated spherical graphite exported to the United States were about $4,500/t in 2022.

Foreign trade

U.S. trade data are from the U.S. Census Bureau and were analyzed by the U.S. Geological Survey (USGS). Total U.S. natural graphite imports increased by 68 percent in terms of tonnage to 89.1 kt in 2022 from 53.1 kt in 2021, and the value increased by 161 percent to $186 million in 2022 from $71.2 million in 2021. The increase in natural graphite imports resulted from substantial increases in quantity and in value of imports from China, which increased by 132 percent and 325 percent respectively. Principal import sources of natural graphite were China (50 percent), Mexico (14 percent), Madagascar (12 percent), and Canada and Mozambique (9 percent each).

In 2022, natural SPG imports increased by 525 percent in tonnage to 14.4 kt from 2.3 kt in 2021, and the value increased by 609 percent to $64.5 million compared with $9.1 million in 2021. All natural SPG was imported from China. SPG imports represented about 16 percent of the tonnage and about 35 percent of the value of all natural graphite imports in 2022.

Industry news

In 2022, two SPG facilities were under construction in the United States. Syrah Resources Ltd. was constructing a plant in Vidalia, LA, and Westwater Resources was constructing a plant in Kellyton, AL. Both projects were expected to begin commercial production during 2023-2024.

Three graphite projects were under construction globally in 2022, with production expected to begin in 2023. In Brazil, South Star began construction on the Santa Cruz graphite project, located in southern Bahia. Santa Cruz would be the first new graphite operation in the Americas since 1996. In Madagascar, NextSource Materials Inc. completed construction of the processing plant for the Molo graphite mine, with plant commissioning expected in 2023 followed by commercial production. In Tanzania, Walkabout Resources Ltd. continued to develop the Lindi Jumbo project. Construction began in 2021; the first of many projects moving forward in the country.

In February 2022, Volt Resources Ltd. halted graphite production in Ukraine, citing Russian military action. Operations recommenced in August, although future production was uncertain as the conflict continued. Additionally, the United States and many other countries have suspended normal trade relations with Russia, removing supplies of Russian graphite from much of the global market.

Outlook

Worldwide demand for natural and synthetic graphite is expected to continue increasing as more nonhydrocarbon energy applications that use graphite are developed. Steel production and other types of metallurgical activity, which are important consumers of graphite, are expected to increase as well. Global graphite consumption is expected to increase owing to new technologically advanced applications, such as aerospace applications, fuel cells, graphene, lithium-ion batteries, energy storage, pebble-bed nuclear reactors and solar power.

The lithium-ion battery industry has created high demand for natural flake graphite. This has led to large increases in exploration and development, with much of it being focused on Africa. Multiple projects globally are under consideration in Australia, Canada, Madagascar, Mozambique, Namibia and Tanzania.

GYPSUM

by R.D. Crangle, Jr., National Minerals Information Center, U.S. Geological Survey

Production

The United States was the world's leading producer and consumer of mined crude gypsum. Production of crude gypsum in the United States during 2022 was estimated to be 21 Mt, a slight decrease compared with 2021 production. The average price of mined crude gypsum was $12/t. Synthetic gypsum sales in 2022, most of which were generated as a flue-gas desulphurization product from coal-fired electric power plants, were estimated to be 13 Mt and priced at approximately $5/t. Forty-seven companies mined gypsum in the United States in 16 states. Crude gypsum exports from the United States totaled 38.8 kt. Imports were 6.89 Mt.

As a low-value, high-tonnage bulk commodity normally mined in openpit operations from deposits widely distributed throughout the world, gypsum tends to be consumed within the many countries where it is produced rather than exported. Less than 20 percent of the world's crude gypsum production was estimated to enter international trade. Only a few countries, such as Canada, Mexico, Spain and Thailand, were major crude gypsum exporters; of these, Canada and Mexico were significant exporters because of their large deposits in proximity to gypsum-consuming facilities in the United States.

World production of gypsum in 2022 was estimated to be 150 Mt, slightly less than that of 2021. The United States was the largest producer of natural gypsum in 2022 with an estimated 21 Mt, followed by Iran with an estimated 16 Mt, China with 13 Mt, Oman with 12 Mt, Spain with 11 Mt, and Thailand and Turkey, each with 9.3 Mt. Crude gypsum was thought to have been produced in 81 countries in 2022.

Consumption

An estimated 2.6 billion m^2 of gypsum-derived wallboard products were produced in 2022 domestically. Synthetic gypsum accounted for 40 percent of total domestic gypsum consumption. Demand for gypsum depends principally on the performance of the building construction industry, particularly in the United States, where about 60 percent of consumed gypsum is used for building plasters, the manufacture of portland cement, and wallboard products. Gypsum has no practical substitute in the manufacturing of portland cement.

Trade

World gypsum reserves are large in major producing countries, but data for many countries are not available. Domestic gypsum resources are adequate but unevenly distributed. Synthetic gypsum, most of which is byproduct from coal-fired power plants, coupled with substantial imports from Canada, augment U.S. domestic crude gypsum supplies for wallboard manufacturing in the United States, particularly in the eastern and southern coastal regions. Imports from Mexico supplement domestic supplies for wallboard manufacturing along portions of the U.S. Western Seaboard. Large gypsum deposits occur in the Great Lakes region, the midcontinent region and several Western states. Foreign resources are large and widely distributed; 81 countries are thought to produce gypsum.

Outlook

Approximately 700 kt of gypsum scrap that was generated by wallboard manufacturing, wallboard installation and building demolition was recycled. That quantity included an estimated 600 kt of preconsumer wallboard waste recycled by wallboard manufacturers coupled with an estimated 100 kt of post-consumer wallboard. Recycled gypsum was used primarily for agricultural purposes and as feedstock for the manufacture of new wallboard. Other markets for recycled gypsum include athletic field marking, cement production, as a stucco additive, grease absorption, sludge drying and water treatment.

The use of synthetic gypsum may continue to grow, albeit at a slower pace. As power companies convert coal-fired electric generation plants to natural gas to take advantage of an abundant and inexpensive supply of shale gas, the production of synthetic gypsum could further decline because fewer coal-fired power plants would be operating. Nevertheless, the use of synthetic gypsum by U.S. wallboard manufacturers is likely to continue. Similarly, should the economy continue to expand, and if residential and commercial construction continues to increase, gypsum consumption is also expected to increase in the near future.

INDUSTRIAL DIAMOND

by Donald W. Olson, National Minerals Information Center, U.S. Geological Survey

Production

World production of natural and synthetic industrial diamond was estimated to be about 15.4 billion carats in 2022, the vast majority of which was synthetic. Natural diamond resources have been identified in more than 35 countries; natural industrial diamond was produced in at least 12 countries and an estimated 46 million carats were produced in 2022. At least 15 countries have the technology to produce synthetic diamond, and synthetic industrial diamond was produced in 11 countries during 2022. About 99 percent of the combined natural and synthetic global output was produced in China, Ireland, Russia, South Africa and the United States. During 2022, China was the world's leading producer of synthetic industrial diamond followed by the United States and Russia. In 2022, the two U.S. synthetic producers, one in Pennsylvania and another with facilities in Florida and Ohio, produced an estimated 150 million carats, valued at about $48 million. This production was entirely synthetic diamond bort, dust and powder and grit. Also, in 2022, at least four U.S. firms manufactured polycrystalline diamond (PCD) from synthetic diamond dust and powder and grit. Data are not available for either domestic PCD producers or domestic chemical vapor deposition (CVD) diamond producers for quantity or value of annual production. Current trade and consumption quantity data are not available for PCD or for CVD diamond. Consequently, PCD and CVD diamond are not included in the industrial diamond quantitative data reported here.

The U.S. Geological Survey (USGS) estimated a total of 1.2 million carats of used industrial diamond, valued at about $510,000, was recycled in the United States during 2022. Of this total, an estimated 75,000 carats were recycled diamond stone with a value of $110,000 and the remainder was diamond bort, dust and powder, and grit. Diamond stone recycling operations have reduced in scale and number, owing to the lower price of newly produced synthetic industrial diamonds. Most of this recycled material was recovered from used drill bits, diamond tools and other diamond-containing wastes. Some diamond also was recovered from residues generated in the manufacture of PCD.

Since the mid-1980s, the use of CVD diamond has seen strong growth and has been increasingly accepted by multiple industries as an enhanced material of choice owing to its properties of exceptional strength, hardness, durability, stiffness, high thermal conductivity, chemical inertness and electrical isolation. Early applications for CVD diamond focused largely on thin- and thick-film PCD for cutting tools and dressing applications because of the mechanical properties of diamond. Newer applications that take advantage of CVD diamond's mechanical properties include wear parts, such as watch gears and chemical mechanical polishing pad conditioners. Diamond has tremendous potential for electronics applications because of its high thermal conductivity. It can significantly improve thermal management while remaining highly cost competitive with other materials. CVD diamond is used in microelectronic components, such as high-speed processors, medical devices, wide-bandgap radio frequency devices, power conversion devices, and optoelectronic devices (light-emitting diodes, laser diodes) that generate exceptionally high heat densities requiring innovative approaches to thermal management. Diamond coatings are increasingly being used in these applications because the thermal conductivity of diamond is 10 times that of silicon. Boron-doped diamond (BDD) electrodes for water treatment are attracting significant interest because of diamond's potential as an environmentally friendly, high-performance electrode material. BDD electrodes have many characteristics that make them ideal for eliminating organic contaminants from water.

Historically, diamond has been perceived as an expensive material, but advances in CVD diamond manufacturing, such as the development of microwave carbon plasma technology and the development of higher-throughput hot-filament CVD diamond reactors, have significantly reduced diamond costs and allowed for the use of CVD diamond for an increasing number of applications. In addition to the existing opportunities for synthetic diamond use as gemstones, research and development projects by several companies that use single-crystal CVD diamond materials in high-voltage power switches, lasers, quantum communications and computing, and water treatment and purification have been ongoing.

Industrial diamond also was used in medical applications such as bionic eye implants, bioimaging, biomarking, cancer treatments, and surgical tools; in dental applications such as cavity treatments; in cosmetic applications such as beauty treatments, facial exfoliation, wrinkle treatments; in glass shaping and window production; in military uses; in sound speakers; in super lasers and in many other applications.

Consumption

The United States remained one of the world's leading consumers of industrial diamond in 2022. Estimated U.S. apparent consumption of natural and synthetic industrial diamond bort, dust and powder, grit and stones was 390 million carats, valued at $69 million. Industrial diamond is used for applications such as truing and dressing grinding wheels, production of fine wire, waterjet nozzles for material cutting, direct precision cutting and material processing, material testing, drilling, grinding, polishing and finishing materials. The major consuming sectors of industrial diamond are computer chip production; construction; drilling for minerals, natural gas and oil; machinery manufacturing; stone cutting and polishing; and transportation (infrastructure and vehicles). Highway building, milling, and repair and stone cutting consumed most of the industrial diamond stone. During 2022, more than 95 percent of the industrial diamond market used synthetic industrial diamonds because the diamond quality can be controlled, and properties can be customized to fit specific requirements.

Prices

Both natural and synthetic industrial diamonds had prices with a range of values depending on their crystallinity, purity, shape, size and in the case of synthetic, the absence or presence of metal coatings. During 2022, the average unit value for diamond bort, dust and powder, and grit material produced in the United States was $0.32/carat. According to the U.S. Census Bureau, U.S. imports of all types of industrial diamond had an average unit value of $0.21/carat in 2022. These imports were a combination of natural and synthetic diamond stone that had an average unit value of $8.39/carat and natural and synthetic diamond bort, dust and powder, and grit that had an average unit value of $0.19/carat.

Foreign trade

During 2022, the United States led the world in industrial diamond trade. Trade data in this report are from the U.S. Census Bureau. U.S. imports of industrial-quality diamond stones (natural and synthetic) were about 786,000 carats valued at about $6.60 million from 20 countries or localities. U.S. imports of industrial-quality diamond dust, grit and powder (natural and synthetic) were about 300 million carats valued at about $56.4 million from 29 countries or localities. During 2022, U.S. exports of industrial diamond dust, grit and powder (natural and synthetic) were about 94 million carats valued at $47 million to 49 countries or localities.

Outlook

The United States is expected to continue to be one of the world's leading consumers of industrial diamond into the next decade and likely will remain a significant producer and exporter of synthetic industrial diamond as well. Demand for synthetic diamond grit and powder is expected to remain greater than that for natural diamond material. Constant-dollar prices of synthetic diamond products, including CVD diamond films, are expected to continue to decline as production technology becomes more cost effective; the decline is even more likely if competition from low-cost producers in China and Russia continues to increase.

It is expected that global natural industrial diamond production will decrease in the next few years as mines close and there is lower output as mines approach the ends of their mine lives. The world's largest diamond mines have matured and are past their peak production levels, and several of the largest diamond mines are expected to close by the end of 2025.

As these mines are depleted, global production is expected to continue to decline in quantity, and the global supply of crude natural diamond, which includes both gem-quality and industrial diamond, is forecasted to steadily decrease to about 120 million carats in 2030.

INDUSTRIAL GARNET

by Donald W. Olson, National Minerals Information Center, U.S. Geological Survey

Garnet's angular fractures, high hardness, specific gravity, chemical inertness and nontoxicity make nongemstone-grade garnet ideal for many industrial applications. In addition to those properties, garnet is free of crystalline silica and can be recycled. Garnet is the general name given to a group of complex silicate minerals, all with an isometric crystal structure and similar physical properties and chemical compositions. Higher-quality garnet is used as a loose grain abrasive because of its hardness, while lower-quality garnet is used as a filtration medium as it is relatively inert and resists chemical degradation. Garnet is also being used as a proppant in oil and natural gas well drilling. It may be mixed with other proppants when high temperatures are encountered or in very deep formations.

Production

In 2022, industrial garnet was mined by four firms — one in Idaho, one in Montana and two in New York. In 2022, U.S. production of crude garnet concentrate for industrial use (industrial garnet) was estimated by the U.S. Geological Survey (USGS) to be 76 kt valued at about $17 million, a 7 percent decrease in quantity compared with 2021 crude production. This decrease was due to the closing of the Emerald Creek Garnet Mine in Idaho in July 2022. The other U.S. garnet mines produced 3 percent less than in 2021. The majority of industrial garnet mined in the United States was almandite (iron aluminum silicate). Some andradite (calcium iron silicate) also was mined domestically for industrial uses. Refined garnet material sold or used was estimated to be 120 kt valued at $52 million, a 6 percent decrease in quantity compared with 2021 refined production.

Total world industrial garnet production was estimated to be about 980 kt, 6 percent more than that in 2021. Australia (370 kt), China (310 kt) and South Africa (150 kt) were the leading producers in 2022. The United States produced about 8 percent of the industrial garnet mined worldwide.

Consumption

In 2022, apparent consumption of industrial garnet in the United States was estimated to be 240 kt, accounting for 24 percent of global garnet production. U.S. apparent consumption increased by 17 percent compared with that in 2021.

Major end uses for industrial garnet in the United States, in descending order by estimated market share, include abrasive blasting, water-filtration media, water-jet-assisted cutting and other end uses, such as in abrasive powders, nonslip coatings and sandpaper. Domestically, the industrial sectors that consume industrial garnet include aircraft and motor vehicle manufacturers, ceramics and glass producers, electronic component manufacturers, water filtration plants, the petroleum industry, shipbuilders and wood-furniture-finishing operations.

Prices

The price of industrial garnet depends on application, quality, quantity purchased, source and type and therefore, prices encompass a wide range. During 2022, estimated domestic values of industrial garnet crude concentrate averaged about $200/t. The average unit values of refined garnet sold in the United States during the year averaged $595/t. The average customs unit value of U.S. garnet imports in 2022 was $194/t, a decrease of 31 percent compared with the average unit value in 2021.

Foreign trade

The industrial garnet market is very competitive. Lower-priced foreign imports slowly began displacing U.S. production in domestic markets during the 1990s. Since then, despite increasing domestic production in recent years, the United States has become increasingly dependent upon foreign sources of industrial garnet.

According to data from the U.S. Census Bureau that was adjusted by the USGS, U.S. imports in 2022 were estimated to be 268 kt, an increase of 85 percent from those in 2021. The increase was partially caused by the U.S. production shortfall owing to the closing of the Emerald Creek Garnet Mine in Idaho during 2022. Most of the increase was attributed to an increase in imports of garnet from South Africa.

In 2022, South Africa (65 percent), Australia (19 percent), India (8 percent) and China (7 percent), were the leading suppliers of imports to the United States. U.S. exports were estimated to be 23 kt, an increase of 14 percent compared with those in 2021. U.S. exports of industrial garnet were shipped to Canada (56 percent), Mexico (17 percent) and Peru (8 percent), with the remainder going to several other countries and localities.

Outlook

The domestic industrial garnet industry is expected to stabilize after the volatility of the past few years. However, higher production costs and tighter profit margins will continue to affect the industry. To increase profitability and remain competitive with imported material, production may be restricted to only high-grade industrial garnet ores or those deposits that contain other salable mineral products, such as kyanite, marble, mica minerals, sillimanite, staurolite, wollastonite or metallic ores.

Industrial garnet production in India, which is still recovering from the effects of the COVID-19 pandemic, is expected to slowly return to prepandemic levels. Worldwide, industrial garnet production is expected to slowly increase, with the highest growth in consumption in water-jet-assisted cutting and abrasive blasting.

IODINE

by Emily K. Schnebele, National Minerals Information Center, U.S. Geological Survey

Production

Chile was the world's leading producer of iodine, followed by Japan and the United States. In the United States, iodine was produced from brines by three companies operating in Oklahoma. U.S. production information in 2022 was withheld to avoid disclosing company proprietary data. World production in 2022, excluding the United States, was estimated to be 33 kt, slightly more than the 32.5 kt in 2021. Excluding production in the United States, Chile accounted for about two-thirds of world production in 2022.

Consumption

Worldwide, the leading uses of iodine and its compounds were X-ray contrast media, pharmaceuticals, liquid-crystal-display (LCD) screens, and iodophors, in descending order of quantity consumed. Other applications included animal feed, biocides, fluoride derivatives, food supplements and nylon. Crude iodine and inorganic iodine compounds were thought to account for more than 50 percent of domestic iodine consumption in 2022. U.S. reported consumption of iodine in 2022 was estimated to be 4 kt.

Foreign trade

In 2022, according to the U.S. Census Bureau, United States imports of crude iodine were 4.27 kt, a 4 percent increase from the 4.12 kt imported in 2021. The average unit value of crude iodine imports in 2022 was $45.81/kg, a 40 percent increase from $32.72/kg in 2021. Chile was the leading source of crude iodine imports into the United States, accounting for 88 percent of the total quantity imported, followed by Japan (nearly 12 percent).

Exports of crude iodine decreased by 11 percent to 1.13 kt compared with 1.28 kt in 2021. The primary recipients of U.S. exported crude iodine in 2022 were Germany (55 percent), Canada (18 percent) and India (16 percent). The average unit value of exported crude iodine in 2022 was $36.15/kg, a 44 percent increase from $25.15/kg in 2021.

Outlook

Future growth in iodine consumption will likely follow the market demand for medical applications and LCDs as these are the primary consuming markets of iodine and iodine derivatives.

KAOLIN

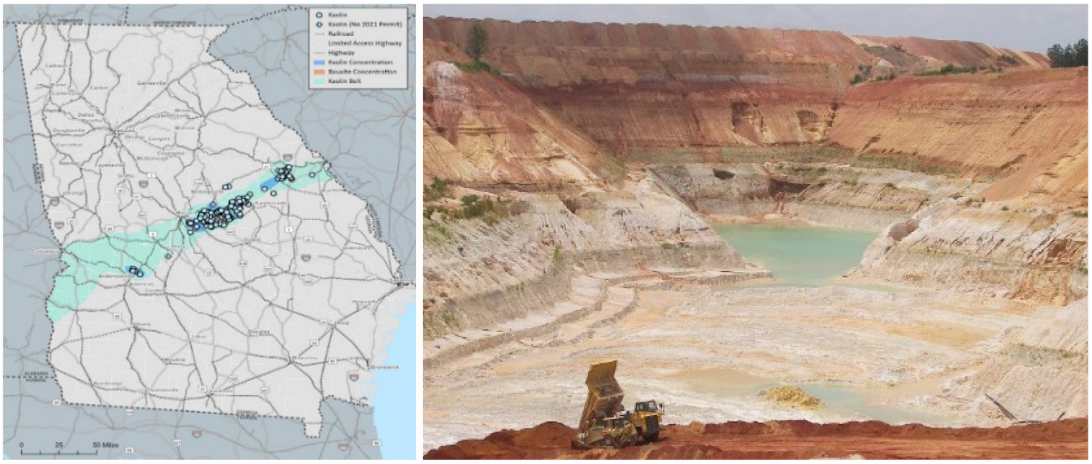
by Keith D. Gray, RESPEC, LLC

Background

The kaolin subgroup of layer silicate clay minerals includes halloysite, nacrite, dickite, kaolinite and odinite (Dana classification system). With the exception of odinite and halloysite, these industrially important minerals show the same chemical composition: $Al_2Si_2O_5(OH)_4$. Formed largely by the weathering of feldspar and muscovite (for example, alteration of granitic rocks), kaolin minerals are extremely common in sediments and soils of tropical and temperate regions. Kaolinite is used to manufacture a variety of brick, ceramic and cosmetic products, and as filler material in plastic, paint, rubber and paper. This and other kaolin minerals have played a prominent role in human cultural history, both in the United States and abroad. Kaolin mining has a long history in the Southeastern United States, particularly central Georgia (1897 to present), which according to its Washington county residents hosts the "kaolin capital of the world." Key producing countries outside of the United States include Uzbekistan, Ukraine, China, India, Germany and the Czech Republic. Global players in the market include BASF SE, Sibelco and Imerys SA.

Figure 1

Left: Kaolin belt through central Georgia. (Source: RESPEC, Georgia EPD) Right: Kaolin mine in Sandersville, GA. (Source: sandersvillega.org)



Production and consumption

Based on statistics released by the U.S. Geological Survey (2023 Mineral Commodity Summary), domestic clay production in 2022 was estimated at 26 Mt for a total market value of $1.7 billion, with approximately 120 companies operating mines in 38 states. Kaolin minerals accounted for about 4.6 kt, or about 17.7 percent of all clay materials recovered in the United States. One-half of the total kaolin produced (about 52 percent) went into development of coatings, fillers, extenders and binders, while about 25 percent was used in ceramic products. Large revenue generated by paper production has been attributed to continued economic and cultural impacts of the COVID-19 pandemic: for example, increasing consumer demand for packaging, such as for food deliveries.

Exports and imports

In 2022, the United States exported about 2.1 Mt of kaolin minerals to Mexico, China and Japan (listed in descending order of tonnage; USGS statistics). Compared to 2021, the total clay and shale exports decreased by 4 percent. This decline has been explained by a decrease in product exported to Belgium, India and Germany. By comparison, in 2022 only 0.17 Mt of kaolin was imported into the United States. In total, kaolin exports accounted for $53.5 million, and imports $903,000, resulting in a positive U.S. trade balance of $52.6 million.

Trends and outlook

Academic research showed that the annual global kaolin market was approximately $4.41 billion before the end of 2022 and is projected to reach $5.87 billion by 2030. According to the same study, growth is primarily driven by the rising demand for kaolin used in the paint, plastic, paper and ceramic industries. Its high silica and aluminum contents can be utilized in the production of paint, a cheaper alternative to titanium dioxide. More cost-effective and chemically inert kaolin pigment may also reduce environmental burdens. *References are available from the author.*

KYANITE, ANDALUSITE AND SILLIMANITE

by David W. Hawkins, Virginia Department of Energy, Geology and Mineral Resources Program

The sillimanite minerals group includes the naturally occurring polymorphic minerals kyanite, andalusite and sillimanite. These minerals share the same chemical composition (Al_2SiO_5) but have differences in their respective physical, thermodynamic and crystalline structure properties. The high alumina content (more than 60 percent Al_2O_3), thermal and volumetric stability of these minerals make them useful for refractory applications, metallurgy, investment casting molds, glass manufacturing and ceramics. Additionally, high-quality samples of these sillimanite minerals have a market for use as gemstones.

Geology and economic deposits

Kyanite, andalusite and sillimanite are accessory minerals in some high-grade metamorphic rocks. Kyanite forms under relatively high pressure and low to high temperature conditions, andalusite forms under relatively low pressure and low to moderate temperature conditions, and sillimanite forms under low to moderate pressure and high temperature conditions. Deposits may occur within thermally altered rocks associated with contact metamorphism, such as hornfels. Alumina enrichment of silica-rich metasedimentary and metavolcanic rocks via hydrothermal alteration is also a source of stratiform replacement deposits. Sillimanite may occur within mineralized quartz veins and pegmatites. Additionally, these minerals may occur as paleo and modern heavy mineral beach and stream placers.

Economic and subeconomic concentrations of kyanite, andalusite and sillimanite occur in the Appalachian regions of the Southeastern United States. Other known localities for occurrences include Alaska, California, Florida, Idaho, Nevada and New Mexico. Other economic occurrences outside of the United States include Australia, Brazil, Cameroon, Canada, China, Finland, France, India, Ireland, Kenya, Madagascar, Nigeria, Norway, Peru, Russia, South Africa, Spain, Ukraine and Zimbabwe.

Industrial properties and uses

The unique thermodynamic properties of these refractive minerals provide resistance to thermal shock and corrosion, and volumetric stability during high-heat intensive manufacturing processes. The sillimanite group minerals convert to mullite ($3Al_2O_3.2SiO_2$) and silica at temperatures ranging from 1,250 to 1,650 °C at predictable stable volumes. Pure mullite may have up to 72 percent Al_2O_3 content. Synthetic mullite has a melting point of about 1,840 °C, which contributes to highly resistant ceramic products. Up to 70 percent of mined sillimanite minerals are used in steel and iron manufacturing annually, so the production of iron and steel is a good proxy of mineral production trends at the global scale. Approximately 30 percent of these minerals are used to produce ceramics, glass, nonferrous metals and cement. Other refractory uses include insulating brick, firebrick, refractory concrete, kiln furniture, mortar and gunning mixes. Additional end products include brake shoes and pads, abrasive products, electrical insulators, additives and fillers. Kyanite has recently been used to filter aluminum slag and impurities during the production of aluminum cans.

Mineral production

Globally, the supply of sillimanite group minerals is primarily sourced from the United States, France, India, Peru and South Africa. Although refractory minerals are mined in other countries such as China, Australia, Madagascar and Nepal, production data are not readily available. Annual world production estimates reported by the U.S. Geological Survey (USGS) from 2017 to 2021 averaged approximately 357 kt. Global production in 2022 was estimated at 368 kt and included 160 kt of andalusite from South Africa, 86 kt of kyanite and calcined kyanite from the United States, 65 kt of andalusite from France, 42 kt of andalusite from Peru, and 15 kt of combined sillimanite and kyanite from India (not including reclassified beach deposits). The 2022 global production total is based on preliminary estimates by the USGS and production data from the Virginia Department of Energy's Mineral Mining Program. It represents an increase of approximately 3 percent over the previous five-year average (2017-2021), but production remained lower than 2021 levels.

Kyanite Mining Corp. (KMC), located in central Virginia, is the world's largest producer of industrial-grade kyanite and mullite under the trademark names Virginia Kyanite and Virginia Mullite, respectively. Ore deposits are extracted at KMC's Willis Mountain and East Ridge mine sites, located near Dillwyn, VA. The geology consists of kyanite quartzite associated with a sequence of interlayered felsic and mafic metavolcanic strata of Ordovician age. Each mine site is located on a resistant topographic ridge along opposing limbs of the Whispering Creek Anticline. KMC has operated surface mines and processing facilities since 1945 and produces and markets a range of milled kyanite and calcined kyanite (more than 55 percent Al_2O_3, less than 0.85 percent Fe_2O_3) products that are shipped mainly by truck to domestic customers and port facilities for delivery to international customers. Ore-grade material contains 10 to 40 percent kyanite, averaging about 25 percent.

In 2022, KMC reported production of approximately 86 kt of combined kyanite and mullite product. Annual production capacity at the Virginia operations is about 130 kt for commercial-grade kyanite concentrates and up to 39 kt for calcined kyanite per permit specifications and demand. In 2022, KMC received a statewide reclamation award given jointly by the Virginia Department of Energy's Mineral Mining Program and the Virginia Transportation Construction Alliance. The award acknowledges KMC's commitment to environmental stewardship and accomplishments in reclamation of the multiphased East Ridge Reclamation site, where refuse had been placed since 1993.

Resco Products Inc. (Piedmont Minerals Division) has mined andalusite from an andalusite-pyrophyllite ($AlSi_2O_5(OH)$)-sericite deposit to produce high-alumina firebrick and other specialty foundry and ceramic products in Hillsborough, NC. The mineral deposit formed in hydrothermally altered and structurally controlled andesitic to dacitic metavolcanic rocks that are part of the Proterozoic-age Carolina terrane.

Globally, France, South Africa and Peru produce the largest amount of industrial-grade andalusite. Imerys Group mines andalusite from the Brittany region of France at its Kerphalite Mine in Glomel. It is the leading producer of andalusite, with operations in France and South Africa. The source of the andalusite near Glomel, France is highly weathered Ordovician-age schists adjacent to granitic rocks of the Armorican Massif. Imerys Group mines andalusite from the Rhino Mine in the Limpopo Province in South Africa. Mineral deposits are hosted in highly weathered pelitic rocks of the Pretoria Group associated with contact metamorphic rocks of the Bushveld Igneous Complex. Production statistics for 2022 are not readily available for these mine sites. Andalusite Resources (Pty) Ltd. began mining operations in 2001 at the Maroelasfontein Mine, located near Thabazimbi, in the Limpopo Province, South Africa. Additional details have not been made available for the status of andalusite production for the company since 2019. Andalucita S.A. has been recovering andalusite since 2009 in northern Peru, with an estimated production capacity of 50 kt as of 2018.

India is the primary source for the global supply of sillimanite. The Indian Bureau of Mines has estimated total resources of more than 70.2 Mt of sillimanite, which includes about 6.5 to 7.2 Mt in the reserves category. Upward of 73 percent of the sillimanite resources occur in heavy mineral sand placers along India's modern beaches. Production statistics for sillimanite, kyanite and andalusite are not available for 2021 or 2022. The production estimate for 2019-2020 was 13.2 kt from three mines within the state of Maharashtra. Trimex Sands Pvt Limited carries out mining and mineral separation activities in the Srikurman deposit in Srikakulam, in the state of Andhra Pradesh, with capacity to produce 50 kt/a of sillimanite. Sillimanite is also mined in the states of Odisha and Kerala, in association with other heavy minerals. The Indian Bureau of Mines has estimated there is approximately 105 Mt of kyanite resources in the country, with medium- to high-grade deposits occurring at less than two percent of these resources. Between 2019 and 2020, kyanite production was reported at 3.5 kt from three operations within the states of Karnataka and Maharashtra. Andalusite production has not been reported since 1988.

Foreign trade and prices

Prices of imported and exported mineral commodities are dependent upon multiple factors that vary annually such as grade and purity, quantity, particle (mesh) size, packaging, monetary exchange ranges, source and destination. In 2022, the U.S. Census Bureau reported global exports of approximately 52 kt of kyanite and 26 kt of mullite. Kyanite was valued at $383/t, up from $369/t in 2021, and mullite was valued at $509/t, also an increase from $430/t in 2021. According to the U.S. Census Bureau, imports of sillimanite minerals to the United States were estimated at 7.6 kt in 2022, up from the previous year.

Trends and outlook

The market demand for sillimanite minerals is typically associated with the global steel manufacturing industry, as this industry predominantly utilizes refractory mineral products. The World Steel Association estimated that global steel production decreased approximately 4 percent from 2021 levels to 1,885 Mt for 2022. China produced the most steel in 2022 (1,018 Mt), equivalent to 54 percent of the global output. The United States was the fourth largest producer of steel in 2022 at 80.5 Mt, down 6 percent from the 2021 production level. Countries of the European Union produced 136.2 Mt of steel in 2022, down 11 percent from the 2021 level.

The decrease in steel production was likely influenced by multiple factors, including but not limited to, the ongoing Russia-Ukraine war, COVID-19 related restrictions, supply-chain disruptions, and increased inflation costs. In the United States, the push for vehicle electrification and increased manufacturing, increased urban development, and funds from the Infrastructure Investment and Jobs Act will likely bolster construction and improvement projects and result in a low to medium increase in demand for steel. Due to the Russia-Ukraine war, increased costs for raw materials and transportation, there remains uncertainty for significant growth in the refractory minerals market in Europe, while demand for these materials is likely to continue in North America, Asia and Africa. *Source citations available from the author on request.*

LIME

by L.E. Apodaca, National Minerals Information Center, U.S. Geological Survey

In 2022, all commercially produced lime in the United States was manufactured from limestone or dolomite, but lime also can be produced from a variety of similar carbonate materials, such as aragonite, chalk, coral, marble and seashells, if they are of high chemical purity. The term lime in this report refers to high-calcium and dolomitic quicklime, their hydroxide (hydrated) forms and dead-burned dolomite.

In the United States, most lime (about 80 percent) is produced as quicklime. Hydrated lime (also called slaked lime) is a dry calcium hydroxide powder made from reacting quicklime with a controlled amount of water in a hydrator. Slaked lime is widely used in aqueous systems as a low-cost alkali to neutralize or balance acidity. Dead-burned dolomite is the primary form of lime used in refractories.

Production and consumption

In 2022, an estimated 17 Mt of quicklime and hydrate were produced (excluding independent commercial hydrators), essentially unchanged from that in 2021. At year end, 28 companies were producing lime, which included 18 companies with commercial sales and 10 companies that produced lime strictly for internal use (for example, sugar companies). These companies had 73 primary lime plants (plants operating quicklime kilns) in 28 states and Puerto Rico. Five of these 28 companies operated only hydrating plants in nine states. In 2022, the five leading U.S. lime companies produced quicklime or hydrate in 22 states and accounted for about 79 percent of total U.S. lime production. Principal producing states were, in alphabetical order, Kentucky, Missouri, Ohio and Texas. The United States was the world's second-ranked lime producer in the world after China.

Apparent consumption at 17 Mt was estimated to be essentially unchanged from that in 2021. Major markets for lime were, in descending order of consumption, steelmaking, chemical and industrial applications (such as the manufacture of fertilizer, glass, paper and pulp, and precipitated calcium carbonate and in sugar refining), flue-gas treatment, construction, water treatment, and nonferrous-metal mining.

Foreign trade

Imports of lime increased by 10 percent to 354 kt in 2022 from 323 kt in 2021. Canada (79 percent) and Mexico (17 percent) were the leading sources of U.S. lime imports. U.S. lime exports decreased by 9 percent to 303 kt in 2022 from 335 kt in 2021. Lime exports were primarily shipped to Canada (96 percent).

Prices

The U.S. Geological Survey calculates unit values of lime products from the quantity and value data reported for lime sold or used by the lime producers on a free-on-board plant basis, including the cost of containers. These calculations provide average values that eliminate variables such as potentially significant differences between list prices and individual supply contracts. Lime prices are not published in trade publications.

To avoid disclosing company proprietary data, value data for dead-burned dolomite have not been reported separately but are included within the weighted average of all types of lime. The total weighted average price of all quicklime sold or used was $140/t and hydrate sold or used was $160/t in 2022, which was 5 percent higher and unchanged from those in 2021, respectively.

Outlook

Lime sales in markets such as chemical and industrial, construction and steel are expected to follow the trend in gross domestic product in the overall economy. The outlook for flue-gas systems (lime's second-ranked market) serving coal-fired power plants, incinerators and other industries is easier to predict. With the recent boom in natural-gas exploration, large increases in natural-gas reserves, and low natural-gas prices, U.S. electric utilities have increasingly shifted their fuel use from coal to natural gas either by conversion of the coal-fired plants or by shutting down coal-fired plants. Natural gas has the advantage of producing lower emissions than coal and, as a result, does not usually require SO_2 scrubbing, which could lead to decreased use of lime in flue-gas scrubbing systems.

In 2022, 20 percent of domestic utility-scale electricity generation was from coal, a 3 percent decrease from 2021, as a result of increased electricity generation from renewable sources.

LITHIUM

by B.W. Jaskula, National Minerals Information Center, U.S. Geological Survey

Production

Domestic lithium production data were withheld in 2022 to avoid disclosing company proprietary data. Albemarle Corp. produced lithium compounds from domestic brine resources near Silver Peak, NV. U.S. Magnesium LLC produced lithium carbonate from a stockpile of cell salt residue accumulated over the course of 50 years from the production of magnesium in Rowley, UT. Estimated world lithium production (excluding production in the United States) was about 130 kt of lithium content (690 kt lithium carbonate equivalent) recovered from minerals and brines, a 21 percent increase from that of 2021. Six mineral operations in Australia, one mineral tailings operation in Brazil, two brine operations each in Argentina and Chile, and three mineral and two brine operations in China accounted for the majority of world lithium production. Additionally, smaller operations in Brazil, Canada, China, Portugal, the United States and Zimbabwe also contributed to world lithium production. Australia increased its spodumene concentrate production by about 10 percent in 2022 and remained the world's leading lithium producer. Chile increased its brine-sourced lithium production by about 38 percent in 2022 and was the world's second leading lithium producer. Owing to the rapid increase in demand and prices of lithium in 2022, established lithium operations worldwide have increased, or are in the process of increasing, production capacity.

Consumption

World lithium consumption was about 134 kt of lithium contained in minerals and compounds, a 41 percent increase from that of 2021, owing to strong demand from the lithium-ion battery market. Estimated U.S. consumption was about 3 kt of lithium contained in minerals and compounds, rounded to one significant digit to avoid disclosing company proprietary data. The United States was a leading producer of higher-value downstream lithium products such as butyllithium and lithium metal.

Estimated global distribution for lithium used in 2022 was batteries, 80 percent; ceramics and glass, 7 percent; lubricating greases, 4 percent; continuous casting mold flux powders, 2 percent; air treatment, 1 percent; medical, 1 percent; and other uses, 5 percent. Lithium's important properties include low density, high specific heat, low coefficient of thermal expansion, high electrochemical potential and excellent thermal conductivity.

Price

Spot lithium carbonate prices in China increased from approximately $35,000/t at the beginning of the year to about $70,000/t at year end owing to increased worldwide demand. For large-fixed contracts, Benchmark Mineral Intelligence Ltd. reported an annual average-nominal, battery-grade lithium carbonate price of $37,000/t in 2022, almost three times higher than that in 2021.

Foreign trade

According to the U.S. Census Bureau, U.S. imports of lithium compounds in 2022 were 17.5 kt (gross weight), a 23 percent increase compared with those of 2021. Import sources of lithium chemicals were Chile (53 percent), Argentina (44 percent) and others (3 percent). Exports of lithium compounds from the United States were 15.7 kt, an increase of 32 percent from those of 2021. About 83 percent of all U.S. exports of lithium compounds went to the top five countries: Japan (40 percent), Canada (14 percent), Germany (12 percent), China (9 percent) and Poland (8 percent).

Government programs

Funded through $1.6 billion from the 2022 U.S. Bipartisan Infrastructure Law, 12 lithium-based projects were selected by the U.S. Department of Energy to support new commercial-scale domestic facilities to extract and process lithium, manufacture battery components, recycle batteries and develop new technologies to increase U.S. lithium reserves.

Outlook

Lithium-ion batteries have rapidly gained importance because of their extensive use in portable electronic devices, portable electric tools, electric scooters and bicycles, hybrid-electric vehicles (HEVs), plug-in hybrid-electric vehicles (PHEVs), electric vehicles (EVs), and grid storage applications. Increased use of lithium-ion batteries in HEVs, PHEVs and EVs in the past several years have created high demand for lithium chemicals.

Lithium supply security has become a top priority for technology companies in Asia, Europe and North America. Strategic alliances and joint ventures among technology companies and exploration companies continued to be established to ensure a reliable, diversified supply of lithium for battery suppliers and vehicle manufacturers. Brine-based lithium sources were in various stages of development or exploration in Argentina, Bolivia, Chile, China and the United States; mineral-based lithium sources were in various stages of development or exploration in Australia, Austria, Brazil, Canada, China, Congo (Kinshasa), Czechia, Ethiopia, Finland, Germany, Ghana, Kazakhstan, Mali, Namibia, Nigeria, Peru, Portugal, Russia, Serbia, Spain, Thailand, the United States and Zimbabwe; and lithium-clay sources were in various stages of development or exploration in Mexico and the United States.

MAGNESIUM COMPOUNDS

by Adam M. Merrill, National Minerals Information Center, U.S. Geological Survey

Production

In 2022, the estimated domestic production of magnesium compounds was 450 kt magnesium oxide equivalent, 4 percent more than that in 2021. Seawater and natural brines accounted for about 67 percent of U.S. magnesium compound production in 2022. The value of U.S. production of all types of magnesium compounds was estimated to be $460 million. In 2022, world mine production of magnesite, excluding U.S. production, was estimated to be 27 Mt magnesium oxide equivalent, 5 percent less than that in 2021. China was the world's leading producer of magnesite, accounting for 63 percent of the estimated world total, followed by Australia (10 percent), Turkey (7 percent) and Brazil (6 percent).

Consumption and end uses

In 2022, the estimated apparent consumption of magnesium compounds in the United States was 950 kt, 5 percent less than that in 2021. About 75 percent of the magnesium compounds consumed in the United States were used in agricultural, chemical, construction, deicing, environmental and industrial applications in the form of caustic-calcined magnesia, magnesium chloride, magnesium hydroxide and magnesium sulfates. The remaining was used for refractories in the form of dead-burned magnesia, fused magnesia and olivine.

The primary end use of dead-burned magnesia and fused magnesia was for refractory products; however, fused magnesia has not been produced in the United States since 2013. Caustic-calcined magnesia is mainly used in agriculture for feed supplements and fertilizer; to produce magnesium hydroxide; and in environmental applications, such as wastewater treatment. Magnesium hydroxide is primarily used for water treatment, fire-retardant additives and the production of magnesium-based chemicals. Magnesium chloride's chief uses are deicing, dust control, drilling fluids and environmental applications.

Foreign trade

According to the U.S. Census Bureau, imports of dead-burned and fused magnesia in 2022 were 238 kt, 11 percent less than those in 2021. The leading sources of U.S. imports were China including Hong Kong (77 percent) and Brazil (12 percent). The annual average import unit value for dead-burned and fused magnesia was $800/t in 2022, 39 percent more than that in 2021. Exports of dead-burned and fused magnesia in 2022 were 8 kt, slightly more than those in 2021. The annual average export unit value (free alongside ship [f.a.s.]) for dead-burned and fused magnesia in 2022 was $1,066/t, 5 percent more than that in 2021.

Imports of caustic-calcined magnesia in 2022 were 284 kt, 14 percent more than those in 2021. The leading source of U.S. imports were China including Hong Kong (75 percent) and Canada (19 percent). The annual average import unit value for caustic-calcined magnesia in 2022 was $361/t, essentially unchanged from that in 2021. Exports of caustic-calcined magnesia in 2022 were 61 kt, 81 percent more than those of 2021. The annual average export unit value (f.a.s.) for caustic-calcined magnesia in 2022 was $948/t, 6 percent more than that in 2021.

Imports of magnesium hydroxide in 2022 were 13 kt, 3 percent more than those in 2021. The leading source of U.S. imports were Mexico (57 percent), the Netherlands (15 percent) and Israel (14 percent). The annual average import unit value for magnesium hydroxide in 2022 was $1,993/t, 20 percent more than that in 2021. Exports of magnesium hydroxide in 2022 were 15 kt, 11 percent less than those in 2021. The annual average export unit value (f.a.s.) for magnesium hydroxide in 2022 was $1,141/t, 23 percent more than that in 2021.

Imports of magnesium chloride in 2022 were 57 kt, 39 percent less than those in 2021. The leading sources of U.S. imports were Israel (51 percent), the Netherlands (25 percent) and Austria (9 percent). The annual average import unit value for magnesium chloride in 2022 was $458/t, 43 percent more than that in 2021. Exports of magnesium chloride in 2022 were 15 kt, 24 percent more than those in 2021. The annual average export unit value (f.a.s.) for magnesium chloride in 2022 was $595/t, 16 percent less than that in 2021.

Outlook

Consumption of dead-burned and fused magnesia is expected to closely follow trends in the steel industry. Owing to high inflation and interest rates, the World Steel Association short-term outlook anticipates world steel demand to increase by 1 percent in 2023, while increasing by 1.6 percent in the United States. For all magnesium compounds, consumption is expected to follow the general growth trend of the agricultural, construction and manufacturing industries. The International Monetary Fund projects that the global economic output will increase by 2.7 percent in 2023, while increasing 1 percent in the United States.

MICA

by S.M. Jasinski, National Minerals Information Center, U.S. Geological Survey

Mica has several unique physical properties. The crystalline structure of mica forms layers that can be split or delaminated into thin sheets. These sheets are chemically inert, dielectric, elastic, flexible, hydrophilic, insulating, lightweight, platy, reflective, refractive, resilient and range in opacity from transparent to opaque. Mica is stable when exposed to electricity, light, moisture and extreme temperatures. The mica group represents 37 phyllosilicate minerals that have a layered or platy texture. The commercially important micas are muscovite and phlogopite, which are used in a variety of applications. Muscovite is the principal mica used by the electrical industry to make mica-based capacitors that can operate in environments with temperatures and (or) frequencies that are too high for polypropylene capacitors. Phlogopite mica is used in plastic composites for automotive applications because of its dimensional stability, increased stiffness and improved heat distortion temperature.

Production

In 2022, U.S. mine production of scrap and flake mica was an estimated 42 kt, which was a 3 percent increase from that in 2021. Production of ground mica was an estimated 67 kt compared with 66.8 kt in 2021. Mica was mined in Georgia, North Carolina and South Dakota. Scrap mica was recovered primarily from mica and sericite schist and as a byproduct from feldspar, industrial sand beneficiation and kaolin. Ground mica was produced from domestic and imported scrap and flake mica. In 2022, world production of scrap and flake mica was estimated to have increased to 390 kt from 384 kt in 2021. China (100 kt), Madagascar (65 kt), Finland (60 kt) and the United States (42 kt) were the leading producers. Information on the world production of sheet mica was unavailable in 2022, but India (1 kt) was thought to be the leading producer.

Consumption

Domestic consumption of all forms of scrap and flake mica was estimated to have been 60 kt, unchanged from that in 2021. Consumption of sheet mica was estimated to have decreased to 3.3 kt in 2022 from 3.35 kt in 2021, owing to an increase in exports.

The leading domestic use of ground mica was in joint compound for filling and finishing seams and blemishes in gypsum wallboard (drywall). The mica acts as a filler and extender, provides smooth consistency, improves the workability of the compound and provides resistance to cracking.

The second-ranked use of ground mica was as an additive to drilling muds by the oil and natural-gas well drilling industry. Coarsely ground mica flakes help prevent the loss of circulation by sealing porous sections of the drill hole. Mica was used in paint, where ground mica is used as a pigment extender that also facilitates suspension, reduces chalking, prevents shrinking and shearing of the paint film, increases resistance of the paint film to water penetration and weathering, and brightens the tone of colored pigments.

The plastics industry used ground mica as an extender and filler, especially in parts for automobiles as lightweight insulation to suppress sound and vibration. Other significant uses for ground mica are in the rubber industry as an inert filler and mold release compound. As a surface coating in the production of rolled roofing and asphalt shingles, mica prevents the sticking of adjacent surfaces. Mica was used in decorative coatings on wallpaper, concrete, stucco and tile surfaces. Ground phlogopite mica was used in automotive brake linings and clutch plates to reduce noise and vibration (asbestos substitute). Wet-ground mica, which retains the brilliancy of its cleavage faces, is used primarily in pearlescent paints by the automotive industry. In the cosmetics industry, its reflective and refractive properties make mica an important ingredient in blushes, eyeliner, eyeshadow, foundation, hair and body glitter, lip gloss, lipstick, mascara, moisturizing lotions and nail polish. Mica is added to latex balloons to provide a colored shiny surface.

Sheet mica was used principally in the electronics and electrical industries. Its usefulness in these applications is derived from its unique electrical and thermal insulating properties and its mechanical properties, which allow it to be cut, punched, stamped and machined to close tolerances.

Prices

In 2022, the average unit value of scrap and flake mica produced in the United States, which included high-quality sericite, was estimated to be $100/t. The average unit value of dry-ground mica was estimated to be $300/t, and the average unit value of wet-ground mica was estimated to be $340/t. Sheet mica prices vary with grade and can range from less than $1/kg for low-quality mica to more than $2,000/kg for the highest quality. The estimated average unit value of mica splittings consumed in the United States in 2022 was $1.80/kg.

Foreign trade

According to the U.S. Census Bureau, U.S. imports and exports of scrap and flake mica were 22.6 kt and 4.75 kt, respectively, in 2022. Imports of scrap and flake mica decreased by 6 percent and exports decreased slightly, compared with those in 2021. In 2022, Canada (36 percent), China (34 percent) and India (12 percent) supplied most U.S. imports of scrap and flake mica, with the remainder from several other countries. Most exports of scrap and flake mica went to Mexico (24 percent), Canada (19 percent) and Brazil (13 percent).

In 2022, U.S. imports and exports of sheet mica were 4,300 kt and 803 t. respectively. Imports of sheet mica increased by 8 percent and exports increased by 27 percent compared with those in 2021. In 2022, China (79 percent), Brazil (6 percent), and India (5 percent) supplied most U.S. imports of sheet mica, with the remainder from several other countries. Most U.S. exports of sheet mica went to Mexico (33 percent), Austria (13 percent), and Canada (10 percent).

Outlook

The major markets for ground mica — drywall joint compounds and paints — are mature and relatively stable, with growth tied to housing construction and interest rates. Demand is also affected by automobile production because interior and exterior parts typically contain dry-ground mica or engineered mica composites, and exterior surfaces may be painted with wet-ground pearlescent pigments and mica-containing coatings.

Demand for ground mica in smaller specialty markets such as coated micas, cosmetics, nylon and polyester resins and polypropylene composites is expected to have an annual growth rate slightly higher than that of the entire ground mica industry.

Consumption of block mica is expected to increase slowly as demand increases in a few specialty markets, such as electronics. A shortage of domestic high-quality block mica is expected to continue because of the generally low percentage of high-quality mica in deposits currently being mined, mostly from pegmatites. Future supplies of all forms of mica are expected to come increasingly from imports, primarily from Brazil, Canada, China and India.

NITROGEN

by L.E. Apodaca, National Minerals Information Center, U.S. Geological Survey

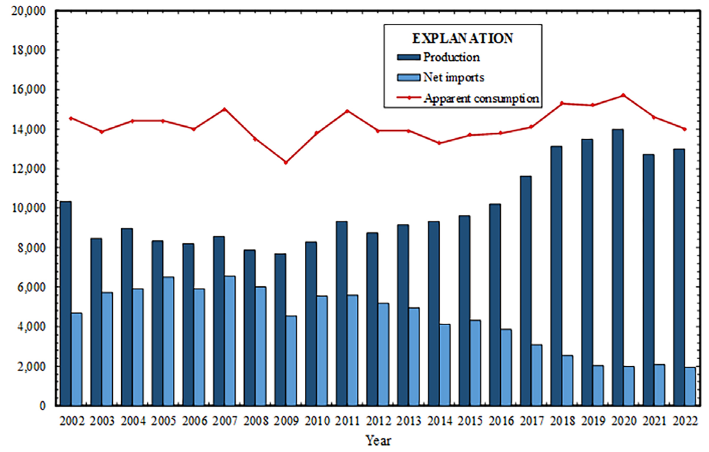
According to U.S. Geological Survey publications, ammonia was produced domestically by 16 companies at 35 plants in 16 states during 2022. About 60 percent of total U.S. ammonia production capacity was based in Louisiana, Oklahoma and Texas because of those states' large reserves of natural gas, the dominant domestic feedstock for ammonia production.

Production and consumption

U.S. production was estimated to be 13 Mt of nitrogen (N) content in 2022, a slight increase from that in 2021. In 2022, U.S. producers operated at about 86 percent of their rated capacity (excluding plants that were idle for the entire year). Apparent consumption was estimated to have decreased by 4 percent to 14 Mt of N content in 2022 from 14.6 Mt of N content in 2021. The United States was the world's third-ranked ammonia producer after China and Russia and the world's second-ranked consumer after China. Urea, ammonium nitrate, nitric acid, ammonium phosphates and ammonium sulfate were the major derivatives of ammonia produced in the

Figure 1

U.S. supply and apparent consumption of ammonia, 2002–2022 (Kelly T.D. and Matos).



United States, in descending order of tonnage.

Approximately 88 percent of domestic ammonia apparent consumption was for fertilizer use, including anhydrous ammonia for direct application, urea, ammonium nitrates, ammonium phosphates and other nitrogen compounds. Ammonia also was used to produce explosives, plastics, synthetic fibers and resins and numerous other chemical compounds.

Foreign trade

According to the U.S. Census Bureau, imports of ammonia by N content decreased by 7 percent to 1.93 Mt in 2022 from 2.08 Mt in 2021. Trinidad and Tobago (51 percent) and Canada (47 percent) were the leading sources of U.S. ammonia imports. U.S. ammonia exports increased by three times to 699 kt by N content in 2022 from 231 kt in 2021. Ammonia exports were primarily shipped to Norway (25 percent) and Morocco (24 percent).

Prices

U.S. Gulf Coast ammonia prices in 2022 averaged $1,068/st, 85 percent higher than the average in 2021. The Gulf Coast ammonia price was $1,030/st at the beginning of 2022, increased to a high of 1,475/st in late March through mid-April and then decreased to $935/st by year end.

Natural gas is often used as the feedstock to produce ammonia fertilizers, and the cost of natural gas can account for 70 to 90 percent of the production costs. The Henry Hub spot natural-gas price ranged between $3.45 and $9.85/million Btu for most of the year, with an average of $6.45/million Btu. The U.S. Department of Energy, Energy Information Administration projected that Henry Hub natural-gas spot prices will average $6.00/million Btu in 2023.

Outlook

A long period of stable and low natural-gas prices in the United States has made it economical for companies to upgrade existing ammonia plants and plan for the construction of new nitrogen projects. The additional capacity has reduced ammonia imports but likely will not eliminate nitrogen imports (Fig. 1). Expansion in the ammonia industry took place in the United States throughout the past five years; however, no additional U.S. ammonia capacity increases have been announced. In the next four years global capacity additions are expected in Africa, eastern Europe and south Asia. As part of the capacity increase, several decarbonized ammonia projects are being proposed. Demand for ammonia is expected to increase by 1 percent per year depending on the availability and cost, with the largest increase in demand expected in Latin America.

According to 10-year projections (2022–2032) by the U.S. Department of Agriculture, plantings for the eight major field crops (barley, corn, oats, rice, sorghum, soybeans, upland cotton and wheat) in the United States are expected to remain at about 100 Mha. Corn, soybeans and wheat are expected to account for about 90 percent of acreage utilization for the eight crops. Corn production accounts for about one-half of U.S. fertilizer use and planting fewer crops affects the demand for nitrogen fertilizers. Overall U.S. corn acreage is expected to remain about the same through the projected period. Corn yields are expected to remain high, with corn being used more for feed and residual use than for ethanol.

PEAT

by A.S. Brioche, National Minerals Information Center, U.S. Geological Survey

Peat is a natural organic material of botanical origin. Peatlands are situated predominately in shallow wetland areas of the Northern Hemisphere. Commercial deposits are formed from the gradual accumulation of plant matter that is partially decomposed under anaerobic conditions. In 2022, peat was known to be harvested in 11 conterminous states, with Florida, Michigan and Minnesota the leading producing states. Although peat has been produced in Alaska, the current status of operations is not known because the Alaska Department of Natural Resources, Division of Geological & Geophysical Surveys discontinued its survey of peat producers in Alaska.

Production and foreign trade

In 2022, domestic production of peat, excluding Alaska, was an estimated 340 kt, compared with the revised 324 kt in 2021. According to the U.S. Census Bureau, imports decreased by 12 percent to 1,440 kt in 2022 compared with 1,630 kt in 2021, and exports increased by 12 percent to 42 kt from 37 kt in 2021. U.S. apparent consumption for 2022 decreased by 14 percent to 1,700 kt compared with 1,970 kt in 2021 (Fig. 1). World production was an estimated 20 Mt in 2022. Reed-sedge peat comprised approximately 87 percent of the reported production in the United States, followed by sphagnum moss with 10 percent.

More than 80 percent of all peat used in the United States was imported from Canada, which has extensive deposits of high-quality sphagnum moss. Deposits of sphagnum moss in the United States occur primarily in the northern states, with active operations in Maine, Michigan, Minnesota, Montana, Pennsylvania and Washington. The permitting procedures for new peat operations have become increasingly time consuming and expensive, causing some companies to abandon harvesting and reducing the number of new fens and bogs brought into production. In addition, extensive areas of peatlands are in protected wetlands, parks or other natural areas that restrict commercial development.

Consumption

Demand for peat generally follows that of horticultural applications. Potting soil mixes and general soil improvement were the leading domestic end-use categories, accounting for about 90 percent of domestic peat sales. Sphagnum moss is preferred for custom soil mixes and for sale to retail consumers because of its more fibrous composition. More decomposed types of peat, such as reed-sedge or humus, are used primarily in bulk by commercial landscapers and on golf courses.

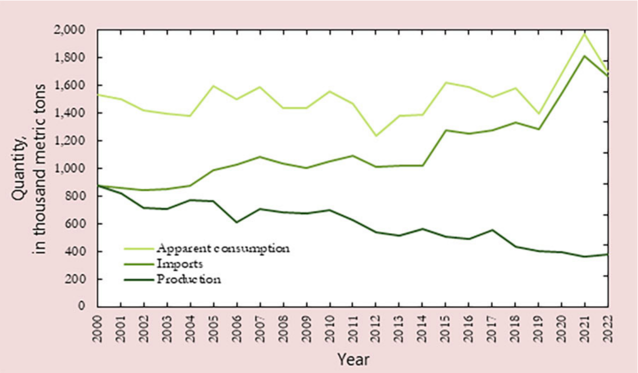
In the industrial sector, peat was used as an oil absorbent and as an efficient filtration medium for the removal of waterborne contaminants in mine waste streams, municipal storm drainage and septic systems. Data for the end-use distribution of peat imported from Canada were unavailable, but the imported peat was sold both in bulk for soil blending and packaged for direct horticultural use. Packaged peat, regardless of origin, commanded a higher price than bulk sales.

International events, trends and issues

Finland, Germany, Sweden, Latvia, Belarus and Canada were the world's top six leading peat producers, in descending order of production, based on estimated 2022 world production. Climate change concerns have prompted several countries to plan

Figure 1

U.S. production, imports and apparent consumption of peat, 2000–2022.



to decrease or eliminate the use of peat, owing to peatland's ability to act as a carbon sink.

Finland continued to make strides to reach its goal of becoming carbon neutral by 2035. To achieve this, peat production was to be phased out in favor of other forms of noncarbon energy. In 2022, only about 14 percent of Finland's energy consumption was supplied by peat and other fossil fuels. Restoration of peatlands in several European countries, including Belarus, Ireland and Sweden, were being planned or implemented to help combat greenhouse gas emissions and restore wildlife habitats. In August 2022, the United Kingdom announced a ban on peat sales to amateur gardeners by 2024 in an effort to protect peatlands. These initiatives were expected to decrease peat production across Europe in the future.

Outlook

Peatlands also are used for agriculture, forestry, recreation and wildlife management. Factors such as the growing interest in gardening, golf-course development, and landscaping related to residential use indicate that peat usage is likely to remain near current levels for the next several years. However, producers in the United States face increasing competition from imports of peat from Canada and alternative soil amendments, such as composted organic waste, coir (coconut fiber) and wood byproducts (for example, wood fiber and composted bark). The availability of alternative soil amendments as substitutes for peat will determine the future use of peat in different parts of the world. Peat production is expected to decrease across Europe during the coming years as peatland restoration efforts and use of alternative fuel sources increase.

PERLITE

by Kristi J. Simmons, National Minerals Information Center, U.S. Geological Survey

Perlite is an amorphous siliceous volcanic glass that contains between 2 and 5 percent water. Light gray to black in color, perlite is found worldwide and is most often mined using openpit methods. When perlite ore is rapidly heated to about 900 °C, the contained water converts to steam and the ore expands up to 20 times its original volume. The resulting material, which is lightweight and bright white, has many properties suited for multiple industrial applications.

Production

In 2022, domestic processed crude perlite sold and used was estimated to be 520 kt valued at $34 million compared with 496 kt valued at $31.7 million in 2021. The average unit value of processed crude perlite sold and used by U.S. operations in 2022 was $66/t, a 3 percent increase from $64/t in 2021. Crude ore production was from nine mines operated by six companies in six western states (Arizona, California, Idaho, Nevada, New Mexico and Oregon). New Mexico continued to be the leading producing state. Processed crude perlite was expanded at 51 plants in 27 states. World production of perlite was estimated to be 4.3 Mt, an increase from 4.15 Mt in 2021.

Consumption

The low-density and porous-structure attributes of expanded perlite, as well as its durability, fire resistance, inertness, low acoustical and thermal conductivity and water-retention capacity make it useful for a range of applications. In 2022, construction-related uses, such as concrete aggregate, formed products and masonry- and cavity-fill insulation remained the leading markets for expanded perlite with 44 percent of total sales and use. Perlite has been increasingly used by commercial growers and hobby gardeners for horticultural uses, accounting for 19 percent of perlite use in 2022. Other uses are fillers (15 percent), filter aides (14 percent) and other (8 percent). Domestic apparent consumption, defined as processed crude perlite sold or used by producers plus imports minus exports, increased in 2022 to an estimated 720 kt from 640 kt in 2021.

Substitutes

Substitutes for perlite are dependent on the application. In construction uses, diatomite, expanded clay and shale, pumice and slag can be substituted for perlite. For horticultural uses, coco coir, pumice, vermiculite and wood pulp are alternative soil additives and are sometimes used in conjunction with perlite.

Foreign trade

Trade data for perlite are not collected as a separate category by the U.S. Census Bureau but are included within the group “vermiculite, perlite and chlorites, unexpanded.” An estimated 240 kt of perlite valued at $35 million was imported into the United States during 2022 compared with 170 kt valued at $21 million in 2021. The estimated average unit value of imported perlite in 2022 was $150/t, compared with $120/t in 2021. Most imports originated from Greece (91 percent) while smaller quantities also came from China (7 percent). The remainder of imported perlite originated from Australia, Mexico and Turkey. In 2022, exports of perlite were estimated to have decreased to 22 kt valued at $3.4 million compared with 27 kt valued at $4.3 million. The estimated average unit value of exported perlite was unchanged from 2021 at $160/t in 2022. An estimated 94 percent of exports were shipped to Canada.

International

In 2022, global production of perlite was estimated to have increased by 4 percent to 4.3 Mt from 4.15 Mt in 2021. China (1.5 Mt) continued to be the leading perlite producing country, followed by Turkey (1.1 Mt), Greece (710 kt) and the United States (520 kt).

Outlook

While demand for perlite is expected to continue, growth is related to the strength of the construction and horticulture markets. Difficulty in obtaining vermiculite has caused at least one horticulture company to substitute perlite for vermiculite in their products. Increased substitution by additional companies may also influence the perlite market. New and innovative uses continue to be developed due to the numerous characteristics of perlite.

PHOSPHATE ROCK

by T.M. “Mike” Gurr, Gurr Professional Services, Inc. and Stephanie Gurr, The Vertex Companies

U.S. marketable phosphate rock production for the 2022 crop year (July 1, 2021 to June 30, 2022) showed a decrease to 20.7 Mt from the 2021 crop year production of 22.4 Mt, as reported to the U.S. Department of the Interior by the mining companies operating in the United States during crop year 2021. Domestic consumption decreased in the 2022 crop year to 23.7 Mt, compared with the 24.4 Mt consumed in crop year 2021. U. S. imports of phosphate rock decreased to 2.42 Mt for the 2022 crop year from the 2.54 Mt for crop year 2021. Imports of phosphate rock were from Peru and Morocco. There was a decrease of 0.8 Mt in producers’ stocks from 10.9 Mt in crop year 2021 to 10.1 Mt in crop year 2022 (Table 1).

For calendar year 2022, phosphate ore was mined by nine mines in four states, for an estimated 21

Table 1

Phosphate rock production.

Crop year (July 1-June 30)						
	Production (marketable, beneficiated)				Consumption	
Crop year	Phosphate rock tonnage²	% BPL	Value (f.o.b. mine)¹	Ending stocks tonnage²	Tonnage²	Value¹
2012	28.8	63.1	$98.36	5.6	31.3	$100.51
2013	31.9	62.6	$99.58	7.14	30.9	$95.51
2014	28	62	$80.97	7.94	30.4	$80.97
2015	26.1	61.3	$72.41	6.87	28.4	$72.94
2016	26.2	61.3	$76.90	9.34	27.7	$83.78
2017	27.9	60.4	$75.45	7.45	27.2	$77.55
2018	25.7	65.6	$74.61	10.3	28.3	$74.30
2019	23.3	61.1	$69.00	10.6	26.5	$68.90
2020	24.0	60.6	$70.76	10.3	25.9	$70.00
2021	22.4	60.0	$81.00	10.9	24.4	$81.00
2022	20.7	60.0	$89.00	10.1	23.7	$87.00

¹ Price (U.S. dollars per metric ton), ² million metric tons, ᵉ estimated. (Source: Stephen M. Jasinski, USGS Minerals Industry Surveys)

Mt of marketable product. Florida and North Carolina phosphate rock production accounted for 75 percent of the total U.S. production, with the balance produced in the western states of Idaho and Utah. The Florida and North Carolina percentage of U.S. production is declining. The United States is responsible for less than 10 percent of the world production of 220 Mt for calendar year 2022 (Table 2).

In calendar year 2022, U.S. phosphate production decreased slightly by 0.6 Mt; in addition, companies decreased stocks of phosphate rock by 0.7 Mt. The domestic production for the calendar year 2022 of 21 Mt represents 67 percent of the domestic production capacity of 31.1 Mt.

U. S. production and consumption of phosphate rock were lower in 2022 due to slightly lower production of phosphoric acid and elemental phosphorus. Adverse weather conditions and damage related to these weather conditions in areas of the United States, including a major hurricane during planting season, resulted in lower domestic consumption.

In 2022, supply disruptions, including the conflict between Russia and Ukraine, as well as China's new restrictions on exports of diammonium phosphate (DAP) and monoammonium phosphate (MAP) impacted the world production of phosphate rock and fertilizer. China has revised the phosphate rock production to only report production from large mines, which totals 90 Mt to 85 Mt as compared to earlier reported annual production at 140 Mt. Morocco's production has increased to 40 Mt in calendar year 2022, which is approximately 19 percent of the world's production (Table 2). While other countries increased exports, they were unable to compensate for the loss to the world market by China and Russia. Figure 1 displays the U.S. proportion of world phosphate production from 1900 through present day.

Imports/exports

There were no reported U.S. exports of phosphate rock in crop year 2022, nor have there been any reported exports of phosphate rock since crop year 2004. U.S. producers continue to prefer to export the higher-value fertilizer products, such as MAP, DAP and triple super phosphate (TSP), in preference to phosphate rock. Approximately half of the MAP, DAP and TSP produced in calendar year 2022 were exported.

Imports of phosphate rock in calendar 2022 were estimated by the U.S. Geological Survey (USGS) at 2.4 Mt, compared with 2021 imports of 2.46 Mt. Imports were from Morocco (5 percent) and Peru (85 percent).

Uses

The manufacturing of fertilizers and the production of animal feed supplements account for more than 95 percent of phosphate rock consumption. The remainder of phosphate rock was used to produce elemental phosphorus, defluorinated phosphate rock or was used for direct application to the soil. Major fertilizers include DAP, MAP and TSP. The balance is used in a variety of products, such as vitamins, pharmaceuticals, soft drinks, toothpaste, flame retardants, glass, photographic film and other consumer goods. Continued growth of the world population and the need for dependable food supplies underscore the need for phosphate fertilizers.

Synthetic eqivalents

There is no natural or synthetic substitute for phosphorus, which is essential for life in all growing things, plants and animals alike. There currently is no economical alternative to phosphate rock as the major source of phosphorus.

Prices

The calendar year 2022 average price at the mine was reported at $90/Mt, which is 6.9 percent higher than the calendar year 2021 average price of $83.10/Mt. The value of the imported phosphate in calendar year 2022 of $136/Mt also increased from $84.80/Mt in the prior calendar year.

The world capacity to produce phosphate rock is

Table 2

World phosphate production, and U.S. position.

Calendar year	Tons[1, 2]				Percentage	
	World	China	Morocco[3]	United States	United States	Morocco[3]
2012	217.0	95.3	28.0	30.1	13.87	12.90
2013	225.0	108.0	26.4	31.2	13.87	11.73
2014	218.0	100.0	30.0	25.3	11.61	13.76
2015	241.0	120.0	29.0	27.4	11.37	12.03
2016	255.0	135.0	26.9	27.1	10.63	10.55
2017	263.0	144.0	27.0	27.9	10.61	10.27
2018	267.7	140.0	33.0	25.7	9.6	12.33
2019	240.0	110.0	36.0	23.3	9.70	15.00
2020	233.0	90.0	37.0	23.5	10.54	16.59
2021	226.0	90.0	38.1	21.6	10.00	18.51
2022	220.0	85.0	40.0	21.0	10.00	19.05

[1] Estimate for 2022, [2] million metric tons, [3] includes Western Sahara. (Source: Stephen M. Jasinski, USGS Mineral Commodity Summaries, Phosphate Rock and Marketable Phosphate Rock in January 2023)

expected to continue to increase as a result of many other phosphate mine expansion projects. Active exploration and feasibility studies of the potential for development of phosphate deposits worldwide are ongoing.

Morocco. Morocco phosphate rock prices at 70 percent BPL increased from $173/Mt in January 2022 to a high of $320/Mt during July through September 2022, closing in December 2022 at $300/Mt.

Fertilizers. DAP spot prices, U.S. Gulf granular, free on board (f.o.b.), increased from $699.38/Mt in January 2022 to a high of $954/Mt in April, closing in December 2022 at $625/Mt. TSP increased from $674.38/Mt in January 2022 to a high of $856/Mt in April, closing in December 2022 at $584.38/Mt.

Industry news

There are currently two phosphate rock producers mining in Florida, one in the Central District (Mosaic) and one in the North District (Nutrien, Ltd). There is one producer in North Carolina: Nutrien Ltd. Mosaic's phosphate operating earnings were $1.3 billion in 2022, up from $1.2 billion in 2021, despite Hurricane Ian's impacts to Mosaic facilities, affecting production and shipments. Higher prices offset lower production and sales, and production has returned to normal rates as of February 2023. Mosaic anticipates a recovery in demand for fertilizers in 2023 due to strong agricultural commodity pricing trends. Nutrien's phosphate earnings were $7.7 billion in 2022, up from $3.2 billion despite a reduction in sales volumes, due to a significant increase in fertilizer prices.

In Idaho and Utah, there are currently three producers: Bayer (which acquired Monsanto); Itafos, a Brazilian operation (which acquired Nutrien); and J. R. Simplot. All the producers are developing/permitting replacement mines for mines nearing exhaustion of reserves. The new mines will generally be located near existing facilities. Southeast Idaho has the largest, most complex nonenergy leasable minerals program in the Forest Service and Bureau of Land Management (BLM). BLM is the leading agency for administering and approving phosphate mining. These openpit phosphate mines are responsible for approximately 22 percent of domestic production and four percent of world production.

China has transitioned from the largest importer of phosphate to the largest exporter of phosphate. China is reported to be ahead of the United States in exports of all phosphate products except MAP. In addition, China is the largest exporter of P_2O_5 products in the world. However, in 2022 China exports were reported to be less than in prior years.

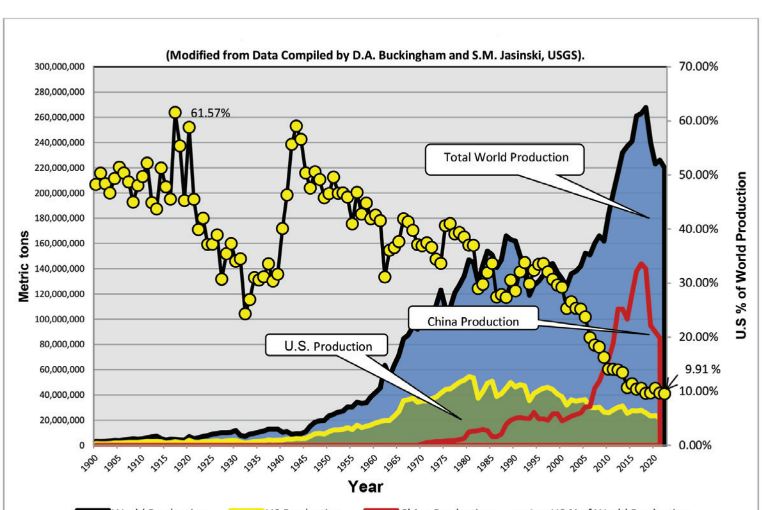
Saudi Arabia's Ma'aden's phosphate mine is currently producing up to 5 Mt/a of concentrated phosphate rock from the Beneficiation Plant. Peru is also producing 5 Mt/a.

Environmental, regulatory and reclamation issues

Mosaic has continued to mine the newly permitted

Figure 1

U.S. proportion of world phosphate production.



extension reserves of the Wingate East Mine, the South Pasture Mine extension, the Ona Mine, and the newly permitted South Ft. Meade Eastern Extension Mine. The future Desoto Mine, which was denied mining permits by the local county commission, has the Florida Department of Environmental Protection mining permits, but the Army Corps of Engineers application was withdrawn, and public information workshops are still being held at the county level prior to any future county commission hearings. Mosaic is preparing the permit applications to further extend the South Fort Meade Eastern Reserves approximately 6,000 acres further east in Hardee County. Permits are estimated to be submitted in 2023.

Because of the difficulties of permitting and declining reserves in Florida, there are numerous permitting activities ongoing in the western states.

Exploration activities on western phosphate lands have been extensive over the past few years. The permitting activities include extensions of existing phosphate mines, expansions of existing mines, or new phosphate mines.

The BLM issued a record of decision for the J.R. Simplot Dairy Syncline Mine in April 2020 and the J.R. Simplot East Smokey Canyon Mine in July 2020. In July 2020 the BLM Salt Lake and the U.S. Department of Agriculture Forest Service approved the new Falcon Isle Resources Inc. Diamond Fork Phosphate Mine, Spanish Fork, UT. The mine will produce phosphate for direct application to soil for organic farming. The BLM is currently processing the application for the Itafos Husky 1/North Dry Ridge Mine.

Trends and outlook

Domestic production and consumption were lower in 2022 due to adverse weather conditions causing facility damage and shipping delays during planting season. However, higher prices offset the decrease in production. Repairs have been completed on facilities, and production has returned to normal rates.

POTASH

by S.M. Jasinski, National Minerals Information Center, U.S. Geological Survey

Potash encompasses a variety of mined and manufactured salts, all of which contain the element potassium in water-soluble form.

The term potash, however, also can refer specifically to potassic fertilizers, which are potassium chloride (KCl, or the mineral sylvite), potassium sulfate (K_2SO_4, or sulfate of potash (SOP), usually a manufactured product) and SOPM ($K_2SO_4{\cdot}2MgSO_4$, or langbeinite or double sulfate of potash magnesia). Muriate of potash (MOP) for fertilizer use is an agriculturally acceptable mix of KCl (95 percent pure or greater) and sodium chloride (halite) that includes minor amounts of other nontoxic minerals from the mined ore and is neither the crude ore sylvinite nor pure sylvite. Because the potassium content of its common salts varies, the potash industry has established a common standard of measurement for defining a product's potassium content (or purity) related to the approximate potassium oxide (K_2O) content.

Production

U.S. potash production was estimated to be 440 kt of K_2O in 2022, 8 percent lower than that in 2021. World production was estimated to be 40 Mt of K_2O, 14 percent lower than that of 2021. Canada (16 Mt), China (6 Mt), Russia (5 Mt) and Belarus (3 Mt) were the leading producers, accounting for 75 percent of total production.

In the United States, MOP was produced by Intrepid Potash Inc. from solar evaporation and solution mines in New Mexico and Utah. Mosaic Co. and Intrepid each produced SOPM from underground mines in New Mexico. Compass Minerals International Inc. produced SOP from solar evaporation of brine from the Great Salt Lake in Utah. SOPM and SOP accounted for the majority of U.S. production in 2022.

The world potash market experienced uncertainty of supply in the first half of the 2022 as potash exports from Belarus and Russia were reduced owing to economic sanctions on both countries. In January, the government of Lithuania, citing national security concerns, canceled the rail transport contract that allowed the state-run producer in Belarus, JSC Belaruskali, to ship potash from the port of Klaipeda on the Baltic Sea, its only marine export facility. This followed the enactment of economic sanctions on Belarus in 2021 by the European Union (EU) and the United States, which banned the import of potash. Belaruskali was the third leading potash supplier prior to 2022, shipping more than 6 Mt/a of K_2O equivalent. Some Belarus potash was shipped by rail through Russia to China and other countries in the region and from a Russian port later in the year, but exports and production of potash from Belarus were significantly lower in 2022.

Following Russian troops entering Ukraine in February 2022, the EU, the United States and other countries placed economic sanctions on Russia. Fertilizer products, including potash, were exempt; however, the EU placed import quotas on potash from Russia. The United States' sanctions on certain Russian companies, financial institutions and individuals limited the amount of potash that could be imported.

Russia responded by suspending fertilizer exports to countries that it deemed unfriendly. Russia continued exports to China, India and some countries in Africa and South America, but in 2022, its exports were estimated to have been about 30 percent lower and production was estimated to have been 45 percent lower compared with those in 2021.

The effects of the economic sanctions on Belarus and Russia initially resulted in higher prices and supply disruptions. The higher prices caused many farmers worldwide to delay potash purchases, which led to growing stocks and lower prices in the second half of the year. As a result of the reduction in world supplies of potash from Eastern Europe, producers in Canada announced production increases that would be phased in over the next year of more than 600 kt of K_2O equivalent.

Consumption

U.S. potash consumption was estimated to have decreased by 26 percent to 5,100 kt of K_2O compared with 6,900 kt of K_2O in 2021, owing to poor weather in some areas in the spring planting season and higher prices.

According to a report from the International Fertilizer Association, world consumption of potash fertilizers in 2022 was estimated to have decreased to 37.5 Mt from 41.4 Mt in 2021, because of supply disruptions and high prices. Asia and South America were the leading consuming regions.

Because it is a source of soluble potassium, about 90 percent of potash consumed globally is used as fertilizer (plant nutrient). Potassium is one of the three primary nutrients required for plant growth and maturation; the others are fixed nitrogen and soluble phosphorus. The remaining 10 percent of potash consumed is used to produce potassium chemicals, which are used in such applications as aluminum recycling, animal feed supplements, oil-well drilling mud, snow and ice melting, soap manufacturing, steel heat-treating, and water softening.

Trade

According to the U.S. Census Bureau, U.S. imports of potash decreased by 23 percent to 4.97 Mt of K_2O in 2022, compared with 6.48 Mt of K_2O in 2021, owing to decreased consumption of potash fertilizer. The United States was 91 percent net import reliant for potash in 2022. Canada (80 percent), Russia (11 percent), and Israel (4 percent) were the leading suppliers.

The United States is not a significant exporter of potash. In 2022, exports increased to 267 kt of K_2O from 112 kt of K_2O in 2021, owing to an increase in shipments of high-value potassium chloride.

Prices

The North American price of potash increased substantially owing to tighter world supply after Belarus was forced to stop shipping potash and Russian exports were limited by trade restrictions. The Vancouver, British Columbia, Canada spot price for standard potash began the year averaging $263/t ($290/t) and ended the year at $533/t ($587/st). The U.S. price for SOP began 2022 in the range of $800/st to $830/st and ended the year in the range of $900/st to $1,055/st. The U.S. price for SOPM, fob Carlsbad, NM, began the year in the range of $445/st to $505/st and ended the year in the range of $480/st to $540/st.

Industry developments

A new potash mine was in the development stage in Osceola County, MI. The proposed solution mine would have an initial production capacity of 650 kt/a of MOP and was planned to increase to 1 Mt/a of MOP. The company planned to start production in 2025.

Canada is the leading potash-producing country in the world, with 38 percent of global capacity. All production in Canada was from Saskatchewan in 2022. Potash was produced by three companies: Nutrien Ltd., which controls 24 percent of world MOP capacity at six mines; Mosaic, which operated three mines; and K+S Aktiengesellschaft, which operated one mine. Total production in Canada was estimated to be 16.0 Mt K_2O in 2022, up from 14.2 Mt K_2O in 2021.

Outlook

Potash is an essential fertilizer nutrient for which no substitute exists. Growing world population and its need for food will require continued increases in potash production and consumption. Additionally, increased ethanol production from corn and other crops will require proportional increases in fertilizer use.

World annual potash production capacity was projected to increase to about 67 Mt in 2025 from 64 Mt in 2022. Most of the increase would be MOP from new mines and expansion projects in Belarus, Canada and Russia. However, the development of new mines in Belarus and Russia may be affected by economic sanctions on both countries. Production capacity in Canada was planned to increase by more than 3 Mt/a of K_2O equivalent by 2025. New SOP mines were planned in Australia and Eritrea, and a polyhalite mine in the United Kingdom would also contribute to the capacity growth. New MOP mines in Brazil, Canada, Ethiopia, Morocco, Spain and the United States were planned to begin operation beyond 2025. Production in other exporting countries was planned to increase as well. The conflict between Russia and Ukraine may limit exports of Russian potash over the next several years, leading to a shift in world potash supply patterns.

PUMICE

by R.D. Crangle, Jr., National Minerals Information Center, U.S. Geological Survey

Pumice is an extrusive igneous volcanic rock formed through the cooling of air-pocketed lava, which results in a highly porous, low-density rock. The low density allows some pumice to float on water. Large pumice rafts, consisting in some instances of thousands of individual pieces of pumice clumped together, are a unique geologic phenomenon and have been documented to be as long as 30 km and to have drifted for several years in oceanic waters. Pumicite is defined as grains, flakes, threads and (or) shards of volcanic glass finer than 4 mm in diameter. Pumicite and volcanic ash are descriptive terms that are often used interchangeably. The porous, lightweight properties of pumice are well suited for its main use as an aggregate in lightweight building blocks and assorted building products.

Production and price

According to U.S. Geological Survey publications, mine production of pumice in the United States during 2022 was estimated to be 510 kt, which was essentially unchanged from that of 2021. The unit value of pumice was estimated to be $50/t in 2022, 9 percent higher than that of 2021. Production occurred at 10 operations in California, Idaho, Kansas, New Mexico and Oregon. According to the U.S. Census Bureau, U.S. pumice exports totaled about 13.9 kt. Imports were higher at 1.03 Mt.

World resources of pumice are adequate for the foreseeable future. However, transportation costs may encourage development of deposits closer to markets. Total world production of pumice was estimated to be 15 Mt in 2022. Pumice is used more extensively as a building material outside the United States, which explains the large global production of pumice relative to that of the United States. The top world producers in 2022 were, in descending order of production, Turkey (5.4 Mt), Uganda (1.1 Mt), Greece (960 kt), Algeria (900 kt), Jordan (900 kt) and Ecuador (800 kt).

Processing and consumption

Pumice is usually extracted by simple openpit methods using rippers, bulldozers and front-end loaders. Processing typically is limited to drying, crushing and screening, although some abrasive grades may require fine grinding and classification. Lightweight pumice building blocks, the primary use for pumice, may be sawn into a variety of shapes and sizes. In 2022, other major applications included abrasives and horticulture (including landscaping). Minor applications include the use of pumice as an absorbent, as a concrete aggregate and admixture, as a filter aid, and as a traction enhancer for tires. A small percentage of pumice was used in abrasive-type products, including pencil erasers, polishing agents for circuit boards and television monitors, tooth-filing mechanisms for chinchillas, exfoliants in cosmetics and the removal of henna tattoos, and a variety of heavy-duty hand cleaners. Imports were primarily used as raw material for building block (for example, cinderblock) and other lightweight aggregate applications. Several substitutes exist for pumice in agriculture, in horticulture, as an aggregate, as a concrete additive, and in other end products.

Outlook

Although pumice and pumicite are plentiful in the western United States, legal challenges and public land designations could limit access to known deposits. Pumice and pumicite production is sensitive to mining and transportation costs. An increase in fuel prices would likely lead to increases in production expenditures; imports and competing materials could become attractive substitutes for domestic products.

RARE EARTH ELEMENTS

by Himesh Patel, McClelland Laboratories Inc.

Rare earth elements (REEs), also referred to as rare-earth oxides (REOs) are 17 elements primarily recovered from a handful of minerals. These minerals are bastnaesite (or bastnäsite), loparite, lateritic ion adsorption clays, monazite and xenotime. In 2022, rare earth elements were mined and processed at the Mountain Pass mine, in California. Bastnaesite was the mine's primary product, from a Precambrian carbonatite deposit.

REEs have applications across a wide range of industries and products. Products with REE components include cell phones, magnetic resonance imaging (MRI) scanners, and nuclear control rods. Wind turbines can include up to 60 kg of dysprosium and 372 kg of neodymium. Hybrid and electric-vehicle (EV) batteries can include up to 11.3 kg of various REEs. REEs are also used in crude oil refining, as polishing compounds, glass additives, and ceramics. Permanent magnets developed from REEs are used in an array of medical devices like pacemakers, insulin pumps and sleep-apnea machines. Additional applications include technology and equipment utilized by the U.S, Department of Defense such as Terfenol-D used in stealth technology, precision-guided munitions, radar systems, satellites and avionics.

Production and reserves

The global production of REOs continued an upward trend in 2022. Figure 1 shows that U.S.

Figure 1

Rare earth production worldwide.

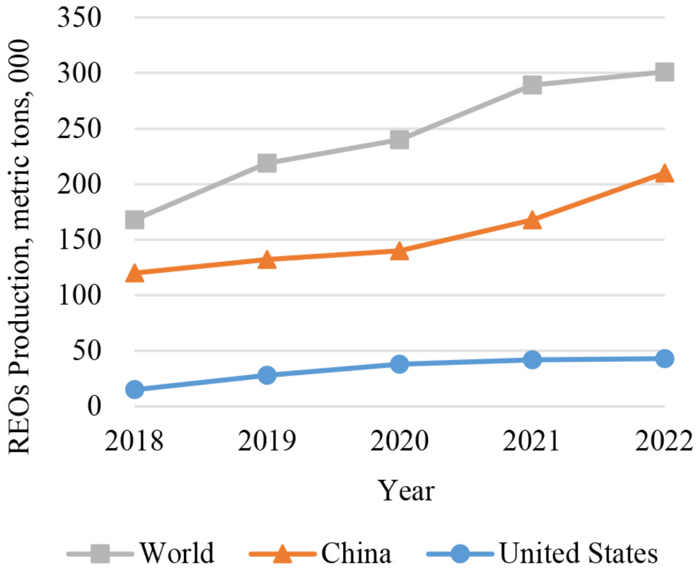
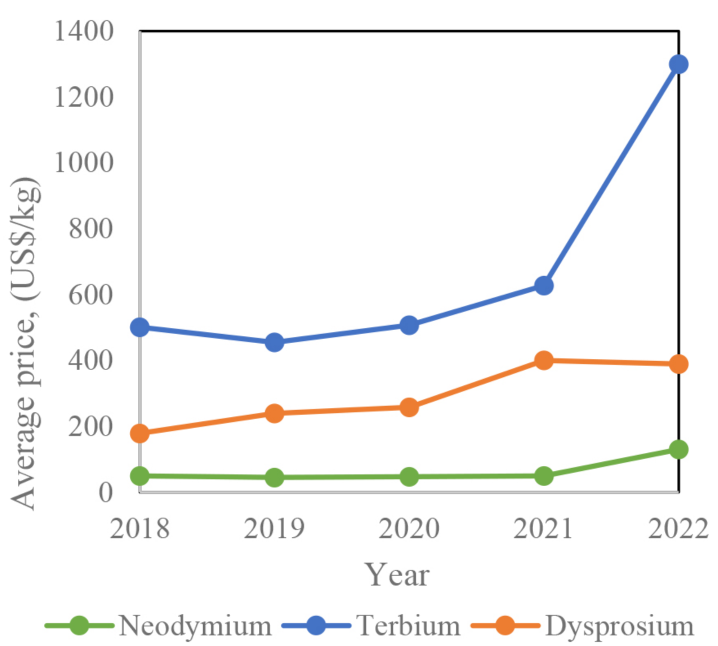


Figure 2

Neodymium, terbium and dysprosium prices, 2018-2022.



production has increased over the past few years from 15 kt to 43 kt of REOs in 2022. China remains the largest producer, producing 210 kt of REOs in the previous year. This is approximately 70 percent of the total world production of REOs. Over the past five years, the total contribution from China has decreased from 80 percent to 70 percent because of a significant increase in REO production by other countries.

Table 1 shows the statistics on REO production and minable reserves. Countries like China, Vietnam, Russia and Brazil have the world's largest reserves of REOs. In North America, reserves are estimated to be 1.8 Mt in the United States and about 0.8 Mt in Canada.

Imports, exports and apparent consumption

Imports, exports and apparent consumption of rare earth compounds and metals increased domestically from 2021. The United States imported approximately 11.9 kt in the form of either compounds or metals. China was the primary import source at approximately 74 percent. The primary U.S. exports of ores, compounds and metals were approximately 45.7 kt, up 10 kt from 2021. Apparent consumption, defined as production plus imports less exports, increased approximately 35 percent, a significant increase in the last seven years. The United States was more than 95 percent net import reliant as a percentage of apparent consumption of compounds and metals.

Prices and economics

In 2022, most REO prices stayed steady. The average estimated prices for cerium, europium, lanthanum and mischmetal did not change significantly. As shown in Fig. 2, the prices of neodymium, terbium and dysprosium oxides increased significantly in the past few years. Neodymium prices were stable at around $50/kg for a few years but increased to $130/kg in the last year. Terbium prices continuously increased, and the average price reached $1,300/kg. The average price of dysprosium reached $390/kg.

The trade balance between the United States and the rest of the world in REOs, compounds and metals stood at $200 million (net imports) in 2022, representing a 25 percent increase from $160 million in 2021.

Resources and recycling

REEs are not as rare as their name suggests, and they are generally found to be relatively abundant in the Earth's crust.

However, mineable and recoverable quantities are less common than for most other mineral commodities. Rare earth resources are generally categorized as alkaline, carbonatites, igneous systems, ion-adsorption clay deposits, and monazite-xenotime-bearing placer deposits. Light REEs are mostly recovered from carbonatites and placer deposits. Ion-adsorption clays are the major source of heavy REEs. Recycling is expected to increase in the future, driven by government regulation and economics. There are few substitutes for rare earth oxides for their various applications, those substitutes generally are considered less effective when used.

Trends and outlook

Supply-chain issues continue to act as a barrier to market growth. However, with growing demand from emerging economies, advances in green technology, and increasing aerospace applications, the REE market compound annual growth rate is projected to increase by 4 percent over the next five years. China is projected to remain the top producer, occupying more than half of the market, and as a consequence making the global REE market sensitive to the health of its manufacturing sector.

Demand for magnets seems to be disproportionally higher than other REE applications. A vast majority of automakers use neodymium-incorporated permanent magnet motors, with increased use projected for 2023. Increased demand and large investments in medical equipment across the Asia-Pacific region, the Middle East and Africa are projected to drive magnet growth and, by extension, REE use.

Table 1

Global mine production and reserves in metric tons.

	2021	2022	Reserves
Australia	22,000	18,000	4,000,000
Brazil	500	80	21,000,000
Burundi	100	NA	NA
China	168,000	210,000	44,000,000
India	2,900	2,900	6,900,000
Madagascar	6,800	960	NA
Myanmar	35,000	12,000	NA
Russia	2,600	2,600	21,000,000
Thailand	8,200	7,100	NA
United States	42,000	43,000	1,800,000
Vietnam	400	4,300	22,000,000
Other countries	60	80	280,000

SALT

by Cody Vining and Peter Christensen, RESPEC

Salt remains the most cost-effective material on the market for maintaining full mobility on roads and highways and preventing accidents during the winter snow season.

This mineral is also the most useful component in regenerating the ion exchange resins that are used for water conditioning, is critical in the production of animal feed products and is the most ubiquitous ingredient used in the food industry. The method used to obtain salt varies depending on the end benefit, with salt being derived from rock salt, salt in brine, vacuum pan salt and solar salt.

For 2022, the total apparent U.S. salt consumption (that is, domestic sold or used minus exports plus imports) is an estimated 59 Mt. Compared to previous years, the estimated 2022 apparent consumption of salt is similar to 2021 (59 Mt), greater than 2020 (53 Mt) but less than 2018 and 2019, both of which had an apparent consumption greater than 61 Mt. The source of the consumed salt for 2022 was rock salt (43 percent), salt in brine (40 percent), vacuum pan salt (9 percent) and solar salt (8 percent).

Domestic annual salt production in the United States differs from year to year and was approximately 42 Mt in 2022, which is similar to the 2021 domestic salt production (42 Mt) and is in line with the five-year and 10-year averages of approximately 42.7 Mt/a. At the beginning of 2022, 64 salt-producing plants existed in 16 states with approximately 94 percent of the total production coming from Kansas, Louisiana, Michigan, New York, Ohio, Texas and Utah.

Most of the domestic production (98.3 percent) was consumed within the United States in 2022 with only a small amount (0.7 Mt) of the total domestic production being exported. The estimated 2022 exports are less than the five-year average for exports, which has been approximately 1 Mt/a. To meet the 2022 demand, the United States imported an estimated 18 Mt of salt (30.4 percent of total apparent consumption). Historically, these imports have originated from Chile (29 percent), Canada (28 percent), Mexico (13 percent), and Egypt (11 percent) with the remaining imports (19 percent) coming from several other producing countries.

The total value of the United States' salt sales in 2022 was estimated to be $3.5 billion. The average price of vacuum pan salt in 2022 was $230/t, which is a modest price increase over the past five years from $200/t in 2017. The average price of solar salt has also modestly increased in the past five years from $100/t in 2017 to $130/t in 2022. The average price for rock salt in 2021 was $60/t; it has been fairly stable over the past five years, ranging between a high of $61/t (2018) and a low of $55/t (2017), while the price of salt in brine has also remained fairly consistent with historical trends at about $9/t.

Total world production in 2022 is estimated at 294 Mt. China remains the world's largest salt producer at approximately 64 Mt, while India and the United States (the world's second and third largest producers, respectively) produced an estimated 45 Mt and 42 Mt in 2022, respectively. Over the past two years, India has increased production by 150 percent from an estimated 29 Mt in 2020. These three countries combined account for 51 percent of the total world production, while 19 other countries collectively produce a total of approximately 143 Mt (49 percent of the total world production).

The U.S. Geological Survey (USGS) expects the demand for salt in brine that is used in the chloralkali industry to continue to increase in 2023 as demand for caustic soda and polyvinyl chloride increases globally, especially in Asia.

Table 1

World production of salt, estimated.

Country	Production (thousand metric tonnes)	
	2021	2022
China	64,000	64,000
India	45,000	45,000
United States	42,000	42,000
Germany	15,000	15,000
Australia	12,200	13,000
Canada	11,800	11,000
Mexico	9,000	9,000
Chile	8,570	9,000
Brazil	7,400	7,400
Turkey	6,900	6,900
Netherlands	6,120	6,200
Russia	6,500	6,000
France	5,400	5,500
Spain	4,200	4,200
Poland	4,000	4,000
Pakistan	3,000	3,300
United Kingdom	2,400	2,800
Iran	2,700	2,700
Saudi Arabia	2,330	2,400
Italy	1,900	2,000
Ukraine	1,800	1,000
Belarus	0	0
Djibouti	0	0
Other countries	31,000	32,000
World total (rounded)	**293,220**	**294,400**

SAND AND GRAVEL

by Robert C. Goodin, National Minerals Information Center, U.S. Geological Survey

Industrial sand and gravel, often called silica, silica sand and quartz sand, includes sands and gravels with high silicon dioxide (SiO_2) content. These sands are used for foundry, glassmaking, hydraulic fracturing (frac), and many other industrial applications.

Production

U.S. production of industrial sand and gravel increased by 30 percent to an estimated 97 Mt in 2022 from 74.6 Mt in 2021, and the value increased by 78 percent to an estimated $5.7 billion. The estimated average unit value of domestically produced industrial sand and gravel in 2022 was $58/t compared with $42.40/t in 2021. Industrial sand and gravel was produced by 122 companies from 201 operations in 32 states in 2022. The leading producing states were, in descending order of production, Texas, Wisconsin, Illinois, Louisiana, Missouri, Oklahoma, Arkansas, Alabama, California and Tennessee. Combined production from these states accounted for about 87 percent of total domestic sales.

World production of industrial sand and gravel was estimated to be 380 Mt in 2022. The United States was the world's leading producer and consumer of industrial sand and gravel based on estimated world production figures.

Consumption

U.S. apparent consumption of industrial sand and gravel was estimated to be 91 Mt in 2022, a 31 percent increase from that of the previous year. The industrial sand and gravel industry remained closely tied to the production and sale of frac sand. Industrial sand and gravel consumption decreased in recent years, primarily as a result of decreased oil and natural-gas drilling activity in North America. These decreases were exacerbated by restrictions imposed as the result of the global COVID-19 pandemic. These restrictions resulted in a significant decline in consumption of petroleum products, which in turn prompted a decrease in demand for frac sand. In 2022, industrial sand and gravel consumption increased as demand for frac sand increased.

Approximately 75 percent of the U.S. tonnage was used as hydraulic-fracturing sand and well-packing and cementing sand. Other uses were, in decreasing quantity of use, glass sand, foundry sand, whole-grain fillers for building products, filtration sand and recreational sand, which accounted for 19 percent, combined. Other minor uses were, in decreasing quantity of use, chemicals, abrasives, roofing granules, silicon and ferrosilicon, ceramics, fillers, filtration gravel, traction and metallurgic flux, which accounted for 3 percent, combined. Other unspecified uses accounted for 3 percent, combined.

Foreign trade

According to the U.S. Census Bureau, the United States remained a net exporter of industrial sand and gravel, shipping it to almost every region of the world. High global demand for U.S. industrial sand and gravel can be attributed to the high quality and advanced processing techniques used in the United States for many grades of industrial sand and gravel, meeting specifications for virtually any use. Imports of silica are generally of two types — small shipments of very high-purity silica, or a few large shipments of lower grade silica shipped only under special circumstances (for example, very low freight rates).

Outlook

The industrial sand and gravel industry continued to be concerned with safety and health regulations and environmental restrictions, especially those concerning crystalline silica exposure. Local shortages of industrial sand and gravel were expected to continue to increase owing to land development priorities, local zoning regulations and logistical issues, including ongoing development and permitting of operations producing hydraulic-fracturing sand. Increased efforts to reduce cost, emissions and the risk of exposure to crystalline silica have led to an increase of undried “wet sand” being sold or used as frac sand instead of conventional “dry sand.”

SODIUM CARBONATE

by Keith D. Gray, RESPEC

Background

One of the most economically important carbonate minerals on Earth belongs to the acid carbonate class. This evaporite mineral is called trona and consists of hydrated sodium bicarbonate: $Na_3H(CO_3)_2{\cdot}2H_2O$. Mineral species of this class usually form in the presence of carbonic acid, a byproduct of carbon dioxide dissolved in water. Composed largely of sodium carbonate (approximately 70 percent), trona is also known as “natural soda ash” (trade name). Refined soda ash is used to manufacture flat glass for automobiles and buildings, as well as a variety of cleansing products (soap, detergent). Other derivatives include baking soda/powder, toothpaste, soft-drink sweetener and cattle feed. The Romans used soda ash to make bread. Southwestern Wyoming is home to the world’s largest trona deposit, which covers 1,300 square miles of its Green River Basin. According to the Bureau of Land Management, this region supplies about 90 percent of the nation’s soda ash. Trona deposits are typically found in freshwater lakes surrounded by silica-rich (acidic) volcanic rocks.

Production and consumption

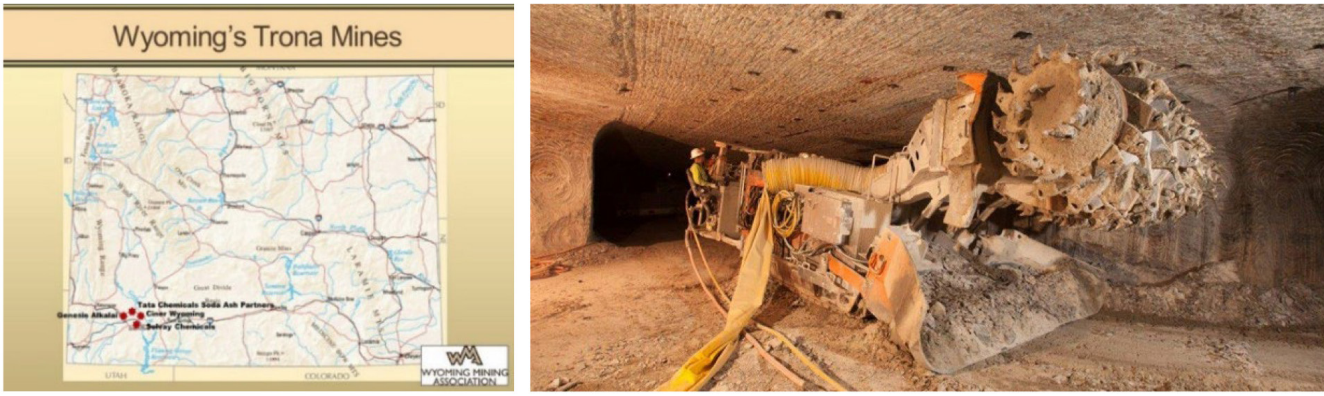
Based on statistics released by the U.S. Geological Survey (2023 Mineral Commodity Summary), domestic sodium carbonate produced in 2022 was estimated at 11 Mt for a total market value of $1.4 billion, slightly less than the 2021 output. The U.S. industry consists of four companies in Wyoming (Fig. 1) and one in southeastern California (Searles Valley Minerals Inc.), which have a combined production capacity of 13.9 Mt/a. Nearly half of the total soda ash developed in 2022 (approximately 48 percent) went into glass products, with about 28 percent used in chemicals and the remaining for soaps/detergents, flue-gas desulfurization, distributors and paper. Like other natural materials, the global market (trona) is driven by technological advances. China is a major player, with annual production exceeding 25 Mt. As such, the Asia-Pacific region is expected to dominate the soda ash market over the next decade (2022 Market Research Report).

Exports and imports

During 2022, the United States exported about

Figure 1

Left: Soda ash source rock locations in southwest Wyoming. Right: An underground trona mine. (Source: Wyoming Mining Association)



6.4 Mt of soda ash, more than one-half of its total production (USGS statistics). While only 100,000 t were received from other nations, mostly Turkey, this quantity more than doubled the average of annual imports over the past decade. Development of Turkey's major trona deposits (Beypazari and Kazan) is proving disruptive to the long-established European chemical industry.

Trends and outlook

U.S. production, consumption, and exportation in 2022 continued at levels comparable to those recorded before the COVID-19 pandemic.

One of the primary factors influencing growth of the global market is the burgeoning glass industry. The demand for glass products has risen significantly in recent years due to increased automobile sales and construction activities.

In many countries, new environmental regulations have resulted in greater wastewater treatment efforts, and thus, utilization of soda ash cleansing products. *References are available from the author.*

STRONTIUM

by A.K. Hatfield, National Minerals Information Center, U.S. Geological Survey

Production and consumption

Although strontium is the 17th most abundant element in the Earth's crust, only the minerals celestite (strontium sulfate) and strontianite (strontium carbonate) contain strontium in sufficient quantities to make recovery practical. Celestite has been the leading source of strontium since the 1870s because it occurs more frequently in economically attractive sedimentary deposits. The largest celestite deposits are found in China, Iran, Mexico, Spain and Turkey, although no production has been reported for Turkey in recent years. Strontianite has been identified in various countries worldwide.

The world's leading producers of celestite in 2022 were Spain, Iran, China and Mexico. Of an estimated 340 kt (370,000 st) of celestite produced worldwide, nearly all of it was produced in those countries. Although celestite deposits occur in the United States, no celestite has been mined domestically since 1959. In 2022, U.S. apparent consumption of strontium (contained in celestite and manufactured strontium compounds) was estimated to be 12 kt (13,200 st), a significant increase from that in 2021. The increase in 2022 was likely the result of improved economic conditions following the effects of the COVID-19 pandemic in 2020, and continued economic recovery in 2021.

Foreign trade

According to the U.S. Census Bureau, the gross weight of total imports of strontium compounds and minerals in 2022 was 10.2 kt (11,300 st), 14 percent more than that in 2021. Mexico was the source of 75 percent of all strontium imports. Imports of celestite, nearly all of which came from Mexico, increased significantly in 2022, likely the result of increased use of celestite in natural-gas and oil well drilling fluids. In recent years, celestite imports have been variable, corresponding with the number of operating rotary drill rigs; celestite may be used as an additive in drilling muds or as a substitute for barite in drilling muds, and the substitution is more likely when barite prices increase and drilling activity is high. In 2022, drilling activity increased by about 50 percent from that in 2021, but remained more than 20 percent below that in 2019 before the pandemic. Similarly, celestite imports increased significantly in 2022 but remained about 10 percent below that seen in 2019 before the pandemic. Strontium carbonate exports were 26 t gross weight (15 t of strontium content) in 2022, a significant increase compared with those in 2021.

Prices

In 2022, the average U.S. customs unit value of imported strontium carbonate was \$1.61/kg (\$0.73/

lb), and for strontium nitrate, the average unit value was \$2.31/kg (\$1.05/lb). The average value of imported celestite decreased to \$114/t (\$103/st), a 46 percent decrease from that in 2021; high-value celestite imports were most likely mineral specimens.

Legislation and government programs

On Feb. 24, 2022, a final U.S. critical minerals list was published in the Federal Register (87 FR 10381). The 2022 critical minerals list was an update of the list of critical minerals published in 2018 in the Federal Register (83 FR 23295). The 2022 critical minerals list contained 50 individual mineral commodities instead of 35 minerals and mineral groups. The changes in the 2022 list from the prior list were the addition of nickel and zinc and the removal of helium, potash, rhenium, strontium and uranium. The four commodities recommended to not be included in the revised list (including strontium) did not meet the revised criteria for inclusion. The list is to be updated every three years and revised as necessary, consistent with available data. On Dec. 9, 2022, strontium nitrate, strontium peroxide and strontium oxalate were identified as critical chemicals in a Defense Production Act Title III Expansion of Domestic Production Capability and Capacity funding opportunity announcement. The program's objectives included improving supply-chain resiliency and establishing domestic suppliers of critical chemicals essential for national defense.

Outlook

Celestite is rarely consumed directly, except as an additive to drilling fluids for oil and natural-gas exploration and production, for which celestite is ground but undergoes no chemical processing. In other uses, it is typically converted to strontium carbonate through chemical processing. Strontium carbonate is used directly in some applications and is also converted into downstream chemicals such as strontium chloride, strontium hydroxide or strontium nitrate.

The amount of strontium carbonate used in ceramic ferrite magnets was estimated to be similar to the use of strontium nitrate in pyrotechnics and signals in 2022. These two end uses are thought to account for most strontium consumption other than in the form of celestite. Other applications for strontium compounds include master alloys for aluminum casting, pigments and fillers in corrosion-resistant paints, electrolytic production of zinc and glass. With developments in advanced applications, consumption of strontium in new end uses may increase. *References are available from the author.*

SULFUR

by Gerard D'Aquin, CEO, Con-Sul Inc.

Mining sulfur using Frasch technology has ended. The last mine in Poland is said to be operating, but economics contradict that notice. The Mishraq Mine in Iraq has minuscule production of very-high-carbon sulfur. It was to have been rehabilitated, and sulfur purification technology added, five years ago. However, establishment of the ISIS Califate left the task undone and equipment scattered in the Iraqi desert.

Sulfur recovered from refineries, having grown dramatically due to clean-air mandates, is now generally declining (except in China and the Arab Gulf). The development of electric transport should eventually temper that growth. Sulfur extracted from the purification of natural gas, on the other hand, will continue to rise as a source of "blue" energy. Production increases are presently located in China and West Asia, including the Arab Gulf. The area, led by Saudi Arabia and Abu Dhabi, just displaced North America as the locus of global production.

Revamping logistics and the present molten sulfur infrastructure is the principal challenge confronting suppliers and consumers. U.S. consumers are facing the most challenges to transform infrastructure to enable imports of solid sulfur for melting. That challenge is particularly severe in California, Nevada and northwest Mexico, where extraction and processing of lithium, copper and other elements are growing.

Decline in mined sulfur output

Commercial mining of sulfur began to decline in the early 1980s as global environmental regulation focused on eliminating atmospheric sulfur emissions. Motor fuels became a primary target, lowering almost all fuels to a 15 parts per million (ppm) sulfur content 40 years later. U.S. statistics best illustrate the point due to its large output of Frasch-mined sulfur and numerous competing oil refineries.

Prior to the Clean Air Act, offroad equipment and rail locomotive fuels contained at least 3 percent (30,000 ppm) sulfur. Fuel oils and marine bunkers reached as much as 6 percent (60,000 ppm). Table 1 illustrates the transformative impact of fuels desulfurization: a six-fold increase from 1970 to 2017's peak output of sulfur from refinery and gas output of 9.1 mt, leading to Frasch sulfur mining's demise in 2001.

A drop in refinery production from 2017 to 2019

Table 1

U.S. sulfur production, 1970–2022, in million metric tons (U.S. Geological Survey, Con-Sul-2022e).

Source	1970	1975	1982	1987	1992	1997	2002	2012	2017	2019	2020	2021	2022e
Total	**9.8**	**11.7**	**10.6**	**12.7**	**11.9**	**12.5**	**10.3**	**9.0**	**9.8**	**8.7**	**7.9**	**8.1**	**8.2e**
Frasch	7.2	7.3	4.2	3.6	2.3	2.8	—	—	—	—	—	—	—
Refinery	1.5	3.0	4.4	6.6	7.1	7.7	8.5	8.4	9.1	8.1	7.3	7.5	8.0e
Natural gas	0.7	1.4	2.0	2.5	2.5	2.0	1.8	1.0	0.7	0.3	0.4	0.4	0.3e
Subtotal	2.2	4.4	6.4	9.1	9.6	9.7	10.3	9.4	9.8	8.4	7.7	7.9	8.3

is linked to the sweet/sour crude price relation. The differential between sour (with high carbon dioxide (CO_2) and hydrogen sulfide (H_2S) content) and sweet crudes delivered to U.S. refineries narrowed to the point where sweet crudes were preferred even by refineries technically specialized in processing "sour" feedstocks. Collapsing bituminous crude oil prices in Canada led the Alberta Energy Regulator Control Board to mandate production curtailments at oil sands operations in the province hoping (in vain) to raise the price of the "Alberta Select" crude oil grade and posted-price-associated bitumen feedstocks.

Evaluating market and logistical conditions that led to sulfur production's 2019 decline, we believe 600 kt of the 1.1 Mt drop represents a permanent drop linked to using "sweeter" feedstocks.

The drop in 2020 is directly attributable to the COVID-19 pandemic, which was followed by a late 2021-2022s slight recovery. This trend is expected to continue toward what may become a "new normal" sulfur production of 8.7 t/y.

Comparing U.S. performance to the U.S. Geological Survey's global data (USGS Mineral Commodity Summaries for specific years) shows interesting trends:

- World sulfur output in all forms rose almost 29 t (57 percent) from 1994 to 2020.
- That growth was driven by dramatic increases of 15.5 t in West Asia that more than offset the U.S. and Canadian drop of 7.9 t (38 percent) in the period.

The sole Frasch mine in the world might still operate at Osiek, in Poland. However, given the reduction in Russian natural-lgas exports and resultant increase in European energy prices, we find this implausible. If production at Osiek has ceased, resuming production may be technically and economically impractical. This is due to Frasch mining requiring heating of the limestone-containing crystalline sulfur formation to a temperature that only slightly exceeds the melting point of sulfur, once liquefied sulfur percolates down to a point where a double annulus collection well(s) has been drilled. Extraction utilizes compressed air injected down one annulus to lift molten sulfur up the other. If the formation cools for lack of superheated water injection, molten sulfur will solidify in the limestone's pores, effectively preventing hot water/steam from repenetrating that portion of the deposit. Further, this will lead to overheating certain areas being revitalized, and overheated sulfur becomes increasingly viscous to the point of immobility. Allowing a formation to cool prior to full sulfur extraction is always avoided.

Supply outlook

The USGS' evaluation of world resources is that resources of elemental sulfur in evaporite and volcanic deposits, and sulfur associated with natural gas, petroleum, tar sands and metal sulfides total about 5 billion t. The sulfur in gypsum and anhydrite is almost limitless, and 600 billion t of sulfur is contained in coal, oil shale and shale that is rich in organic matter. Production from these sources would require the development of low-cost methods of extraction. The domestic sulfur resource is about one-fifth of the world total.

North American challenge

Following the demise, and dominance, of a domestic Frasch mining industry, North America has been affected by several wild price swings. These developed as a consequence of consumer angst regarding immediately available supply, which Frasch companies tended to mitigate 20 years ago with extensive operating inventories of sulfur and careful contracts.

Price swings are expected to continue over the next five to 10 years as significant supply infrastructure is developed to meet new Western demand, reductions in phosphate fertilizer output and refinery sulfur output, and changing ownership of logistical assets.

While the mining of sulfur has ceased, the large demand fluctuations, inventory management issues and logistics common to that activity remain.

Table 2

World production of sulfur, 1994–2020.* All forms (elemental and H_2SO_4 in S equivalent, million metric tons/year – Mt/y).

Country	1994	2001	2009	2020	Difference 1994-2020
United States	11.5	9.3	9.8	7.8	(3.7), (32)%
Australia		0.7	0.9	0.9	0.2
Brazil				0.5	0.5
Canada	9.1	9.4	6.9	4.9	(4.2), (46)%
Chile		1.2	1.6	1.3	0.1
China	6.0	5.4	9.4	17.3	11.3, 188%
Finland		0.5	0.6	0.7	0.2
France	1.1	1.1	1.3		(1.3)
Germany		1.2	3.8	0.6	(0.6), (50)%
Greece				0.5	0.5
India		0.9	1.2	3.5	2.6, 288%
Iran		1.0	1.6	2.2	1.2
Iraq	0. 8	0.7			(0.8)
Italy			0.7		0.7
Japan	2.9	3.4	3.4	2.2	(0.7), (24)%
Kazakhstan		1.7	2.0	4.5	2.8, 165%
Korea (Rep. of)		1.3	1.6	3.1	1.8
Kuwait		0.5	0.7	0.6	0.1
Mexico	2.9	1.4	1.7		(2.9), (100)%
Netherlands		0.5	0.5		
Poland	2.8	1.4	0.7	1.0	(1.8), (36)%
Qatar				2.0	2.0
Russia		6.3	7.1	7.5	1.2
Saudi Arabia	1.6	2.4	3.2	6.5	4.9, 300%
South Africa			0.5	0.9	0.9
Spain	0.7	0.6	0.6	0.6	(0.1)
Turkmenistan				0.7	0.7
Uzbekistan			0.5		0.6
UAE		1.5	2.0	6.0	4.5, 300%
Venezuela			0.8		(0.8)
Other countries	11.9	5.1	4.8	4.2	(7.7), (65)%
World					
Tons	**51.0**	**57.3**	**67.8**	**79.8**	**28.8, 56.5%**
Increase from 1994 (tons, %)		**6.3, 12%**	**16.8, 33%**	**28.8, 56.5%**	

TALC

by G. P. Tomaino, Minerals Technologies Inc.

Talc is a layered, hydrous magnesium silicate mineral. It has a soft, soapy feel and typically a smooth texture and is known for its insulation, heat resistance, chemical stability, oil absorption and strong covering quality. Talc ($Mg_3Si_4O_{10}(OH)_2$) has a theoretical chemical composition of MgO at 31.7 percent, SiO_2 at 63.5 percent and H_2O at 4.8 percent. However, talc's chemical and mineralogical composition can vary depending on its geological history/parent rock association. These mineral associations are usually chlorite, quartz and carbonates (magnesite, calcite and dolomite), in varying levels. Two key elemental substitutions can occur in the talc crystal structure — iron for magnesium and fluorine for hydroxyl. These compositional differences may limit or enhance the usage of talc in specific market niches. The United States remains self-sufficient in most grades of talc.

Talc deposits are categorized under four origin-types occurring as secondary and/or tertiary alterations of pre-existing rocks: (1) ultramafic, (2) mafic, (3) metasedimentary and (4) metamorphic. Type 1 deposits, while the most abundant, are generally of lower grade and are second to Type 3 deposits based on utilization-commercialization. Type 4 deposits, while historically a dominant source, have diminished substantially in their usage over the years due to elevated amphibole content. Type 2 deposits are the least pure and utilized of all the origin-types. Another representation of the four talc origin categories noted above can be ultramafic/mafic, metasedimentary-carbonate, metasedimentary-silicoaluminous and metamorphic.

Historically, product groupings such as industrial, cosmetic and pharmaceutical had inferred or denoted purity. Presently, these groupings are no longer considered strict purity guidelines. Talc products can be categorized as chloritic-talc, carbonate-talc or tremolitic-talc. The hyphenated statement denotes the second most dominant mineral phase up to 50 percent.

Pyrophyllite is a layered hydrous aluminum silicate mineral. Pyrophyllite has similar physical properties as talc while elemental substitutions are minimal compared to talc. Pyrophyllite ($Al_2Si_4O_{10}(OH)_2$) has a theoretical chemical composition of Al_2O_3 at 28.3 percent, SiO_2 at 66.7 percent and H_2O at 5 percent. Typical accessory minerals are quartz, kaolin, diaspore, boehmite, sericite and chlorite, in addition to iron-containing impurities of hematite, limonite/goethite and pyrite. Grades are differentiated by particle size, moisture content, fired color and purity, as measured by fineness and screen residue. Pyrophyllite deposits are generally classified as hydrothermal or metamorphic. Subtypes are as follows: (1) hydrothermal in metasomatites continental and island-arc volcanic zones, platforms, folded systems, (2) hydrothermal in metasomatites in wall-rock quartz veins-granitoids and metamorphosed clastic suites, (3) metamorphosed metasomatites in submarine volcanic zones enclosing sulfide ores, (4) stratiform metamorphosed clastic clay suites with pyroclastic material and coal seams, and (5) clays formed by weathering. Pyrophyllite has high dielectric strength, low electrical conductivity, reasonably high thermal stability, and chemical inertness that allows for primary usages in refractory and ceramic applications.

Production and consumption

In 2022, the primary producer of pyrophyllite in the United States with worldwide distribution was Vanderbilt Minerals LLC – Standard Mineral Division (owned by R.T. Vanderbilt) in North Carolina. The parent company celebrated its 100-year anniversary in 2016. The division owns more than 1,500 acres of land that have reserves of more than 100 years. Pyrophyllite ore is mined in several openpit mines and is crushed, dry-ground and air-classified at the division's mill in Robbins. The processed pyrophyllite ore is sold under the trade name PYRAX. Piedmont Minerals, also in North Carolina, supplies product but mainly for in-house usage for their parent company, RESCO. While the company's actual domestic production figures were not disclosed by the U.S. Geological Survey (USGS), domestic 2022 pyrophyllite production was estimated to have increased from 2021 as the United States and world work through post-pandemic economics. Consumption was dominant refractory, ceramics and paint. Critical attributes in refractory applications are iron and quartz content, while a critical attribute in ceramics is whiteness before and after firing. Additional industrial usages are in paint, chemical carriers in agriculture, and filler in industrial coatings, sealants, polymers and caulks.

In 2022, three talc companies operated five talc mines and production facilities located in three states, accounting for 99 percent of domestic production. Domestic production is via openpit mining. Montana continues to be the leading state for production, followed by Texas and Vermont. Magris Talc has mines and processing facilities in Montana, Vermont and Canada. Minerals Technologies Inc. through its Barretts Minerals, a subsidiary of Specialty Minerals Inc., has mining and processing facilities in Montana and processing in Texas. CIMBAR Performance Minerals has processing facilities for imported talc in Indiana, Ohio and Texas in addition to facilities in China and Pakistan. Natural Minerals (formerly American Talc Co.) had mining and processing facilities in Texas. IMI FABI has processing facilities in West Virginia, in addition to, mines and operations in Brazil, Italy, Australia, Pakistan and China.

For 2022, estimated talc production continued to rebound from post-pandemic economics and is estimated at 580 kt, an increase of about 1 percent from 2021. Total talc sold by the producers, including domestic sales and exports, was estimated at 560 kt, an increase of about 1 percent from 2021 levels of 556 kt, but overall, the last two years have seen a substantial increase from 2020 levels. The total talc sold was valued at $180 million. For 2022, estimated apparent consumption of talc was at 690 kt, an increase of about 15 percent from 2021 levels. The estimated 2022 average price for a processed metric ton of product decreased slightly from $321 to $320.

The distribution of talc produced and sold domestically was as follows: ceramics including catalytic converter (18 percent), paint (16 percent), paper (23 percent), plastics (18 percent), rubber (4 percent), roofing (2 percent), and the remainder of 19 percent included a variety of applications of cosmetics, pharmaceuticals, refractories, agricultural products, animal-feed, sealant, sculpturing, food and polishing.

Exports/imports

The 2022 estimated talc exports were 200 kt, a decrease of about 14 percent from the 2021 actual exports of 232 kt. The 2022 estimated talc imports were 330 kt, an increase of 18 percent from 2021 at 278 kt and a significant rebound from 2020 pandemic levels. From USGS reporting, imported talc was sourced from Canada, China and Pakistan, with imports from these countries increasing and accounting for approximately half of the import tonnage. The USGS reported that crude ore from Afghanistan was being milled and exported through Pakistan to other countries. Imported talc was used in various applications of cosmetics, paints and plastics with remaining usage for ceramics, paper, roofing and rubber. World mine talc production included dominant sources from the United States, Brazil, Finland, Canada, China, France, India, Italy, Japan and Korea.

Employment

Talc sector employment continued its decline since 2007 with another substantial decline from 2020 to 2022 at approximately 205 percent, from 187 to 150 employment. Pyrophyllite mine employment ranged from 25 to 31 from 2012 to 2022.

Uses, new applications, processing technology and future trends

Talc producers must continue to provide a functional and high-performance mineral additive that can increase the value of their products to the end-use customer. In specific cases, unique properties of the talc product can be achieved by employing proprietary coatings or processing by delamination to increase aspect ratio or to increase the overall purity by beneficiation. Silane- or siloxane-based and directed surface treatments are commonplace. Nanotalc products (10 to 100 nanometers in one dimension) continue to be researched and marketed for uses in various applications. Talc usage covers a multitude of product categories: plastics, cosmetics, flooring, health care, catalytic converters, animal feed, caulks, sealants, gaskets, belts, hoses, specialty antiblocking/antihazing in plastic films, automotive-body putty, asphalt shingles, joint compounds, pharmaceuticals, ceramics and dimension stone.

In ceramic applications of dinnerware, sanitaryware and hobby ceramics, talc provides low shrinkage as well as high brightness upon firing at various temperatures. In other applications, high-quality calcined-talc blends can be tailored to each customer's specifications to impart a controlled shrinkage and reduce firing time. The reduced firing time aids in processing and energy costs for the customer. Another specialty usage for which talc demand remains high is fired-cordierite bodies used for catalytic converters for vehicles. In dimension stone applications, talc is used for countertops, sinks, mantels, fireplace surrounds, pavers and tile brick. In paints, talc is an economic extender and filler while providing brightness and durability to paint coatings. In rubber applications, talc provides reinforcement as well as ultraviolet-radiation resistance and can be used as a processing aid for good extrusion rates, impermeability and improved surface finish. However, more paints are shifting to water-based matrices from oil-based matrices to reduce organic volatiles; talc, being hydrophobic in nature, loses opportunities in these market-product shifts.

The plastics market continues to offer some potential growth opportunities, especially in polypropylene. It is projected that talc usage for lightweight and recyclable products will increase for the automotive market with compacted and submicron talc products to enable manufacture of high-performance end-use products. Talc continues to be used in the papermaking process, especially as a pitch control agent while it faces competition in the paper filler and niche paper coating sectors from precipitated and ground calcium carbonates.

TIN

by Chad A. Friedline, National Minerals Information Center, U.S. Geological Survey

Production and reserves

Tin has not been mined in the United States since 1993, and the last operating tin smelter stopped production in 1989. The United States is reliant on imports and recycling for its tin needs. Domestic apparent consumption of tin content was an estimated 43 kt in 2022, a 10 percent decrease from that in 2021. The value of consumed tin in 2022 was estimated to be

Industrial Minerals

Table 1

Global production by refined tin producers in descending order.

Company	Production (metric tons)
Yunnan Tin Group Co. (China)	77,100
Minsur S.A. (Peru)	32,700
Yunnan Chengfeng Non-ferrous Metals Co. (China)	20,600
PT Timah (Persero) Tbk (Indonesia)	19,800
Malaysia Smelting Corp. (Malaysia)	18,800
Guangxi China Tin Group Co. (China)	10,900
Jiangxi New Nanshan Technology (China)	10,800
Empresa Metalúrgica Vinto SA (Bolivia)	10,300
Thailand Smelting and Refining Co. (Thailand)	9,500
Aurubis Beerse NV (Belgium)	8,200

$1.6 billion, a 3 percent decrease from that in 2021. Industry stocks remained essentially unchanged from those at year-end 2021.

Global tin mine production in 2022 was estimated to be 310 kt of tin content, a slight increase from that in 2021. China, the global leader, produced an estimated 95 kt (31 percent of world production). Other leading sources include Indonesia with 74 kt (24 percent); Burma with 31 kt (10 percent); Peru with 29 kt (9 percent); and Bolivia and Brazil with 18 kt (6 percent) each. World tin reserves were estimated to be 4.6 Mt, about 15 times the estimated 2022 world primary tin production. Most tin reserves were in Asia and South America.

Consumption

During 2022, tin in the United States was used in chemicals (23 percent), tinplate (22 percent), alloys (11 percent), solder (10 percent), babbitt, brass and bronze, and tinning (7 percent), bar tin (2 percent) and other applications (25 percent). Tinplate is a layer of tin adhered to steel or wrought iron substrate for corrosion protection and is commonly used in food-grade cans to inhibit rust. Tin-based chemicals are commonly used in polyvinyl chloride (PVC) production and curing, biocides and catalysts. Tin is used in solder for electrical connections on circuit boards and in industrial applications such as the manufacturing of sheet metal and copper products. Bronze and brass are alloys of tin and copper and are used for decorations and instruments. Historically, bronze and brass are some of the oldest alloys ever created by humans. Babbitt is a low-friction alloy that is often used in engines owing to its ability to resist cycling forces.

Foreign trade

According to the U.S. Census Bureau, U.S. imports for consumption of refined tin totaled 33 kt in 2022, a 13 percent decrease from those in 2021. The leading sources of U.S. imports were Bolivia (32 percent), Peru (28 percent) and Indonesia (16 percent). Refined-tin exports in 2022 were 1.3 kt, essentially unchanged from that in 2021.

Prices

The annual average New York dealer price for Grade A tin in 2022 was $15.46/lb and the annual average London Metal Exchange Ltd. (LME) cash price was $14.23/lb, a slight decrease and a 4 percent decrease, respectively, from that in 2021. The LME remained the principal commodity exchange for trading tin in 2022, but other exchanges include the Indonesia Commodities and Derivatives Exchange, the Kuala Lumpur Tin Market, the Shanghai Futures Exchange and the Shanghai Metals Market.

Industry news and issues

Global production by refined-tin producers remained unchanged in 2022 from that of 2021. The world's leading refined-tin producers and their production in 2022 (in metric tons) are listed, in descending order, in Table 1.

The top 10 companies in 2022 produced 56 percent of refined tin worldwide compared with 59 percent in 2021. Yunnan Tin Group Co. Ltd. was the top producer in 2022, producing 6 percent less tin than in 2021. Yunnan Chengfeng Nonferrous Metals Co. Ltd. had the largest production increase of 21 percent, to 20.6 kt in 2022 from 17 kt in 2021, while PT Timah (Persero) Tbk had the largest production decrease of 25 percent, to 19.8 kt in 2022 from 26.5 kt in 2021. Chinese and South American smelters maintained overall production through 2022.

In May, a copper products manufacturer based in Germany purchased a U.S. metals recycling company capable of processing scrap, including tin, at the rate of 100 kt/a. Also in May, a company announced plans to build a $340 million electronic-waste and nonferrous-metals recycling plant in Fort Wayne, IN. The facility will have the capacity to recycle up to 45 kt/a of feedstock, and construction was expected to begin in 2023 and conclude by 2025. In June, construction began on a secondary smelter for complex recyclable materials in Richmond County, GA. The facility will have the capacity to process up to 90 kt/a of recyclables and will recover multiple metals, including tin. The facility was expected to begin operations in the first half of 2024, costing approximately $320 million to construct.

Throughout the year, smelters were temporarily closed in China owing to COVID-19 pandemic-related mitigation measures and annual maintenance. Intermittent truck driver strikes in Spain caused disruptions and halted shipments of tin and tungsten concentrates. In 2022, mining began from a new pit at the Penouta Mine in northwestern Spain, a deposit containing a measured and indicated resource of 76.3 Mt at 443 parts per million tin. In March, the indicated and inferred resources at the Mpama South deposit in

Congo (Kinshasa) were updated to 105 kt of contained tin. Additionally, the company mining the deposit announced an expansion to begin in late 2023 that would increase its tin production to about 20 kt/a.

Trends and outlook

Globally, consumption increased in 2022 for alloys, chemicals, solder and tinplate, while demand for lead-acid batteries remained steady. According to industry analysts, refined tin demand is expected to increase for use in brass and bronze, chemicals, float glass, electronic solder, and maintenance-free lead-acid batteries. Demand from the solar industry may continue to be a primary growth segment for solder, as it is used in the solar ribbon connecting individual solar cells and solder connections used throughout the electrical system and grid infrastructure. Demand from the automotive industry may increase as tin anodes in lithium-ion batteries develop into proven technology. Domestic tin requirements are expected to continue to be met primarily through imports. *References are available from the author.*

TITANIUM

by Joseph Gambogi, National Minerals Information Center, U.S. Geological Survey

Overview

Titanium minerals of economic importance include ilmenite, leucoxene and rutile. As a metal, titanium is well known for corrosion resistance and for its high strength-to-weight ratio. Approximately 90 percent of titanium is consumed in the form of titanium dioxide (TiO_2), a white pigment in paints, paper and plastics. TiO_2 pigment is characterized by its purity, refractive index, particle size and surface properties.

Table 1

World titanium mineral concentrates production.

World ilmenite and rutile production (in kt of TiO_2 equivalent)		
Country	**2021**	**2022e**
Australia	600	660
Canada[1]	430	470
China	3,400	3,400
India	204	200
Kenya	181	180
Madagascar	414	300
Mozambique	1,100	1,200
Norway	468	430
Senegal	482	520
South Africa[1]	900	900
Ukraine	316	200
United States[2]	100	200
Vietnam	122	160
Other countries	170	109
Total (rounded)	**8,900**	**8,900**

[1] Mine production is primarily used to produce titaniferous slag.
[2] Rounded to the nearest 100,000 tons to avoid disclosing company proprietary data. U.S. rutile production are included with ilmenite.

Production

In 2022, global production of titanium mineral concentrates was estimated to be 9.5 Mt of contained TiO_2, unchanged from that in 2021 (Table 1 and 2). Less than 10 percent of global production was attributed to natural rutile.

Rounded to one significant digit, U.S. production of titanium concentrates was estimated to be 200 kt of contained TiO_2. In the United States, The Chemours Co. produced titanium mineral concentrates at mining operations near Starke, FL and Offerman, GA. In California, Twin Pines Minerals LLC reprocessed mine tailings to produce mixed mineral concentrates containing titanium and zirconium. TiO_2 pigment

Figure 1

Average annual prices (unit values) for ilmenite, rutile and titanium dioxide (TiO_2) pigments 2012–2022.

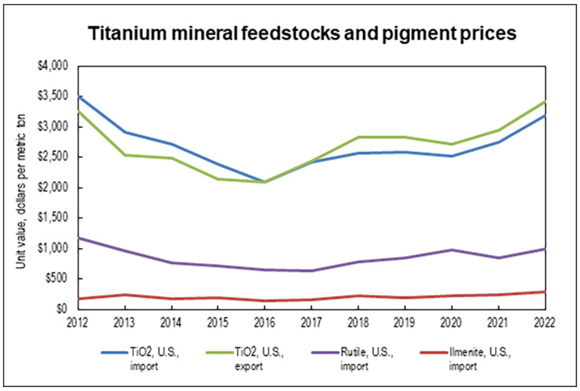


Figure 2

Average annual prices (unit values) for titanium metal sponge and titanium scrap 2012–2022.

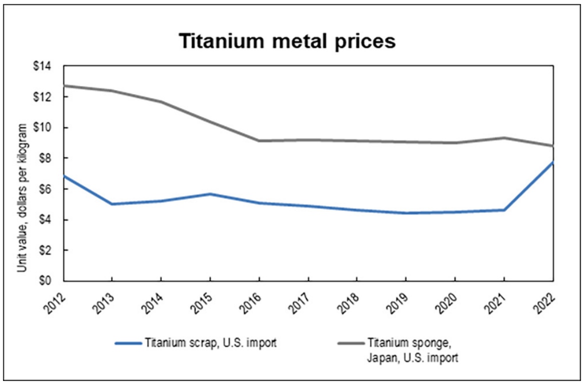


Table 2

World rutile production, in kt of TiO_2 equivalent.

Country	2021	2022e
Australia	190	190
India	12	11
Kenya	72	73
Sierra Leone	123	130
South Africa	95	95
Ukraine	95	57
Other countries	31	31
Total (rounded)	**618**	**590**

production in the United States in 2022 was estimated to be 1.1 Mt, unchanged from that in 2021, with domestic consumption estimated to have been 940 kt in 2022, an increase from 857 kt in 2021. U.S. producers of TiO_2 pigment, all of which used the chloride process, were Chemours, INEOS Pigments USA Inc., Louisiana Pigment Co. L.P., and Tronox Ltd.

Global titanium metal sponge production in 2022, excluding the United States where production data were withheld to avoid disclosing company proprietary data, was estimated to have increased to 260 kt from 240 kt in 2021 (Table 3). In the United States, titanium sponge metal was produced by Honeywell Electronic Materials Inc. in Utah. The 500-t/a Utah plant supported production of high-purity titanium in Fombell, PA.

Foreign trade

Based on data from the U.S. Census Bureau, in 2022, the United States was import reliant for titanium mineral concentrates (ilmenite, rutile and titaniferous slag). U.S. imports were 935 kt based on estimated TiO_2 equivalent, and the leading import sources were South Africa (34 percent), Madagascar (18 percent), and Australia, Canada and Mozambique (9 percent each). The United States was a net exporter of TiO_2 pigments. In 2022, U.S. exports of TiO_2 pigments were 350 kt based on TiO_2 equivalent with the majority of these exports going to Mexico (28 percent), Belgium (22 percent) and Canada (14 percent).

The United States was a net importer of titanium sponge metal and imported 31 kt of sponge in 2022. The leading import sources of titanium sponge in 2022 were Japan (82 percent), Kazakhstan (10 percent) and Saudi Arabia (7 percent).

Table 3

World titanium sponge metal production, estimated, in kt.

Country	2021	2022e
China	140	150
India	0.25	0.25
Japan	49	50
Kazakhstan	15	16
Russia	27	25
Saudi Arabia	5.7	11
Ukraine	6.1	1
United States	Withheld/proprietary data	Withheld/proprietary data
Total (rounded)	**240**	**260**

Prices

Based on U.S. imports for consumption from the U.S. Census Bureau, the average annual prices (unit values) for ilmenite ($285/t) and rutile ($989/t) increased by 18 percent and 17 percent, respectively, in 2022 compared with those in 2021. U.S. import and export prices for TiO_2 pigments increased by 16 percent each (Fig. 1).

The average annual price for titanium sponge metal imported from Japan ($8.78/kg) decreased by 6 percent and the average annual titanium scrap import price ($7.73/kg) increased by 67 percent compared with those in 2021 (Fig. 2).

Outlook

Consumption of titanium pigments in paints and coatings, paper and plastics links to global economic trends. According to the World Bank, the global economic growth rate was expected to slow to 1.7 percent in 2023, one of weakest rates in three decades. Consumption of titanium metal is primarily linked to aerospace demand. According to the International Air Transport Association, airline industry passenger traffic was expected to recover to its 2019 levels in 2024, and then grow at an annual average rate of around 3 percent. The lingering effects of the global pandemic, increased financial market volatility and the conflict in Ukraine may affect titanium metal supply and demand.

VANADIUM

by Desiree E. Polyak, National Minerals Information Center, U.S. Geological Survey

Vanadium is extracted from vanadiferous ores, slags and residues and converted into vanadium pentoxide or trioxide. Most vanadium pentoxide is then converted into ferrovanadium. In 2022, a majority of the world's supply of vanadium was derived either from vanadiferous titanomagnetite (VTM) mineral concentrates or from steelmaking slags, where the steel is produced from VTM.

Production

Industry convention for describing vanadium production usually applies the terms primary production (occurs from mined ore as mineral concentrates from VTM and sandstone-hosted vanadium), joint production (from vanadium slags that are produced during steelmaking) and secondary production (from residues and industrial waste materials), according to the raw-material source for production. The United States did not produce any primary vanadium in 2022. Vanadium production in Utah from the mining of uraniferous sandstones on the Colorado Plateau ceased in early 2020 and has not restarted since. The United States continued to be a major producer of vanadium products from secondary sources such as spent catalysts, ashes and petroleum residues. Secondary vanadium production continued in Arkansas, Ohio and Pennsylvania, where processed waste materials were used to produce ferrovanadium, vanadium-bearing chemicals or specialty alloys and vanadium pentoxide. One additional secondary producer in Texas has reopened.

In 2022, the vanadium-producing nations (from ore, concentrate and slag) included China (68 percent), Russia (17 percent), South Africa (9 percent) and Brazil (6 percent). Combined, they produced an estimated total of 100 kt of contained vanadium, a 3 percent decrease from that in 2021. Significant producers of secondary vanadium outside of the United States included Austria, Germany and Japan.

Energy Fuels Inc.'s White Mesa Mill, near Blanding, UT, had the only vanadium coproduct recovery circuit in the United States. Energy Fuels resumed vanadium production in early 2019 using new recovery techniques to recover vanadium from its existing tailings pond solutions. Vanadium coproduction had not occurred at the White Mesa facility since 2013, owing to low prices. Energy Fuels announced that no vanadium production was expected during 2022, although the company sold some of its existing vanadium inventory in early 2022 and was expected to evaluate the potential for future production in 2023 in response to market changes.

AMG Vanadium LLC announced that its new vanadium spent-catalyst recycling facility started operations in October 2022. The new facility was in Zanesville, OH, 25 miles west of its existing facility in Muskingum County, OH, and was expected to have an annual spent-catalyst recycling capacity of more than 35 kt and an annual vanadium capacity of 2.7 kt.

Largo Resources USA Inc., a subsidiary of Largo Inc., has signed a 10-year offtake agreement with Gladieux Metals Recyling (GMR), a spent petroleum catalyst recycler, for the purchase of all standard and high-purity vanadium products from GMR's recycling facility in Freeport, TX. Gladieux has an annual recycling capacity of 55 kt with an estimated 5 kt/a of V_2O_5 equivalent production capacity.

Consumption

Vanadium's primary use is as a hardening agent in steel, in which it is critical for imparting strength, toughness and wear resistance. These properties are especially important in high-strength, low-alloy (HSLA) steels, particularly for products in the construction industry and in tool steel. A smaller but essential use is in titanium aerospace alloys, for both military and commercial aircrafts. Nonmetallurgical applications include catalysts, ceramics, electronics, and vanadium chemicals, including large-scale energy storage. Catalysts are the leading nonmetallurgical use for vanadium.

Prices

In 2022, the average Chinese vanadium pentoxide price was $9.250/lb of contained vanadium, a 13 percent increase compared with $8.172/lb in 2021. The annual average U.S. ferrovanadium price increased by 51 percent to $23.78/lb of contained vanadium in 2022 compared with $15.77/lb in 2021.

Foreign trade

The United States continued to be a net importer of many vanadium materials in 2022. According to the U.S. Census Bureau, the United States imported (measured in vanadium content) 2.67 kt of ferrovanadium, 1.98 kt of vanadium pentoxide and 222 t of other oxides and hydroxides of vanadium. Total imports for consumption of all vanadium-bearing materials increased by 29 percent from those in 2021. In 2021, the United States exported (measured in vanadium content) 171 t of ferrovanadium, 143 t of vanadium pentoxide and 309 t of other oxides and hydroxides of vanadium. Total exports of all vanadium bearing materials increased by 28 percent from those in 2021.

Outlook

As the majority of vanadium is consumed in the production of steel, consumption trends are greatly influenced by trends in steel production; the range of steel grades that contain vanadium has continued to increase. The outlook for vanadium consumption in nonferrous alloys is largely dependent on trends in demand for titanium alloys in business, commercial and military aircrafts. As worldwide environmental regulations continue to become more stringent on fuels and other environmental waste, recovery of elements including vanadium from spent catalysts and fossil fuel residues is expected to increase.

Consumption of vanadium continued to increase in 2022 as economies recovered from the global COVID-19 pandemic. In addition to growth from the steel sector, one area of continued growth was in the energy storage market, specifically with vanadium redox batteries (VRFBs). China, India and the United States were expected to account for two-thirds of the global renewable-energy expansion. Many countries are seeking to meet renewable-energy targets, and

VRFB storage was a potential solution, with many countries having numerous implementations already underway. However, the VRFB has several barriers that still need to be overcome: the high cost of the electrolyte used in the VRFBs, the system complexity of the batteries, and the lack of proper standards continued to be constraints for widespread use of VRFBs. *References are available from the author.*

VERMICULITE

by Kristi J. Simmons, National Minerals Information Center, U.S. Geological Survey

Vermiculite is a hydrated magnesium-aluminum-iron silicate mined from shallow surface deposits. Raw vermiculite is similar in appearance to mica and contains water molecules within its internal structure. In a raw state, vermiculite ranges in color from black to various shades of brown to yellow. When vermiculate flakes are heated rapidly to a temperature above 870 °C, the intermolecular water flashes into steam and the flakes expand into gold- or bronze-colored accordion-like particles. This expansion process is called exfoliation, and the resulting ultralightweight aggregate is chemically inert, fire resistant and odorless.

Vermiculite was discovered in 1824 by Thomas H. Webb; however the first successful commercial vermiculite mine did not begin production until the 1920s when the Zonolite Co. began mining vermiculite in Libby, MT. Today there are two active vermiculite mining companies in the United States. Vermiculite, which gets its name from the Latin word *vermiculare*, meaning to breed worms, is mostly mined using openpit mining techniques.

Production

In 2022 an estimated 100 kt of vermiculite was produced in the United States by Specialty Vermiculite Corp., a subsidiary of Dicalite Management Group Inc., in Enoree, SC, and Virginia Vermiculite LLC in Louisa, VA. Data have been rounded to avoid disclosing company proprietary data. An estimated 80 kt of vermiculite ore was exfoliated in 2022, a 3 percent increase from 78 kt in 2021. Exfoliation was performed by 13 companies located in nine states: Arizona, Arkansas, Illinois, Massachusetts, Michigan, New Jersey, Ohio, Pennsylvania and South Carolina.

Consumption

Vermiculite concentrate that has not been exfoliated is used primarily in fire protection products, but most vermiculite is consumed in exfoliated form. Exfoliated vermiculite has a wide range of uses because of its attributes, including fire resistance, high liquid-absorption capacity, inertness, low density and low thermal conductivity. Agricultural uses (horticulture, soil conditioning and fertilizer carrier) were estimated to remain the leading uses of exfoliated vermiculite in 2022. When mixed with peat, bark or compost, vermiculite provides excellent aeration and moisture retention as well as promoting fast growth of plants. Other significant uses include aggregates (concrete, plaster and premixes) and insulation (loose-fill, block, high-temperature and packing insulation and sealants).

Substitutes

Several substitutes can be used in lieu of vermiculite. Expanded perlite, as well as less costly alternatives such as expanded clay, shale slag and slate are substitutes for exfoliated vermiculite in lightweight concrete and plaster. In agriculture, alternate materials include bark and other plant materials, peat, perlite, sawdust and synthetic soil conditioners. Substitutes for loose-fill fireproofing insulation include fiberglass, perlite and slag wool.

Foreign trade

Trade data for vermiculite concentrate are not collected as a separate category by the U.S. Census Bureau but are included within the group “vermiculite, perlite and chlorites, unexpanded.” An estimated 24 kt of vermiculite valued at $10.3 million was imported into the United States during 2022. Brazil and South Africa accounted for nearly all vermiculite imports. The United States produces finer-grade vermiculite concentrate and relies on imports for coarser than medium-sized concentrate. Exports were estimated to be 8 kt of vermiculite valued at $1.9 million in 2022, with Canada being the leading destination.

International

Global production of vermiculite was estimated to have increased slightly to 470 kt in 2022 compared with 464 kt in 2021. South Africa continued to be the leading vermiculite producing country, followed, in descending order, by the United States and Brazil.

Outlook

The worldwide production capacity of vermiculite continues to exceed consumption. However, the production of finer grades of vermiculite have far exceeded that of coarser grades for several decades. Exploration and development of vermiculite deposits containing medium, large and premium grades are likely to continue, while producers are also likely to continue to investigate ways to use the finer grades in higher-value markets. New and innovative uses of vermiculite will continue to be developed. Demand for vermiculite remains strong. With less domestic production, as well as global supply issues, vermiculite exfoliation operations are experiencing difficulties obtaining crude vermiculite, which has led consumers to use substitute materials. One company recently announced it will be substituting perlite for vermiculite in the agricultural products it produces.

WOLLASTONITE

by Elizabeth Sangine, National Minerals Information Center, U.S. Geological Survey

Wollastonite, a calcium metasilicate ($CaSiO_3$), has a theoretical composition of 48.3 percent calcium oxide (CaO) and 51.7 percent silicon dioxide (SiO_2), also known as silica, but may contain trace to minor amounts of aluminum, iron, magnesium, manganese, potassium, sodium and (or) strontium. Economic resources of wollastonite typically form when silica-enriched limestone deposits are buried and altered due to moderate to high pressure at depth or chemical alteration of limestone by silica-enriched hydrothermal fluids along faults or contacts with magmatic intrusions. Deposits of wollastonite have been identified in Arizona, California, Idaho, Nevada, New Mexico, New York and Utah; however, New York is the only state where long-term continuous mining has taken place.

Production

In 2022, two companies mined wollastonite in the United States. Imerys Wollastonite USA LLC operated a mine and processing plant near Willsboro in Essex County, NY. The deposit contains diopside and garnet, which are removed using high-intensity magnetic separators, and up to 60 percent wollastonite. Vanderbilt Minerals LLC, a wholly owned subsidiary of R.T. Vanderbilt Holding Co. Inc., operated a mine and processing plant near Balmat in Lewis County, NY. The Vanderbilt Minerals deposit is highly differentiated, with large regions of wollastonite separated from gangue zones, and consists primarily of wollastonite (up to 90 percent) with minor amounts of calcite, diopside and prehnite. Wollastonite production quantities for NYCO and Vanderbilt are withheld to avoid disclosing company proprietary data.

Consumption

Domestic wollastonite use in the United States includes construction-related markets, such as adhesives, caulks, cement board, ceramic tile, paints, stucco and wallboard, as well as friction product, metallurgical, plastic and rubber and miscellaneous applications.

The U.S. Geological Survey does not collect consumption statistics for wollastonite, but consumption was estimated to have increased slightly in 2022 from that in 2021. In 2022, trends in domestic manufacturing sectors that use wollastonite were mixed. According to the U.S. Census Bureau, U.S. privately-owned housing starts decreased by 3 percent for all types of homes with single-family units decreasing by 11 percent, but multiunit starts of five or more increased by 15 percent. According to the American Iron and Steel Institute, steel production was 6 percent lower in 2022 compared with that in 2021. According to the Bureau of Economic Analysis, domestic automobile production increased by 12 percent in 2022 from that in 2021.

Ceramics (frits, sanitaryware and tile), friction products (primarily brake linings), metallurgical applications (flux and conditioner), paint (architectural and industrial paints), plastics and rubber markets (thermoplastic and thermoset resins and elastomer compounds) and miscellaneous uses (including adhesives, concrete, glass and sealants) accounted for wollastonite sales in the United States.

The global sales for most wollastonite were ceramics, paint and polymers (such as plastics and rubber). Globally, ceramics were estimated to represent more than 30 percent of wollastonite consumption, followed by polymers (such as plastics and rubber) and paint. Lesser worldwide uses for wollastonite include miscellaneous construction products, friction materials, metallurgical applications, and paper.

Prices

At year-end 2022, prices for domestically produced wollastonite were estimated to be between \$340/t and \$370/t. Price data for wollastonite produced in other countries were unavailable.

Foreign trade

In 2022, wollastonite exports were estimated to be less than 10 kt, and imports were estimated to be about 1,000 t. Most of the trade was with Canada and Mexico by road or rail. Comprehensive trade data were not available for wollastonite because it is imported and exported under a generic U.S. Census Bureau Harmonized Tariff Schedule code that includes multiple mineral commodities.

Outlook

The wollastonite industry closely follows the overall trends in economic growth. As manufacturing sectors that consume wollastonite grow, sales of wollastonite are expected to increase as well. As the United States and the world continue to recover from the effects of the global COVID-19 pandemic and geopolitical actions, the performance of the wollastonite industry will be influenced.

ZEOLITES

by Daniel T. Eyde, St. Cloud Mining

Zeolite production in the United States has been flat since 2018, staying around 86 to 87 kt (estimated), according to U.S. Geological Survey statistics. New Mexico was the leading producer of natural zeolites in 2022, followed by California, Idaho, Texas, Oregon and Arizona. The top three companies accounted for about 75 percent of U.S. production. Domestic uses for natural zeolites were (in decreasing order by tonnage): animal feed, odor control, unclassified other (such as soil amendment, traction control and synthetic turf), water purification/treatment, pet litter, wastewater cleanup, fungicide or pesticide carrier, oil and grease absorbents, gas absorbent (and air filtration, fertilizer carriers), desiccants and aquaculture. The three leading uses accounted for more than 70 percent of the domestic natural zeolite sales tonnage. Synthetic-turf applications and green roofs as well as denitrification applications have grown as a market replacing some of the animal feed applications.

The United States exports high-added-value processed and activated chabazite products for gas adsorption and ion exchange applications, primarily chabazite from the Bowie deposit in Arizona. With the current pricing for natural gas dropping 75 percent, even given the needs in Europe, the demand for natural zeolite sorbents is difficult to predict. But there is a large installed base of plants using chabazite that does need to be replaced on a regular basis. It is also unclear how the war in Ukraine will impact this market. Most likely, demand for zeolite may increase as production increases on existing wells that can be treated. Exports for NSF-certified water filtration products into Europe, Mexico, Central America and South America may increase as well, though again the strength of the dollar may have an impact on this export market, as will increased prices that are being passed through by producers as the cost inputs of labor, fuel and power have increased significantly. There is also a growing market for specialty feed products, but these markets seem to be met by deposits in Europe, Mexico and South America. More low-cost zeolite deposits are being developed in Mexico. Whether they can economically travel to U.S. markets is questionable, and the quality assurance/quality control controls on these deposits are at this time not well established. As with any export market, only higher-value or bulk commodity products are shippable any significant distance.

Prices

Prices are based on the percentage of zeolite and accessory minerals in the product, chemical and physical properties, and particle size. The price of zeolite products is reported fob mine in bulk at $110-950/t in 2022. Due to the COVID-19 pandemic and a flattening of sales, prices were weak at the beginning of 2020, but higher transportation, energy and labor costs changed the market in 2021 and 2022. Price inflation in some products increased by 20 percent or more just to absorb the added costs, with annual added price increases of 5-10 percent being common for many industrial mineral products.

Generally, granular zeolite products carry a premium, particularly for water treatment products that must carry an NSF certification. Products for pool filtration are significantly higher than free-on-board (fob) mine costs due to distribution, packaging, marketing and certification expenses. Prices are generally negotiated; consequently, there are no published price quotes, though Bear River reports its average sales price per ton in the annual report of its parent company, U.S. Antimony. In 2022, Bear River's average sales price for clinoptilolite products was reported as $243/t, up about 11 percent from $219/mt in 2020.

Table 1

U.S. zeolite production, 2018-2022.

	2018	2019	2020	2021	2022e*
Production (t)	86,100	87,800	86,700	85,300	86,000
Sales	80,500	77,100	75,300	73,900	79,000
Imports	<1,000	<1,000	<1,000	<1,000	<1,000
Exports	<1,000	<1,000	<1,000	<1,000	<1,000
Consumption	80,500	77,100	75,300	74,000	79,000

* Estimated

Uses and applications

Worldwide, most natural zeolite mineral products are used in agricultural soil amendments, odor control, filtration applications, and pozzolans that do not require ultra-high-purity natural or synthetic zeolites. In general, most commercial deposits consist of a minimum 70 to 80 percent zeolite minerals. The exception is an Italian chabazite that at about 50 percent pure, is successfully used in a number of markets in compact septic systems at a rate of about 4 kt annually, as well as other specialty applications. Chabazite from the Bowie, AZ deposit is high purity and is processed into beads and extrudates and used in specialty sorption applications. The properties of chabazite from this deposit, primarily resistance to harsh chemical environments, and a cyclical adsorption rate that exceeds those of the competitive synthetic zeolite products, create a performance advantage. The largest application for chabazite is in pressure swing adsorption (PSA) plants that treat natural gas from wells and landfills. This market has and will continue to expand over the long term as worldwide production of natural gas increases.

Health and safety

The natural zeolite, erionite, has been a major health concern. None of the currently operating zeolite producers has fibrous erionite as a component in their zeolite products. Continued work on zeolite mineralogy has also shown that many deposits previously reported as having erionite actually contained the zeolite mineral offretite, or the so-called erionite did not have the chemistry and mineralogy of the current standard for the mineral erionite.

Trends and outlook

One of the trends in the zeolite industry is the development of a series of smaller marketing and distribution companies that do not have their own operations, such as Zeo Inc., in the United States. Natural zeolite production should continue to grow at a rate between 3 and 4 percent per year as the world recovers from the effects of the pandemic.

ZIRCONIUM

by Joseph Gambogi, National Minerals Information Center, U.S. Geological Survey

Overview

The principal economic source of zirconium is most often in the form of the zirconium silicate mineral, zircon ($ZrSiO_4$). Zircon is predominantly recovered as a coproduct of the mining and processing of placer deposits for heavy mineral sands including the titanium minerals, ilmenite and rutile, or tin minerals. Ceramics, foundry sand, metal, refractories, and zirconia, or zirconium dioxide (ZrO_2), and other zirconium chemicals were the leading end uses for zircon with the dominant end use being ceramics, which accounted for about one-half of the total zircon market. Milled zircon is used in ceramics as an opacifier in ceramic bodies and glazes. Zirconia and other zirconium chemicals are used in a variety of other uses. Yttria-stabilized zirconia is used in the manufacture of oxygen sensors that control combustion in automobile engines and furnaces and in the manufacture of diverse products including cubic zirconia, fiber-optic connectors, refractory coatings, and structural ceramics. Zirconium metal is used in corrosive environments and various specialty alloys. Because of its low thermal neutron absorption cross section, hafnium-free zirconium metal is used as cladding for nuclear fuel rod tubes. In refractory and foundry uses, zircon is used for facings on foundry molds where it increases resistance to metal penetration and gives a uniform finish to specialty metal castings. Milled or ground zircon is used in refractory paints for coating the surfaces of molds, and refractory bricks containing zircon are used in furnaces and hearths for containing molten metals.

Production

Global production of zircon concentrates in gross weight, excluding U.S. production that was less than 100 kt, was estimated to be 1.4 Mt in 2022, a slight increase from 1.3 Mt in 2021. The leading producing countries, Australia and South Africa, accounted for

Figure 1

U.S. salient trade statistics for zircon.

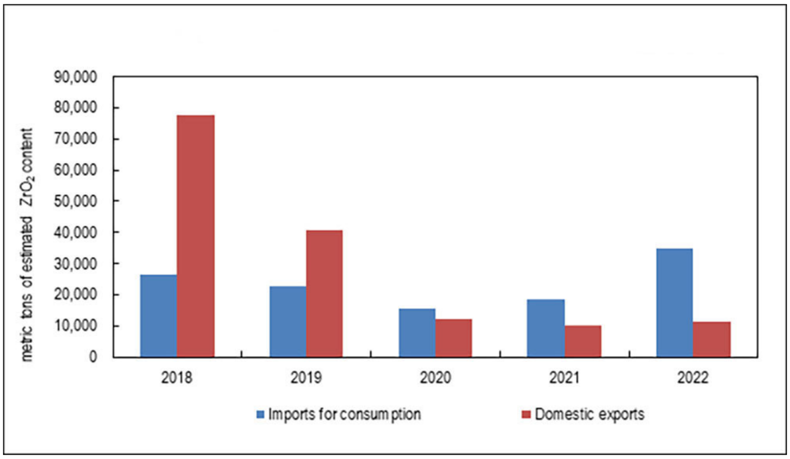


Figure 2

Average annual unit value of imported and exported zircon ores and concentrates, 2018-2022. Import unit value is based on imports from Australia, Senegal and South Africa. Export unit value is based on total domestic exports.

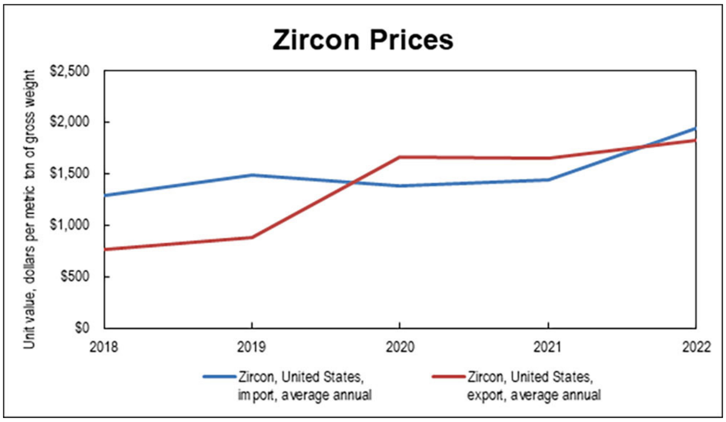


Table 1

World production of zirconium ores and concentrates by country[e] (kt, gross weight). (Source: U.S. Geological Survey)

	2021	2022
United States	<100	<100
Australia	500	500
China	140	140
Indonesia	55	60
Kenya	29	30
Mozambique	100	100
Senegal	64	70
South Africa	320	320
Other countries	150	160
Total (rounded)[1]	1,300	1,400

[e] Estimated production
[1] Excludes U.S. production

about 60 percent of global production (Table 1). In the United States, The Chemours Co. produced heavy zircon mineral concentrates at mining and processing operations near Starke, FL and Nahunta, GA. In California, Twin Pines Minerals LLC reprocessed stockpiled mine tailings to produce heavy mineral concentrates containing titanium and zircon.

Trade

According to the U.S. Census Bureau, the U.S. zircon concentrate exports totaled 11 kt (ZrO_2 equivalent weight) with a value of $31 million in 2022, 12 percent greater on a quantity basis than those in the prior year. In 2022, China (37 percent), India (20 percent) and Mexico (12 percent) were the leading destinations of U.S. exports of zircon concentrates.

In 2022, the United States imported 35 kt (ZrO_2 equivalent weight) of zircon concentrates with a value of $108 million, 1.9 times greater on a quantity basis than those in the prior year (Fig. 1). The leading import sources, in descending order of quantity, were Australia (46 percent), South Africa (35 percent) and Senegal (15 percent). China, the leading global consumer of zircon concentrates, imported an estimated 790 kt (ZrO_2 equivalent weight) of zircon concentrates with a value of $1.4 billion.

Prices

On a gross weight basis, the average U.S. zircon export unit value in 2022 was $1,820/t, a 10 percent increase from that in the previous year. The average annual U.S. zircon import unit values increased by 35 percent to $1,940/t of gross weight (Fig. 2). For comparison in global markets, China's average annual zircon unit value of imports was $1,160/t, almost a 40 percent increase compared with $832/t in 2021.

Outlook

Consumption of zircon is tied to growth in the global economy. According to the World Bank, the global economic growth rate was expected to slow to 1.7 percent in 2023, one of weakest rates in three decades. The ceramics, chemicals, refractories and foundry and casting applications are expected to continue to lead the consumption of zircon. According to a leading mineral sands producer, declining mining grades were expected to constrain long-term supply. ■

Conveyor belt cleaner tensioners; options for safe, efficient operation

by Daniel Marshall

There are many issues to consider when specifying the most appropriate conveyor belt cleaner, not the least of which is maintaining proper tension to achieve optimum cleaning performance without introducing related problems. Inadequate tensioning causes carryback to cling to the belt and spill along its path, piling up under the conveyor and emitting excessive dust. This requires extra labor for cleanup and can affect air quality. Overtensioning leads to friction damage to the carrying side of the belt, premature blade wear and potential splice damage. These scenarios contribute to unsafe work conditions and raise the cost of operation.

"There are two basic approaches to applying tension to the belt cleaner: linear and rotary," said Daniel Marshall, process engineer, Martin Engineering. "The blade's cleaning position and angle of approach to the belt often dictate whether a linear or rotary tensioner is used."

The Conveyor Equipment Manufacturers Association (CEMA) defines the cleaning positions as primary, secondary or tertiary. Primary cleaners typically function with a "peeling" action, while secondary and tertiary cleaners are usually scrapers. Belt cleaners mounted in the primary position generally employ a rotary-style tensioner, while most units mounted in the secondary or tertiary positions use linear-style tensioners.

In most cases, belt tensioners have to be monitored and adjusted manually so they can maintain optimum pressure and carryback removal. Estimating when blades need changing is often a guessing game that, if left too long, could lead to unnecessary complications.

Linear tensioners

"Linear tensioners are most often applied where the compensation for wear is required in small increments, such as with hard metal-tipped cleaners located in the secondary cleaning position or with brush cleaners," Marshall said.

The simple design of linear tensioners often allows just one setting for full blade wear. Further, these tensioners can accommodate actuator deflection for accurate adjustment of cleaning pressure, delivering the ability to accommodate uneven mounting positions or asymmetrical blade wear.

Rotary tensioners

The required tensioning forces can be applied by springs, hydraulic or pneumatic cylinders, electric actuators or from torque stored in an elastomeric element. Rotary tensioners like the Martin Twist tensioner are often used with urethane blades, where the change in blade height and thickness as it wears is significant. Rotary designs tend to be compact and, in most cases, the actuator(s) can be mounted at any orientation, which provides options for installing the belt cleaner in the optimum position.

Air tensioners

Air tensioners use the resilience of a pneumatic cylinder to cushion impact. The

Daniel Marshall is process engineer at Martin Engineering. Email: danielm@martin-eng.com.

tensioners can use Martin's Air Connection Kit to plug them directly into an existing air system, allowing for a more streamlined installation process.

Spring tensioners

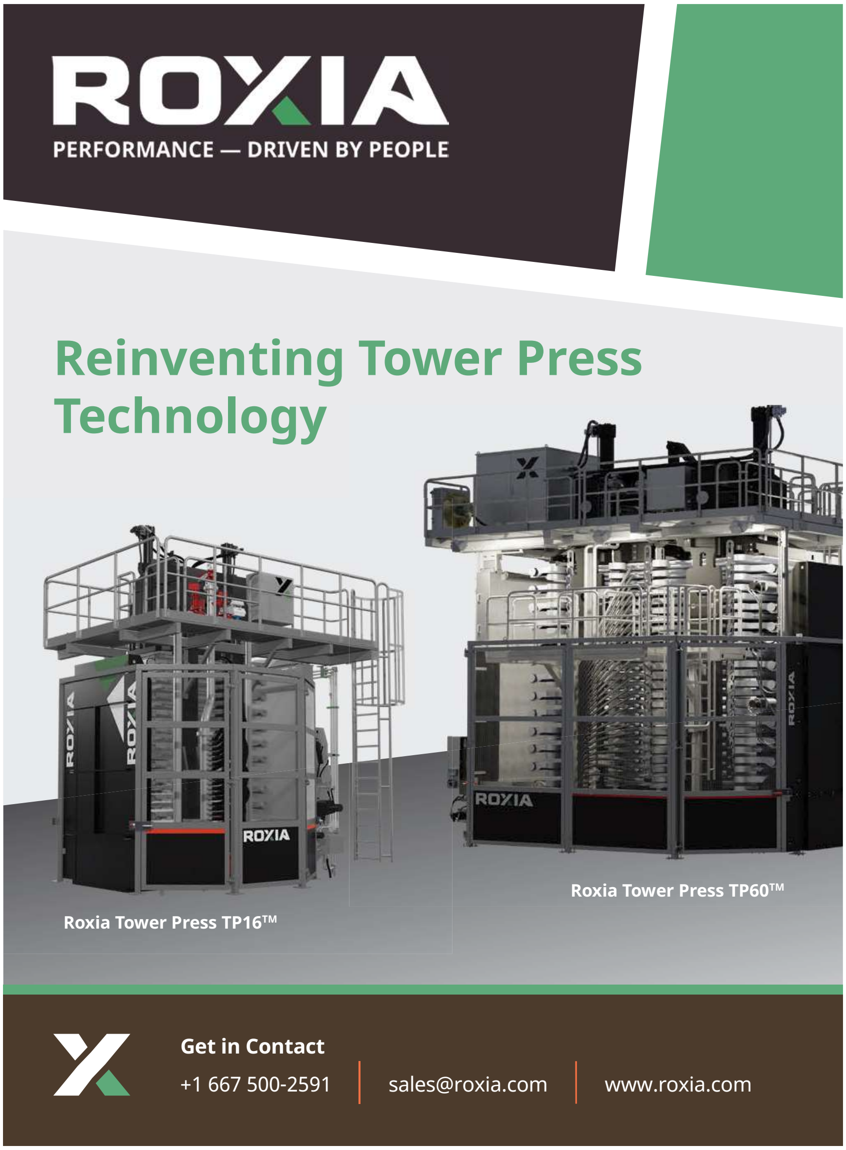
Spring tensioners maintain efficient belt cleaning with a rugged coil spring. The Martin XHD Spring Tensioners deliver effective cleaning while cushioning splice shock to prevent damage — well suited for tensioning heavy-duty belt cleaners while standing up to tough conditions. Dual tensioning is recommended for belt cleaners installed on belts wider than 48 in (1,200 mm). However, dual tensioning does not change the fact that regular adjustment is required to maintain suitable cleaning pressure on the belt, which is where Martin's N2 Smart Technology comes into play.

Auto tensioner/position indicator

Martin Engineering's smart technology platform includes the company's patented N2 Position Indicator to monitor primary cleaner blade wear and inform operators when the blade needs changing. The system uses a cellular gateway that relays data to the cloud and then to the user, delivering actionable information in real time.

The N2 PI and Smart Device Manager app ease the burden on managers and workers so they can focus their attention on other critical details of the operation. Precise tensioning and improved belt cleaning reduce the volume of dust and spillage from carryback, improving workplace conditions and decreasing the labor needed to maintain and clean around the discharge zone.

While manufacturers continue to improve belt cleaner effectiveness, it has become clear that there is no single or ideal solution for belt cleaning and tensioner selection. Safety of personnel and the belt itself is the primary consideration when selecting a tensioner. Ease of inspection and maintenance is critical for belt cleaner effectiveness, so the tensioner must allow quick and safe service. Martin Engineering offers the services and tensioning products that are necessary to meet the multifaceted demands of belt cleaning. ■



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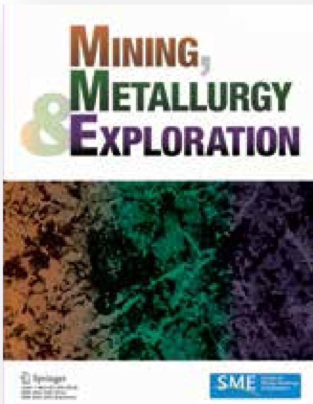

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Optimum auxiliary fan location to control air recirculation

Ramakrishna Morla[1,*], Shivakumar Karekal[2], Ajit Godbole[2], Purushotham Tukkaraja[3] and Ping Chang[4]
[1]Norton Gold Fields, Western Australia, Australia
[2]School of Civil, Mining and Environmental Engineering, University of Wollongong, New South Wales, Australia
[3]Department of Mining Engineering and Management, South Dakota School of Mines, Rapid City, SD, USA
[4]WA School of Mines: Minerals, Energy and Chemical Engineering, Curtin University, Western Australia, Australia
*Corresponding author email: ramsiit99@gmail.com

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Keywords: Dead end, Recirculation, Auxiliary fan, Crosscut, DPF, DPM, CFD simulation

This paper presents the results of a study on optimum auxiliary fan location to control air recirculation in dead-end workings where diesel-powered vehicles operate. Investigations were conducted with various secondary fan locations from the dead-end crosscut and with the intake air quantities varied using a 30-m³/s twin 75-kW auxiliary fan and a 45-m³/s twin 110-kW auxiliary fan to control air recirculation and diesel particulate matter (DPM). The results showed that if the intake-drive airflow rate matched the fan capacity, air recirculation occurred even when the fan was located 10 m away from the crosscut entry. If the intake-drive air quantity was greater than or equal to 150 percent of fan capacity, no recirculation was observed when the twin 75-kW fan location was at least 5 m and the twin 110-kW fan location was at least 10 m away from the dead-end crosscut access.

Introduction

Auxiliary fans are generally installed in a fresh air raise system on the decline or level to supply fresh air to the workings in metal and nonmetal mines. The primary issue with fan installation in decline or level is air recirculation. It mainly depends on the fan installation location from the level access and airflow in the intake drive. If a secondary fan is recirculating the air, there is a chance of increasing the concentrations of diesel vehicle exhaust fumes, heat and dust.

Different DPM control strategies had been investigated to solve the DPM issues in underground mines effectively: for example, by applying passive particulate filters [1] and diesel particulate filters [2], by extending the ventilation ducts to the face [3] and by using positive-pressure environmental cabs and water sprays [4].

This paper presents the results of investigations conducted to control air recirculation and DPM concentration to optimize the location of auxiliary fans and quantity of intake-drive air using field experiments and computational fluid dynamics (CFD). The present work describes simulations of airflow, DPM and controlling air recirculation with different locations of the secondary fan for the level access.

Table 1 — Percentage of air recirculation with respect to location of fan (75 kW) from the crosscut entry.

Air quantity in intake drive (m^3/s)	Location of secondary fan from the crosscut entry (distance, m)						
	0	1	2	3	4	5	10
	Percentage of recirculation air in secondary fan (%)						
30	54	46	41	37	31	24	15
45	36	29	22	18	10	4	0
60	27	20	16	9	3	0	0

Methods

Field experiments. Field experiments were conducted in an Australian metal mine. During the experiment, airflow in the main drive was regulated through a drop board regulator, and the DPM concentration in the intake air was zero. The length, width and height of the experimental dead-end level access were 70, 6 and 5 m, respectively. During the experiment, a 306-kW LHD (load, haul, dump) vehicle was working in a dead-end face, and a twin 75-kW fan with a ventilation bag 1.22 m in diameter was ventilating the dead-end level access. The measured air velocities in the intake drive and the dead-end level access drive were 1.45 and 1.0 m/s, respectively. The measured DPM concentration, dry-bulb and wet-bulb temperatures in the dead-end face were 61.5 µg/m^3, 25.8 °C and 34.1 °C, respectively. An anemometer, a real-time DPM monitor and a hygrometer were used to monitor air velocity, DPM concentration and temperature, respectively.

CFD modeling. *Construction of computational domain.* A model consisting of a fan, ventilation duct and LHD was built to simulate auxiliary ventilation in underground dead-end level access. The computational domain geometry was generated, as shown in Fig. 1. The model also consists of a twin 75-kW fan with a ventilation bag that is 50 m long. A three-dimensional CAD model of an LHD vehicle or bogger was imported into the dead-end crosscut. The loader engine was equipped with a DPM filter, and the exhaust flow was a mixture of DPM and air.

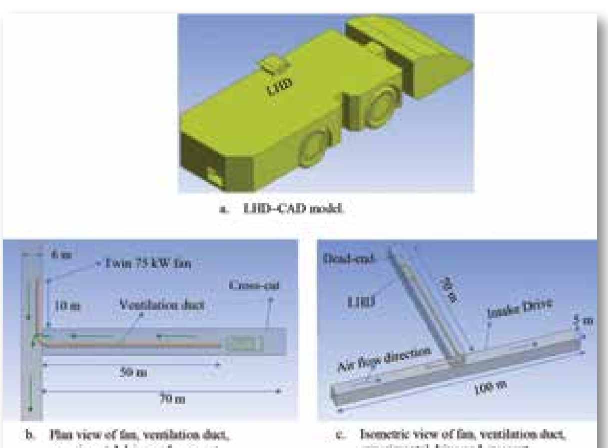

Fig. 1 Computational domain showing fan, ventilation duct, experimental drive and crosscut.

Results and discussion

Results of field experiment and model validation. The CFD model was validated against field measurements. Figures 2a and b show the field data and CFD simulated results. Some differences between the simulated and measured field results are observed due to unevenness in the drive or crosscut wall surfaces that was not considered while modeling. Overall, the difference varies from minus 3 to plus 3 percent.

Effect of air recirculation on twin 75-kW and 110-kW auxiliary fan locations. Simulations were conducted with different air flow rates in the main intake gallery, and with different fan locations, as shown in Tables 1 and 2.

The results for the twin 75-kW fan show that air recirculation occurred at locations 0 to 4 m from the crosscut entry fan. No recirculation is observed for the locations 5 and 10 m from the crosscut fan.

Results of DPM distribution in an unventilated dead-end crosscut, 70 m in length. To investigate the characteristics of DPM accumulation and dispersion in dead-end zones, simulation studies were carried out for a dead-end crosscut, 70 m in length with no secondary ventilation. The results show that after 30 min, 2 h and 6 h, the spot concentrations of DPM were 820, 505 and 100 µg/m^3, respectively.

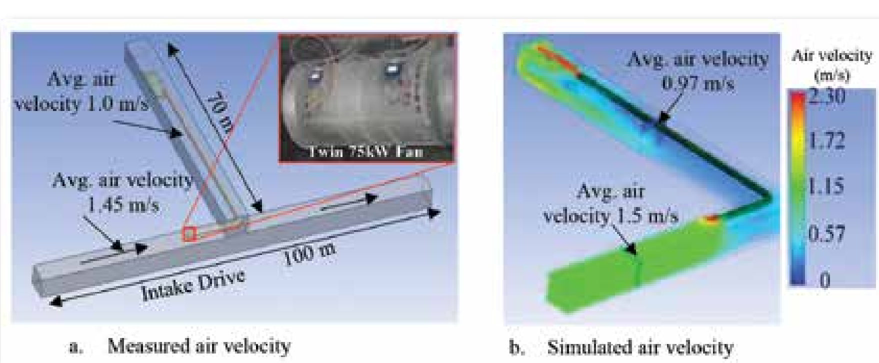

Fig. 2 Comparison of (a) experimental results with (b) simulated results.

Variation of DPM concentration with recirculation. Two scenarios were simulated to investigate how DPM concentration varies with recirculation: (1) with the fan located in the intake drive and in line with the crosscut and (2) with the fan located in the intake drive and at 10 m from the crosscut. From the results, it can be observed that the DPM concentration in the first scenario is 13.8 percent more than in the second scenario due to air recirculation. When the 70-m drive was filled with DPM at a

Table 2 — Percentage of air recirculation with respect to location of fan (110 kW) from the crosscut entry

Air quantity in intake drive (m^3/s)	Location of secondary fan from the crosscut entry (distance, m)				
	2	4	6	8	10
	Percentage of recirculation air in secondary fan (%)				
45	43	35	31	25	18
67.5	22	17	10	5	0
90	14	10	3	0	0

concentration of 820 µg/m^3 and with no recirculation at the secondary fan, it took 127 s for the auxiliary fan to clear the DPM particles from the drive.

Conclusions

This paper describes the results of a study on the best location of an auxiliary fan for the least amount of air needed in the intake drive to control air recirculation in dead-end crosscuts where diesel-powered vehicles operate. The results show that for an unventilated dead-end crosscut 70 m in length it took 6 h for the DPM concentration to be reduced to 100 µg/m^3 from 820 µg/m^3.

Field monitoring and CFD simulation studies were carried out with intake-drive air quantities 1.0, 1.5 and 2.0 times the airflow from twin 75-kW and twin 110-kW auxiliary fans located 1 to 10 m from the crosscut entrance. They demonstrated that the air was always recirculated if the quantity of intake-drive air was the same as the fan capacity. However, the amount of recirculated air decreased as the distance between the fan and the crosscut increased. The studies also showed that if the intake-drive air quantity was higher than or equal to 150 percent of the fan capacity, there would be no recirculation when the twin 75-kW fan was at least 5 m and the twin 110-kW fan was at least 10 m away from the crosscut entrance. ■

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Leaching of silver from mechanically activated naumannite

Katarína Gáborová[1,2], Marcela Achimovičová[1,*], Pavel Škácha[3,4], María Florencia Márquez-Zavalía[5,6], Jaroslav Briancin[1] and Ol'ga Šestinová[1]

[1]Institute of Geotechnics, Slovak Academy of Sciences, Watsonova, Košice, Slovakia
[2]Institute of Metallurgy, Faculty of Materials, Metallurgy and Recycling, Technical University of Košice, Košice, Slovakia
[3]Mining Museum Pribram, Pribram, Czech Republic
[4]National Museum, Prague, Czech Republic
[5]IANIGLA, CCT-Mendoza (CONICET), Mendoza, Argentina
[6]Mineralogía y Petrología, Universidad Nacional de Cuyo, Mendoza, Argentina
*Corresponding author email: achimovic@saske.sk

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Keywords: Naumannite, Mechanical activation, Acid leaching, Silver

In this work, the structure, morphology, chemical composition and leaching of naumannite were studied. Mechanical activation in a planetary ball mill resulted in increasing its specific surface area. The influence of milling time on the particle size was studied by particle size distribution analysis and scanning electron microscopy. The leaching kinetics of nonactivated and mechanically activated samples in nitric acid (HNO_3) were examined. The effect of leaching temperature on the recovery of silver was documented. The maximum yield of silver, 94 percent, was achieved after 120 min of leaching in 7.9 mol/L HNO_3 at 50 °C for the sample activated for 30 min. Based on calculated activation energy values, a mixed leaching mechanism consisting of diffusion and surface chemical reaction as the rate-controlling steps of the solid-liquid reaction was assessed.

Introduction

Naumannite (Ag_2Se), a silver selenide mineral named after the German geologist and crystallographer K.F. Naumann, was first discovered in Tilkerode Mining District, Mansfeld-Südharz, Saxony-Anhalt, Germany in 1828 [1]. Selenides had not received much attention in the past due to scarce occurrence. They are refractory ores similar to sulfides and tellurides, often rich in precious metals, and have to be processed by expensive roasting. Silver as a precious metal is an industrial material with significant corrosion resistance, electrical conductivity, excellent thermal conductivity, high reflectivity, malleability and ductility [2]. Silver and copper selenides (AgCuSe and $(Ag,Cu)_2Se$) are usually part of the raw anode slime from copper refineries, which is treated by pressure leaching in sulfuric acid (H_2SO_4) at a temperature of 180 °C, with some Ag remaining in a solid solution as Ag_2Se [3]. Gendolla and Charewicz used an HNO_3 solution to leach anode slime after copper refining [4]. Štofko and Štofková applied a 30 percent HNO_3 solution at a temperature of 65 °C to leach Ag and Se, achieving maximum recovery from the anode slime with a grain size of 0.2 mm [5]. The HNO_3 leaching of Ag_2Se proceeds according to the chemical reaction reported by Havlík [6]:

$$Ag_2Se + 4HNO_3 \rightarrow H_2SeO_3 + 2AgNO_3 + H_2O + 2NO \quad (1)$$

To date, however, the direct leaching of natural Ag_2Se with HNO_3 has not been documented in the literature. Mechanical activation by milling is an important pretreatment method for minerals and ores, which affects their leachability. High-energy milling in planetary mills results in a complex change in the surface and bulk properties of the activated substances: a several-fold increase in the specific surface area, S_A, compared with conventional milling, and a disordering of the crystal structure — that is, the breaking of bonds in the crystal lattice of the mineral — which lowers the activation energy and raises the leaching rate [7].

Results and discussion

Physicochemical changes of naumannite due to the mechanical activation led to a reduction of particle size in the d_{50} fraction (4.91 µm), particle shape transformation, and a maximum specific surface area of 8.30 m²/g after 30 min of milling in a Pulverisette 6 planetary ball mill made by Fritsch (Germany).

The nonactivated sample was subjected to batch leaching in HNO_3 with concentrations of 3.5, 5.6 and 7.9 mol/L at a temperature of 25 °C. Although silver recovery for the leaching in 7.9 mol/L HNO_3 for 120 min was almost five times higher compared with leaching in 3.5 mol/L HNO_3, it achieved only less than 1 percent. For the subsequent study of the effect of mechanical activation on the leaching kinetics of activated samples, 7.9 mol/L HNO_3 was chosen. Silver recovery reached 50 percent for the sample activated for 30 min after 120 min of leaching (Fig. 1). This result indicates a significant effect of mechanical activation on the leachability of silver.

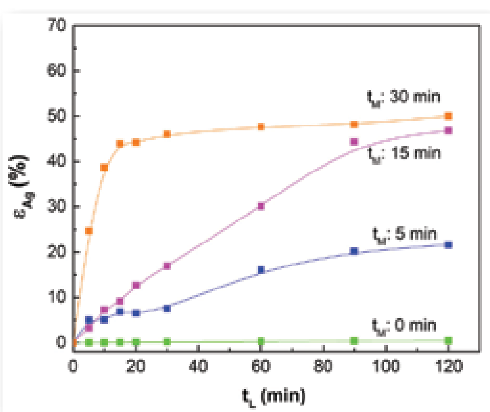

Fig. 1 Recovery of silver, ε_{Ag}, into leachate versus leaching time, t_L, for nonactivated and mechanically activated naumannite (milling time, t_M = 0, 5, 15, 30 min; leaching temperature = 25 °C).

Mechanical activation also caused mild amorphization: that is, reduced intensities and weak broadening of the X-ray diffraction peaks of the naumannite phase after 30 min of milling. This indicates that crystal disordering of the mineral phase increased with the milling time, and together with the increased S_A could contribute to an increase in the rate of Ag_2Se leaching as well. Moreover, the X-ray diffraction pattern of the solid residue after leaching of activated Ag_2Se for 30 min documented the relicts of the main Ag_2Se peaks, but the peaks of the accompanying mineral phases (HgSe, SiO_2, $CaAl_2Si_2O_8$ and Fe_2O_3) were also present, which did not dissolve in HNO_3. Related to the low leachability of iron (Fe) and mercury (Hg), the leaching can be considered selective.

The temperature dependences of the nonactivated and the activated naumannite for 30 min versus time of leaching are presented in Fig. 2. When using 7.9 mol/L HNO_3 at 50 °C, almost 94 percent Ag yield was achieved, which is four times more than for the nonactivated sample. Based on the results, temperature and mechanical activation accelerated the extraction of silver from natural Ag_2Se.

The initial leaching rate constants, k_0 (calculated according to Dutrizac [8]) and specific rate constants, $k_S = k_0/S_A$, of nonactivated and activated naumannite at various temperatures are documented in Table 1. The regression coefficients, R^2 , confirmed a good fit with the reference equation.

The mechanism of leaching was assessed based on calculated activation energy values from the Arrhenius equation giving the quantitative basis for the relationship between the activation energy, the leaching rate and the leaching temperature. The activation energy, E_a, of 132 kJ/mol calculated for the nonactivated sample was within the range of values characteristic for processes controlled by a chemical reaction [9]. For the activated sample, the reaction mechanism in the investigated temperature interval had changed. The calculated E_a of 8 kJ/mol for a temperature range of 25 to 40 °C evidenced that the reaction is controlled by diffusion. In the range of 40 to 50 °C, the rate-controlling reaction step was already shifted to the chemical reaction at the surface with E_a of 45 kJ/

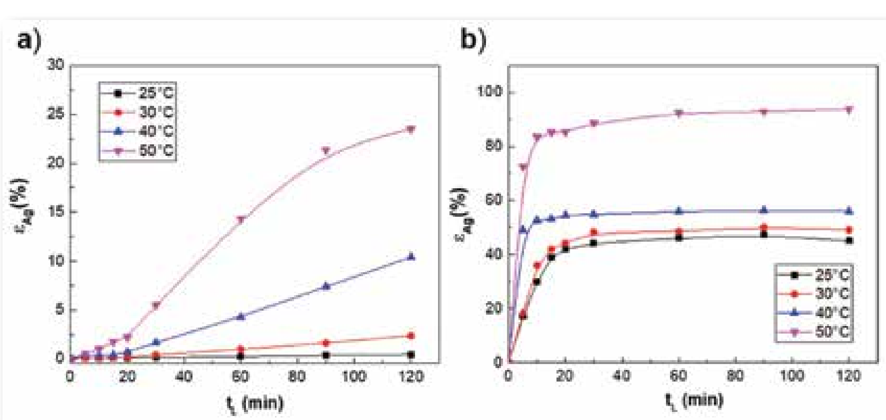

Fig. 2 Recovery of silver, ε_{Ag}, into leach versus time of leaching, t_L, at various leaching temperatures for (a) nonactivated and (b) mechanically activated Ag_2Se for 30 min.

mol. Depending on the reaction (1), no solid products were formed on the surface of the leached particles during the leaching, which could cause slowing down of the leaching process, and therefore the chemical reaction of Ag_2Se leaching proceeds gradually at temperatures higher than 40 °C.

Conclusion

The studied leaching of naumannite represented a heterogeneous solid-liquid reaction, the kinetics and mechanism of which have not yet been discussed in the literature. Mechanical activation of naumannite caused a reduction of particle size, particle shape transformation, and maximization of specific surface area during 30 min of milling. This pretreatment had a positive effect on the recovery of silver at ambient temperature in 7.9 mol/L HNO_3. The temperature sensitivity of the leaching of nonactivated and mechanically activated naumannite in the range of 25 to 50 °C resulted in 94 percent recovery of silver into leach. The mixed mechanism of mechanically activated naumannite leaching was evaluated. For nonactivated naumannite, the leaching process was controlled by a chemical reaction with a much higher E_a value. The obtained results indicate that mechanical activation with $t_M \leq 30$ min might be an applicable pretreatment of naumannite in the hydrometallurgical process of silver extraction. ■

Table 1 — Calculated naumannite leaching kinetics parameters.

Naumannite/ mechanical activation (min)	Leaching temperature (°C)	$k_0 \times 10^{-2}$ (s^{-1})	$k_S \times 10^{-3}$ ($s^{-1}.m^{-2}.g$)	R^2
Ag_2Se/0	25	0.432	0.780	0.996
	30	1.263	2.281	0.998
	40	5.606	10.120	0.995
	50	28.859	52.092	0.995
Ag_2Se/30	25	1.096	1.320	0.984
	30	1.129	1.360	0.981
	40	0.946	1.140	0.942
	50	1.622	1.955	0.953

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Deformation and failure characteristics and bearing mechanism of a pillar group in stage open stope mining

Chao Wu[1,*], Xing Sun[1,2], Yuanhui Li[1], Shuai Xu[1], Changyu Jin[1] and Long An[1]
[1]Key Laboratory of Ministry of Education on Safe Mining of Deep Metal Mines, Northeastern University, Shenyang, China
[2]Shandong Gold Group Xihe County Zhongbao Mining Co. Ltd, Longnan, Gansu, China
*Corresponding author email: 1910358@stu.neu.edu.cn

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Keywords: Stage open stope mining (SOSM), Pillar group, Physical model test, Overload test, Stress rebalance effect

Stage open stope mining (SOSM) maintains the stability of excavation openings by leaving a large number of rib pillars. Affected by the strong unloading due to stage mining and the low width-to-height (w/h) ratio of the pillars remaining, large-scale destabilization disasters of rib pillars or excavation openings easily occur when the distribution of ground stress or the size of rib pillars is unreasonable. In view of these problems, a physical SOSM model test was carried out based on an underground metal mine in the city of Chifeng in China, revealing the deformation and failure characteristics of the SOSM pillar group by overloading. The physical model test results of SOSM and room-and-pillar mining with a weak pillar were compared, and the failure process of the SOSM pillar group showed the characteristics of rapid and severe damage. The strength difference between a weak pillar and the adjacent pillars enhanced the stress rebalancing effect and extended the failure process of the pillar group. Similar to the SOSM pillar group with a low w/h ratio, some high-strength pillars can be used to avoid large-scale destabilization disasters caused by the synchronous failure of pillars.

Introduction

SOSM is widely used in underground metal mines owing to its prominent advantages of high efficiency and low cost. Pillars, as the key structure in mined-out areas, play a dominant role in controlling stope stability. Therefore, understanding the bearing and failure characteristics of the pillars in SOSM is of great significance to guide the safety of underground mines.

Current research on pillar stability mainly focuses on the pillar load, pillar strength and pillar failure criterion. The pillar load can be obtained by theoretical analysis or numerical simulation. The pillar strength is usually estimated through empirical formulas established based on the mine pillar statistical database. The ratio of pillar load to pillar strength is expressed by the factor of safety (FoS), which is usually used to analyze the stability of pillars. Compared with that of a single pillar, the failure process of a pillar group shows systematic features, even domino failure [1]. The overall bearing performance is not only determined by a single pillar but also affected by the interaction among pillars [2]. At present, most efforts devoted to the bearing mechanism of a pillar group are based on room-and-pillar mining, and pillar failure pattern, stress-transfer mechanism and stability assessment have been given significant emphasis. However, the pillar-room structure between the traditional room-and-pillar mining and SOSM is significantly different. Research on the bearing characteristics of pillar groups based on SOSM is rarely reported. In this study, a physical model was built to investigate the deformation characteristics and bearing mechanism of a SOSM pillar group.

The physical model overload test of SOSM was designed based on a prototype of an underground metal mine in Chifeng, China. The stress, deformation and crack development during the loading process were monitored, and the characteristics of stress aggregation and transfer in the failure process of the pillar group were analyzed, revealing their effect on the stress evolution process and failure mode of a pillar group. The stress distribution and evolutionary characteristics of the room-and-pillar mining pillar group with a weak pillar during the failure process were compared, indicating that when the pillar strength of the pillar group changes, the stress rebalancing effect can be enhanced, the failure process can be extended, the synchronous failure of the pillars with a low w/h ratio can be avoided, and large-scale destabilization disasters can be prevented.

Results and discussion

The physical model loading curve of room-and-pillar mining shows that after reaching the peak value, the stress began to decrease. Affected by the interaction of pillars, with stress decreasing to 0.75 MPa, an internal stress adjustment occurred in the pillar group, and the stress was relatively stable during the stress rebalancing process (Fig. 1a). However, during the failure process of the SOSM pillar group, after the stress of the system reached the peak value, the stress decreased rapidly, and the internal stress adjustment process was difficult to identify in the unloading curve (Fig. 1b).

The strength difference between a weak pillar and normal pillars led to the obvious stress rebalancing process during the failure of the pillar group in room-and-pillar mining (Fig. 2a). Different form room-and-pillar mining, the pillar strengths of the SOSM were basically the same (Fig. 2b).

The development process of the stress-time curves of pillars of SOSM is highly synchronous. Thus, the effect of the stress redistribution process on the failure process of the pillar group was weak. For the SOSM case, it was difficult to directly analyze the stress rebalancing effect of the pillar group through the pillar stress-time curves. The existence of the stress rebalancing effect was proven only by incremental analysis of the pillar stress. The stress of the SOSM pillars reached the peak value almost at the same time. After the pillars reached the bearing limit, the stress decreased sharply, and the bearing capacity was lost quickly, causing violent destruction of the pillar group in a short time.

The room-and-pillar mining pillars showed weakly synchronous failure and weak unloading characteristics in the failure process, whereas the SOSM pillars showed highly synchronous failure and strong unloading characteristics in the failure process. The pillar strength difference of the pillar group enhanced the stress rebalancing effect, avoided the synchronous failure of pillars, and extended the failure process of the pillar group. The lower the w/h ratio of the

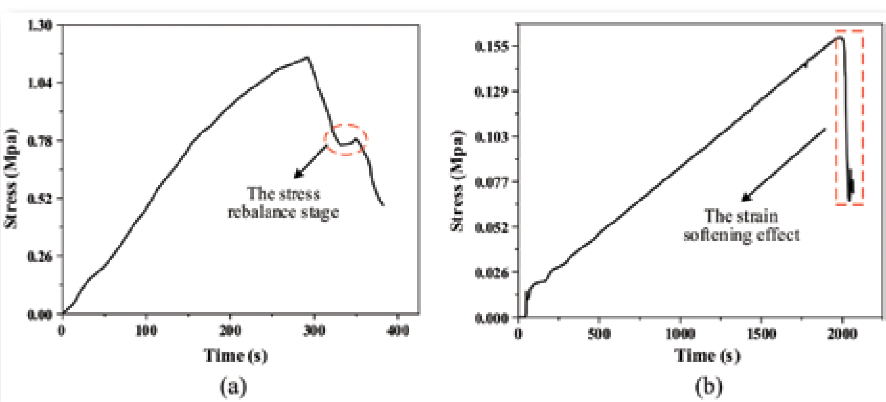

Fig. 1 Loading curves of the physical model: (a) room-and-pillar mining [3] and (b) SOSM.

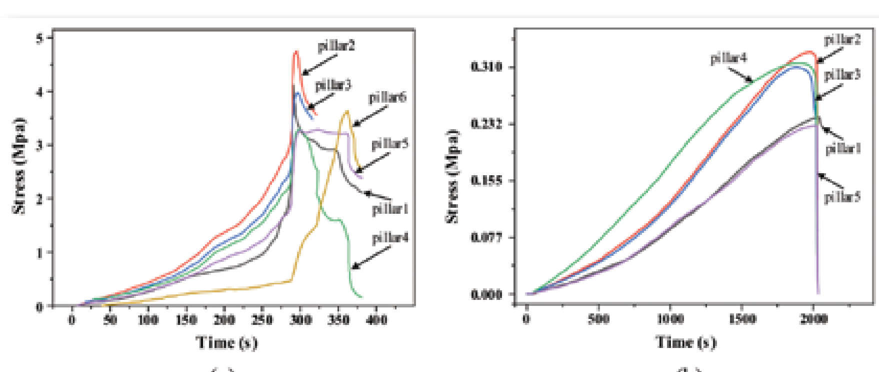

Fig. 2 Stress-time curves of each pillar in the loading process: (a) room-and-pillar mining [3] and (b) SOSM.

pillar, the faster the unloading rate, the lower the residual strength, and the more severe the failure process. The SOSM pillar group is a typical pillar group with a low aspect ratio, and the w/h ratio of the pillar in the physical model test is only approximately 0.5. For a pillar group similar to the SOSM pillar group, the strength difference between the pillars can be increased by setting some strong pillars, which enhances the stress rebalancing effect of the pillar group, avoids synchronous pillar failure and prevents large-scale destabilization disasters.

Conclusions

The SOSM pillars showed the characteristics of highly synchronous strong unloading in the failure process. However, because of the weak pillars, the room-and-pillar mining pillars showed weakly synchronous failure and weak unloading characteristics in the failure process, causing an obvious stress transfer process. In conclusion, the difference in pillar strength can enhance the stress rebalancing effect of the pillar group.

The pillars with low w/h ratio have the characteristics of fast unloading rate, low residual strength and severe failure process. The SOSM pillars are typical pillars with low w/h ratio and easily fail synchronously and rapidly, causing large-scale destabilization disasters. For the pillar group with low w/h ratio, some strong pillars can be designed to increase the pillar strength difference, enhance the stress rebalancing effect, and prolong the failure process of the pillar group. ■

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Dynamic response analysis of a reinforced concrete structure in underground coal mine environments with various strata conditions

Kutay E. Karadeniz, Samuel Nowak, Dogukan Guner and Taghi Sherizadeh*

Department of Mining and Explosives Engineering, Missouri University of Science and Technology, Rolla, MO, USA

*Corresponding author email: sherizadeh@mst.edu

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Keywords: Built-in place, Refuge alternative, Seal, Mine explosion, Numerical analysis

Mine explosions are one of the most concerning risks related to underground coal mining, as a single gas explosion can cause injuries and fatalities among miners. Underground infrastructure seals and build-in-place (BIP) refuge alternatives (RAs) are employed to isolate an area from active workings to mitigate coal mining-related accident risks. They are designed to withstand blast pressures from a possible accidental detonation of the contained gas or a coal dust explosion. Crosscut seals and BIP RAs, typically consisting of steel-reinforced concrete, are prone to strong convergence and have a significant leakage potential due to high convergence damage near mined-out areas. The roof-to-floor convergence can change the structural integrity of these structures, and altered structural integrity can lead to less explosion resistance capability. Hence, a thorough analysis is needed to further understand their explosion response under various strata conditions. In this study, a steel-reinforced concrete wall to be used in seal and BIP RA applications was simulated to examine the performance during an explosion for a coal mine model with different strata conditions using dynamic analysis by a distinct element code. The concrete wall simulated in the models is similar to that in the experimental study conducted by Zipf et al. [1] at the National Institute for Occupational Safety and Health (NIOSH) Lake Lynn Laboratory that is used for the structural tests. Because the roof, rib and floor rocks in the experimental mine consist of limestone, the simulations were first calibrated using the reported limestone strata conditions. Then, the models were generated in different combinations of typical coal mine environments using the calibrated initial model. The presented results can be used to predict the response of such infrastructure for different coal mine environments in the United States.

Background

Modeling methodology. The process of developing the 3DEC numerical model consists of the following steps: de-

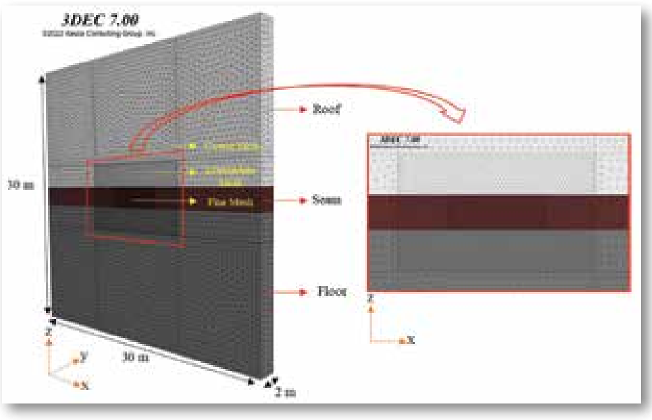

Fig. 1 Model geometry and mesh discretization.

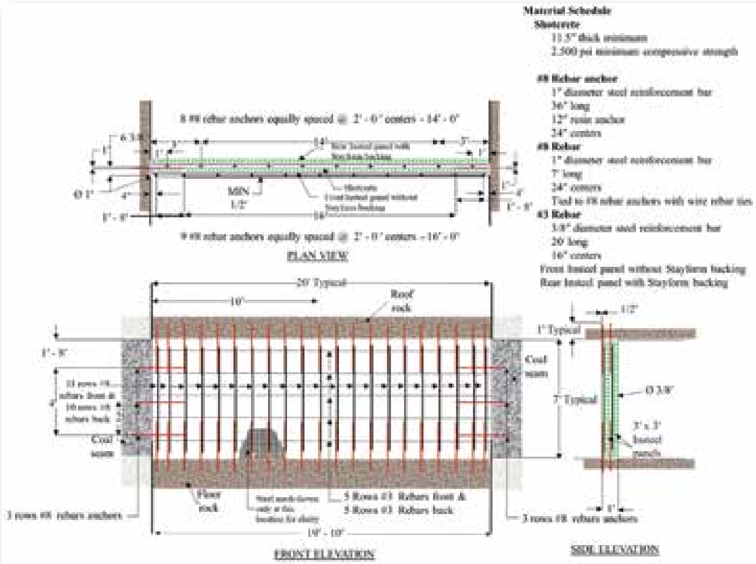

Fig. 2 Structure configuration used in the calibration; Category 1A structure front-view, plan-view and side-view drawings [1].

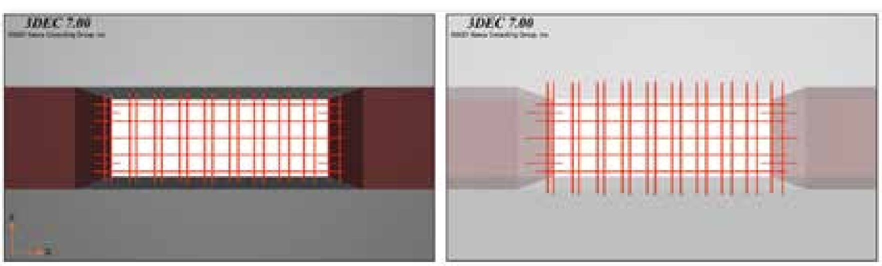

Fig. 3 Representation of rebars and anchors installed at the simulation (left) and the structure with anchors (right).

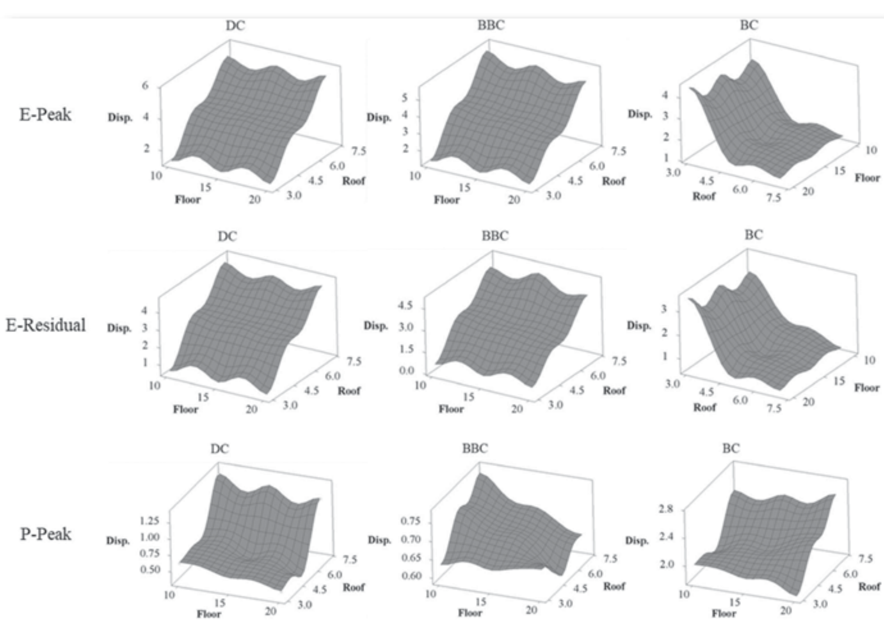

Fig. 4 Three-dimensional plots of peak and residual deformations (mm) to the corresponding stiffnesses of seam and floor (GPa) for three different coal types.

veloping the geometry, selecting appropriate material properties, assigning material and contact constitutive models, establishing boundary conditions, initializing in situ stress, modeling the excavation and fill of the concrete wall, and simulating dynamic loading conditions. For calibration purposes, the roof, seam and floor were assigned as limestone in the initial models. Upon calibration, these units were changed with typical U.S. coal mine lithologic units.

Calibration of the structure. The tested seal is made of concrete, steel reinforcement bar (rebar), and reinforcement wire. The seal is anchored to the surrounding rock by rebars (Fig. 2). The constructed concrete wall is 2.1 m high, 5.8 m wide and 30 cm thick.

The simulated structure (Fig. 3) was exposed to the same explosion overpressure versus time scenario as in the experiment. The calibration was conducted using the lateral deflection of the structure at the center. Upon calibration, the roof, floor and coal seam units were changed with various conditions by assigning distinct elastic and plastic material parameters. Each of the three combinations of these units was employed in the models, and the structure in each mine model was exposed to the same explosion overpressure curve. Input parameters for the rock and coal units used in the models are claystone/fireclay, black shale/gray shale, siltstone/gray shale for the roof; siltstone/sandstone, sandstone, limestone for the floor; and bright coal, banded bright coal, dull coal for the seam [2,3]. The structure under these different combinations of overlying strata conditions was again subjected to the same real-case scenario of the explosion overpressure used in the calibration stage.

Model results and discussion

These models were analyzed and compared in terms of lateral deformation on the wall to capture any possible effect or trends with the stiffness and strength of these three units for a typical coal mine environment. The peak and residual displacements were exported to a three-dimensional plot for each combination with the unit stiffness values (Fig. 4). Although the values for displacement during and after the explosion simulation are small, the changes are significant in terms of yielded elements on the concrete structure. The concrete wall shows some tensile cracks in the middle zone. Because the stress distributions inside the rock layers are governed by the stiffness, elastic parameters of the units become crucial for the convergence of roof to floor and rib to rib.

Conclusion

The results show that the overlying rock mass units of the structure are significantly important for the explosion response. The mining-induced stresses vary with changes in the mine environment, leading to changing clamping effects at the contact between the stopping and the strata. The transition from deviatoric stresses to hydrostatic stress conditions can be said to be resistant to this behavior, making the deviatoric stress difference between the roof and coal seam an advantageous scenario. There is no significant effect on the wall deformation because the used parameters for the floor unit are relatively high compared to the realistic coal mine environment. Because of the reasons stated above, the model with the stiffest and strongest combinations for each unit, roof, seam and floor, showed the highest deformation of the models included in this study. ■

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Effect of lead-zinc mining on the socioeconomic and health conditions of the Enyigba and Ishiagu lead-zinc mining districts of southeastern Nigeria

Anthony Chukwu[1,*] and Smart Chika Obiora[2]
[1]Department of Geology, Ebonyi State University, Abakaliki. Nigeria
[2]Department of Geology, University of Nigeria, Nsukka, Enugu, Nigeria
*Corresponding author emails: achukwu1@gmail.com; Anthony.chukwu@ebsu.edu.ng

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Keywords: Lead–zinc mines, Land contamination, Socioeconomic and health factors, Host communities, Rehabilitation

Mining has been one of the oldest activities of man for survival and development. Lead and zinc have been mined for more than 90 decades in parts of the Lower Benue rift in southeastern Nigeria by mining cooperatives and artisanal mining companies, but there has been little to no interest in the sustainability of the environment and the inhabitants of the host communities. Adverse effects include contamination of soil and food crops, lack of interest in education, poor healthcare provision, unemployment, and no access to potable water supply. In this work, practicable mitigation strategies are suggested, including liaising with relevant government agencies in collaboration with the mine owner, mine workers and host communities to ameliorate these negative effects and promote environmental sustainability.

Background

Mineral resources exploitation may generate huge economic achievements in the short term, but its effects on the environment and the socioeconomic wellbeing of the host communities and beyond can last for decades if steps are not taken to mitigate them. Lead-zinc mining in Nigeria and around the world is known to have adverse effects. About 357 to 857 million kg/a of lead and 462 to 1,380 million kg/a of zinc are reported to be discharged into the environment through mining and processing [1]. These metals migrate through the soil, dust, air, water, plants and animals. Mining processes can result in agricultural soil degradation, deforestation, wastelands, pollution of land, air, water and plants, and socioeconomic destabilization [2]. Although there are minerals and mining acts and regulations in Nigeria calling upon prospective investors' operations to preserve the environment, most mining companies and artisanal mines do not keep to the rules and regulations in their pursuit of profits. This work focuses on the physical and socioeconomic effects of active and abandoned lead-zinc mines in southeastern Nigeria over the years and offers some solutions.

Materials and methods

Twenty-two soil samples measuring 10 cm by 10 cm by 15 cm were collected from farmlands at about 20-m intervals, with three composite samples mixed thoroughly according to the recommendations of Obiora et al. [3] for the project on abandoned mines in Sub-Saharan African countries sponsored by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Swedish International Development Cooperation Agency (SIDA). The samples were air-dried and stored for further analyses. In addition, samples of 16 food crops were collected, washed and air-dried. The dried samples of the soils and food crops were sent to ACME Laboratories in Vancouver, Canada, to determine their contents of heavy metals.

Out of about 600 persons directly affected by mining activities, 61 were interviewed, as recommended by the UNESCO-SIDA project. Statistical analyses were done using Microsoft Excel packages and other relevant software.

Results

The interview results indicate that 80 percent of the mine workers did not wear safety gadgets during mining and had insufficient income from their jobs. More than 77 percent complained that they had no access to education. About 90 percent attested that they had no access to potable water supply in their localities. On environmental rehabilitation, more than 85 percent had no knowledge of planned or ongoing rehabilitation processes across the mining localities.

The soil analysis results show that most of the elements in the agricultural soils were within the permissible limits established in 2009 by the European Union, except for mean values of lead, Pb (1,490.71 mg/kg and 3515.46 mg/kg); zinc, Zn (1,036.11 mg/kg); manganesese, Mn (1,034.69 mg/kg and 2,747.58 mg/kg); and cadmium, Cd (4.07 mg/kg) across the Enyigba and Ishiagu mining district areas.

The concentrations of heavy metals in the food crops varied across the mining districts with most within the permissible limits set in 2006 by the EU and in 2001 by the Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO). However, Pb concentration in all the food crops sampled in both areas exceeded the threshold limit of 0.43 mg/kg set in 2006 by the EU and limit of 0.30 mg/kg set in 2001 by the FAO/WHO.

Discussion

There were alarming physical hazards identified and assessed in the lead-zinc mining areas of southeastern Nigeria. They include continuous exposure to vibrations from heavy moving equipment; noise from machines and electricity generators; lack of protection from sun exposure, especially in the case of open-cast mining (Fig. 1); confined spaces; falls due to gravity; and improper use of heavy machinery.

Around the mine areas, agricultural soil, food crops, vegetables and water were contaminated by lead, cadmium and manganese above permissible standards set in 2001 by the FAO/WHO [3]. Their health risk indexes (HRIs) were greater than 1, indicating serious potential health risk from lead, zinc and cadmium to consumers, with higher prevalence among children than adults.

Fig. 1 Open-cast lead-zinc mine at Enyigba, showing mine workers exposed to adverse conditions.

Environmental problems observed in the Enyigba and Ishiagu lead-zinc mines include contamination of agricultural soils by lead, zinc and cadmium, which directly affect the food crops in the area; destruction of the ecosystem in general, including to grazing flora and crops (Figs. 2a-b); and contamination of surface water by the direct discharge of wastewater into streams in the area.

The socioeconomic impacts of lead-zinc mining in Enyigba and Ishiagu can be measured based on unemployment, which leads to increases in social vices such as robbery, cultism, political thuggery and kidnapping within and in neighboring communities; high poverty in the areas with inadequate healthcare, which results in high maternal mortality; inadequate social amenities such as piped water and electricity; bad roads; low sanitary and hygiene levels; no access to clean water supply for drinking and regular handwashing; high cost of living around the mining host communities; and infertility.

Rehabilitation plans start with the initiation of discussion and enlightenment campaigns through working with the major stakeholders in mining industries, including relevant government agencies such as the Ministry of Mines and Steel Development, the federal and state Ministry of Environment and the National Environmental Standards and Regulations Agency (NESREA); nongovernmental organizations; host communities; mining companies; and mine workers.

Conclusions

This study shows that apart from the benefits of lead-zinc mining in the Enyigba and Ishiagu areas of southeastern Nigeria, there were several negative effects of lead-zinc mining in the areas which still persist, and no proper attention had been given to ameliorate these effects. These problems, which include human and environmental issues, had serious effects on the social development of the host communities and surrounding areas. This study is also meant to bring the major stakeholders in the mining industry to a roundtable discussion on how to secure the environment and develop the host communities from which these minerals are being recovered. There is a need for both the mining companies and surrounding societies to adopt a positive change of culture for better environmental sustainability of the societies. ■

Fig. 2 (a) A rice farm and (b) economic trees, including palm trees, in Ishiagu, kilometers away from the mines.

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MEC K-12 Outreach pilot program

Overview of year one and plan going forward

by Akudo Nwokeukwu, Minerals Education Coalition outreach coordinator

The Minerals Education Coalition (MEC) K-12 Outreach pilot program, chaired by Wendi Cooksey, aims to bring mining and minerals education and awareness to K-12 classrooms by implementing mineral lessons, hands-on activities, field trips and tours to local mines and mining schools.

The pilot program launched in Colorado in August 2022 at two Denver public schools: Place Bridge Academy (grades K-8) and Denver South High School (grades 9-12). The goals of the program are to achieve a greater public understanding of mineral uses, improve recognition of the importance of mining, and get K-12 students interested in careers in the mining and minerals industry. These goals will be met by working on the following objectives:

Dick Beach teaching Denver South High School students the history and common uses of the elements in the periodic table.

- Assist the local sections to establish a speaker's bureau and prepare ready-to-use presentation resources for classroom presentations.
- Help sections participate in mentorship programs and career fairs.
- Help SME members build relationships with their local K-12 teachers.
- Help SME sections plan field trips to mining and minerals museums, mining operations, aggregate plants and/or campus tours.
- Encourage SME members/sections to become more involved in outreach in their local communities.

During the 2022/23 school year, the pilot program completed 12 mining-related lesson presentations, hosted a field trip to the Colorado School of Mines and offered educational resources to K-12 teachers. The following are some of the notable presentations.

Drilling with Donuts

Heather Lammers and Dick Beach led a "Drilling with Donuts" exploration activity for 20 second-grade students. The students engaged in a safety discussion at the start of the presentation and were able to decorate their own hard hats with stickers supplied by the Colorado School of Mines. Each student received a donut: some with filling, and some with toppings. The toppings represent how minerals are located on the surface of the ground, and the donuts with filling represent how minerals are found underground. The students were able to locate "minerals" unique to their donuts using a variety of utensils to represent drilling and sampling methods.

Beach facilitating a mineral conductivity experiment at Denver South High School.

Mineral careers

Over the school year, nearly 100 students attended presentations on careers in the mining industry. The students engaged in a discussion about the mining life cycle and what minerals make up everyday items, and they participated in a mineral career-mapping exercise where they learned more about mining engineers, blasters, equipment operators, exploration geologists, equipment mechanics and mineral processors. The students were able to ask questions throughout the activity about what it is like to work in the minerals industry.

Rocks and minerals

Twenty-three high school students and 70 elementary school students learned about rock formation, rocks com-

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SME News Contents

Summary of the Jackling Lecture

by Adam White, chief technology officer, Deswik, and Jackling Award recipient and lecturer

Mine planning software is a core part of building or operating a mine, and it has evolved significantly over the last 40 years. The process for mine planning has fundamentally remained the same, but the tools available to mine planners have evolved exponentially. The improved accuracy and quality in mine plans have translated into significant improvements in efficiency and profitability in mining operations.

In the 1980s and 1990s, as computing became available to organizations, software was written that modeled the geology of a deposit and allowed the traditional manual methods of resource and reserve estimation to be replaced by digital equivalents. These programs were heavily reliant on the use of scripts to deliver a result. Scripting and command language is not for everyone, so the ability to use these programs well was siloed to a small number of people.

The late 1990s and early 2000s saw mine planning become more sophisticated as software dynamically integrated three-dimensional computer-aided designs to a built-for-purpose scheduling program (not Excel). This supported a repeatable mine planning process that allowed multiple mine plans to be updated every month instead of one plan being produced each year.

Adam White

Over the last decade, the focus has moved to building tools that support mine planning processes through workflow and data management, as well as short-term scheduling systems that manage short interval control (SIC).

With increasing amounts of data being generated at mine sites by multiple complex systems, the approach of storing critical mine data using flat files on a network folder is no longer appropriate. There is no control of these files, no versioning, and no confidence that the right data are being used. This makes the data unauditable and represents a risk to producing accurate mine plans, impacting productivity and safety.

There has also been a major drive to push short-term schedules down into operations and implement SIC as a way of managing a site's production. It has been used in many industries for years with great successes but is still in its infancy in mining.

SIC is a management technique that is growing in popularity in the mining industry. It aims to improve the productivity and efficiency of the mining operations by ensuring that the mine is well planned, the activities that are planned are executed in the desired order of priority, and that unexpected events can be remedied in real time to bring the mine back on track. A key goal of SIC is to improve based on your learnings, then do it again in a better way.

The software that supports this also aims to empower the miners to have the information they need to achieve or increase production targets.

There are many challenges with the technical systems used at mine sites including:

- Complexity of software and models.
- Detail built into designs and plans from different time horizons.
- Amount of data available.
- Bringing cloud compute capabilities to remote operations.
- Providing effective connectivity to the face.
- Optimization is not applied regularly or correctly.
- Systems integration — more open standards needed.
- Change is hard.
- Skills shortage and lack of new mining graduates entering the industry.

As the industry continues to trend toward higher attrition rates, shortages of mining professionals and software developers working in the industry will cause the technology to evolve at a decreased pace. Additionally, this could cause a greater reliance on technology to offset the lack of skilled individuals available to run the mines.

Finally, several trends that we see in the industry include:

- Digital awareness is now pervasive.
- Increased automation and optimization.
- Workflow-based processes.
- Mine scale is increasing.
- Networks are improving (Starlink, 6G).
- Greater use of data and analytics.
- Systems thinking.
- And of course, the use of artificial intelligence, or AI (ChatGPT, etc.).

These all provide both incentives and the foundation to allow technology to continue to evolve and grow in the mining industry. It is an exciting time as, while there are many challenges with bringing forward the next generation of software, the benefits they will have on the industry will be significant. ■

(The Jackling Lecture on "The Evolution of Mine Planning Systems" was presented during the Mining & Exploration Division Luncheon in March at the MINEXCHANGE 2023 SME Annual Conference & Expo.)

Rock in the Box serves as a forum for the presentation and discussion of facts, ideas and opinions pertaining to the interests and technology of the Mining & Exploration Division. Accordingly, all material published herein is signed and reflects the individual view of the authors. It is not an official position of SME or the division. Comments by readers will be referred to that division for response. The division chair in 2023 is Bradley M. Dunn.

The mythology of geometallurgy

by Isabel Barton, assistant professor, University of Arizona

Geometallurgy can be many things. Wikipedia defines it as "the practice of combining geology or geostatistics with metallurgy … to create a spatially or geologically based predictive model for mineral processing plants." Another definition is "the initiative to integrate geologic knowledge into mining operations in order to increase their efficiency and effectiveness, enhance return on investment, and create opportunities for sustainable development" (Olson Hoal and Frenzel, 2022). In other words, geometallurgy is figuring out how the mineralogy of an ore deposit will mess you up when you try to get the metal out of it.

It is difficult to pin down exactly what geometallurgy is. But there are quite a few things that it certainly is not, and all too many of them can be found flying around academia and industry. The following handy guide will help you identify some common myths about geometallurgy and shoot them down before they spatter unwanted nitrate biominerals all over your mine.

Fine Grind **serves as a forum for the presentation and discussion of facts, ideas and opinions pertaining to the interests and technology of the Mineral & Metallurgical Processing Division. Accordingly, all material published herein is signed and reflects the individual view of the authors. It is not an official position of SME or the division. Comments by readers will be referred to that division for response. The division chair in 2023 is David G. Meadows.**

- **Myth 1: Geometallurgy is not worth what it costs.** This species of myth, found in industry, is readily identified by a characteristic call pronouncing automated mineralogy "QEM-Scam," and a firm belief that geometallurgy is for after recovery has mysteriously tanked. In fact, geometallurgy is a big investment up front, but it is still cheaper than "pray, hope, and retrofit" as a strategy (Lotter et al., 2018). Sightings of this myth in the wild are getting rarer as the increasing mineralogical complexities of orebodies, and the escalating economic penalties of not understanding them, drive it toward extinction.
- **Myth 2: Geometallurgy is novel.** This is a myth notable for its proud plumage and strutting gait. It mostly nests in academia, taking advantage of its host's blindness to any work more than 20 years old. Google's NGram viewer shows that "geometallurgy" has indeed taken off since the early 2000s. But search the literature for "process mineralogy" or "deposit knowledge," and you will find that the idea of knowing what you are mining dates back to at least the 1840s. Hugh McKinstry described geometallurgical principles in his 1954 *Mining Geology*. Georgius Agricola covered aspects of it in *De Re Metallica* in 1556. Computerization and automated analytical techniques have made geometallurgy larger in scale and more quantitative in recent years, but the concepts have not changed.

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MPD launches Best Presentation Awards

by Kimberly Mills, secretary-treasurer, MPD Executive Committee

This year, the Mineral & Metallurgical Processing Division (MPD) is launching a new initiative. The MPD wishes to recognize the speakers who made the best presentations during the MINEXCHANGE 2023 SME Annual Conference & Expo for each of the five MPD unit committees — consisting of chemical processing, comminution, flotation, physical separations and plant design — with a Best Presentation Award. The following speakers are recognized as this year's outstanding winners:

Unit committee	Presentation title	Presenter
Chemical processing	Challenges to Establish LIB Supply Chains in North America	Jan Pfeifer
Comminution	Failure Analysis of Large Castings Used in Mineral Ore Processing	Daniel DeMiglio
Flotation	History of Flotation Through the First Chemicals and Early Machines	Courtney Young
Physical separations	Vacuum Disc Filter Go Beyond	Juergen Hahn
Plant design	Tailings Reprocessing Project at Golden Sunlight Mine	Kristine Murphy

The MPD would like to carry on this tradition and

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Corporate Roundtable Partnership

opportunities and benefits

by Lorie Laessig, SME Foundation coordinator

Since 2013, numerous companies have been invited to join the SME Foundation Corporate Roundtable Partnership to contribute and support SME Foundation programs. More than $8 million has been donated to the SME Foundation to date. This campaign has provided opportunities for companies and professionals in mining to give back to their profession and support the next generation of leaders who will define our industry's future. For businesses across the mining and minerals industry, the Corporate Roundtable Partnership is an investment to build a future for world-class mineral education and to encourage young people toward mining careers.

With support from across the industry, SME and the SME Foundation are dedicated to providing targeted programs to recognize the opportunities and meet the enormous challenges facing our industry today and in the years ahead. In order to meet the world's needs, we will need to increase our production, pioneer new capabilities and become a more global industry than ever before.

We invite corporations and businesses engaged in the mining and minerals industries to become Corporate Roundtable Partners today with an annual commitment of $25,000 or more. Currently, there are 15 companies giving at this level. These corporations have something essential in common; they have invested in the people who make our companies and our industry great. The success of the Corporate Roundtable Partnership depends on the support of forward-looking companies who share the SME Foundation's mission to attract and leverage resources for a sustainable mining industry through education and outreach.

Corporate Roundtable Partners receive benefits that include:

- Recognition and acknowledgement in SME Foundation materials and at SME Foundation events.
- Acknowledgement in the SME Drift email newsletter and *Mining Engineering* magazine.
- Complimentary seating at the SME Foundation Annual Gala Dinner (minimum $50,000 Corporate Roundtable Partner level and above).
- Exclusive time at the MINEXCHANGE SME Annual Conference & Expo to meet with and interview students and recent graduates for internships and full-time employment.
- Invitation for an annual forum meeting between SME leadership and corporate partners.

For more information on Corporate Roundtable Partnership opportunities and a full list of benefits, please visit community.smenet.org/smefoundation/crp/home or contact Megan Martin, SME Foundation Manager at martin@smenet.org. ■

Ensure your lasting legacy with a gift to SMEF

The SME Foundation's (SMEF) Legacy Club members are an exclusive group of donors who have included the SMEF in a bequest or in their legacy planning. The first member, Robert Shoemaker, created his lasting legacy through a combination of gifts while he was living and when he passed away. He believed that "each of us must contribute more of ourselves to our (SME) Society" to make it a more effective professional organization. Shoemaker's legacy gift has partially funded 15 Ph.D. Fellowship recipients. His gift was, and continues to be, a living investment in the future.

The Legacy Club is a unique way for us to appreciate your generosity and honor your investment in SME's future if you choose to include the SME Foundation as a named beneficiary or in your estate plans. Many insurance policies, bank accounts, retirement plans, pensions and other accounts have beneficiary designations. You may name your designated beneficiaries to a family member and you may also designate a portion to the SME Foundation, whether as a percentage or a set amount. This is easy and flexible, and you can review and revise your beneficiary designations anytime you wish. In addition, all retirement plan assets can pass to a charity without being taxed.

Many supporters like you have helped strengthen the SME Foundation by donating to meet current and future needs. By leaving a legacy gift, your contributions will support the mining and minerals industry for years to come. The SME Foundation offers flexible options for a variety of circumstances, and each has distinct financial benefits for both the SME Foundation and your family. We will gladly answer any questions you may have; however, we encourage you to talk with your tax advisor or estate planner for your specific situation. Please visit www.smefoundation.org or go to community.smenet.org/smefoundation/plannedgiving/legacyclub for more information. ■

Looking ahead to MINEXCHANGE 2024

by Julie Neilson, research professor in environmental science, University of Arizona

Summer is here, and it is time to submit abstracts for the MINEXCHANGE 2024 SME Annual Conference & Expo. The SME Environmental Division encourages members to submit an abstract to speak in one of the many Environmental Division sessions planned for MINEXCHANGE 2024, which will be held Feb. 25-28, 2024 in Phoenix, AZ. The Environmental Division has 12 sessions planned for the conference. They are:

1. Abandoned mine lands: Considerations and opportunities.
2. ADTI-critical minerals in mine wastes.
3. Environmental solutions to protect the environment.
4. Geophysics for mining applications.
5. Geosynthetics applications.
6. Green mining.
7. Mine closure and reclamation.
8. Mine water management and treatment.
9. Mining hydrogeology.
10. Passive mine water treatment: successes, realities, and lessons for the future.
11. Sustainability and ESG disclosures.
12. Technology's road to compliance.

Abstracts are due by Aug. 1, 2023. Check the SME website at www.smenet.org for conference updates. Questions can be directed to Amar Patel, Environmental Division program committee chair, at APatel@barr.com. ■

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Calling professional-engineer members

please help complete the PAKS survey

by Andy Schissler, SME PE Committee

Every seven years, the Professional Engineers examination for mining/mineral processing (MMP) and the examination subject matter is updated in a process named the Professional Activities and Knowledge Study (PAKS). SME completed the PAKS in 2002-2003, 2009-2010 and 2015-2016.

A critical activity of PAKS is asking engineers if the topical outline of the subject matter is current and reflects what professional engineers do on the job. Please access the survey using this link: ncees.org/ncees-seeks-licensed-mining-mineral-engineers-professional-expertise-and-advice/. Your response will greatly advance our professions and assist in the PAKS. Thank you. ■

Museum community outreach

part-time position now open for applications

by Greg Kruse, project manager – Fluor, Genesis Alkali

The Tate Geological Museum in Casper, WY is advertising for a part-time museum community outreach education specialist who will be responsible for working with the SME grant to be an advocate for the mining industry at Casper College. This position was funded by the Central Wyoming Section and will help facilitate understanding of Earth systems sciences and how we utilize Earth resources in our everyday lives.

The part-time museum community outreach education specialist will organize field trips, schedule guest speakers and conduct other events that will enhance the community's understanding of potential careers in the mining industry. Educational programming that focuses on Natrona County youth will also be an important part of this position to generate an interest in the mining sector.

To see details and submit an application, go to: phe.tbe.taleo.net/phe03/ats/careers/v2/viewRequisition?org=CASPER&cws=51&rid=1386. ■

MEC

(Continued from page 101)

posed of minerals, and how these materials are used to build civilization and sustain a lifestyle. They watched a demonstration of the methods and tools geologists use to study the Earth.

Mineral processing

During a minerals separation activity, more than 50 high school students were provided a "mineral mixture" of sand, beads, iron filings and salt. They worked in pairs to use the tools provided, which included screens, spoons, water, cups and magnets, to separate each of the individual "minerals" from the mixture. The students recorded their procedure in a process flowsheet and competed against each other in speed and completeness of steps.

Mineral scientific method

Using the scientific method, Beach had 25 high school students observing, testing and recording data to determine selected properties of important rock and mineral samples. The samples and presentation were tailored to meet applicable standards.

Erosion

Richard Schwering gave a presentation on erosion and weathering to 23 high school students. After the lecture, small groups conducted laboratory work designed to demonstrate the concepts of weathering and erosion by wind, rain/stream, wave and chemical weathering processes. The lab work included applications and investigations of the scientific method.

Colorado School of Mines field trip

Bruce Yoshioka welcomed 19 high school students on a tour of the Colorado School of Mines. The students received a Mines backpack with admissions information and went to the mining processing laboratory for a short presentation on the mining industry, which included a froth flotation exercise. After the lab exercise, the students took a self-guided tour of the Mines Earth Museum and a walking tour of the Earth Mechanics Institute.

Plan for the future

The pilot program will continue in the same Denver public schools for 2023/24 and will be replicated in two Utah schools for the 2024/2025 school year. If successful, an Outreach Action Plan toolkit will be developed and disseminated to SME sections. In the meantime, resources are available to SME sections for local outreach efforts on the Minerals Education Coalition website at mineralseducationcoalition.org/. ■

Denver South High School students modeling the flotation process at the Colorado School of Mines.

Dick Beach's rocks and minerals presentation to the third-grade class at Place Bridge Academy.

Bill Hancock is the nominee for SME President in 2025

BILL A. HANCOCK is president of Zeroday Enterprises LLC, which supplies water treatment chemicals, process component equipment and custom chemical mix-feed systems, and principal of Argo Consulting LLC, which provides technical and marketing mineral process and water treatment consulting services to the mining industry. Hancock earned his B.S. degree in mineral engineering from the University of Minnesota and an MBA from Northern Michigan University. He is a registered Professional Engineer and SME Registered Member. Hancock has been designated a Fellow of SME and of AusIMM. Prior to founding Zeroday and Argo, Hancock held various executive, senior technical and account management positions at large and medium-sized mining and sales companies as well as holding a university business department adjunct teaching position. Hancock has been awarded two mineral process patents and has published several technical and finance papers.

Hancock has held numerous SME leadership positions, including president of the SME Foundation and of OneMine.org; served three times on the SME Board of Directors and was chair of the Mineral & Metallurgical Processing Division. Additionally, he served as chair of the national GEM Committee, Annual Meeting Program Committee, SME Products & Services and Structure & Governance committees. Further, Hancock has served on four symposia organizing committees and on the editorial board of the *Minerals & Metallurgical Processing* journal. For his efforts on behalf of SME and the mining industry, Hancock has been recognized with the SME Fellow, Mill Gentleman of Distinction and Foundation Backbreaker awards and has been awarded two Presidential Citations; once for his work as the national GEM Committee chair and then a second time for organizing and leading early SME's eLearning development efforts.

Bill A. Hancock

Nominees for the 2024 SME Board of Directors

COURTNEY ALAN YOUNG is the Lewis S. Prater Distinguished Professor, Metallurgical and Materials Engineering at Montana Technological University (Montana Tech). He was born in Great Falls, MT where he attended public schools, graduating from Great Falls High School as salutatorian (#10 of 525). While in high school, he toured various Anaconda Copper Co. operations and Montana Tech, ultimately deciding on a career in minerals and metals. He affirmed his choice and not only graduated from Montana Tech with a B.S. in mineral processing engineering but also with an M.S. in mining and minerals engineering from Virginia Tech and a Ph.D. in metallurgical engineering from the University of Utah.

Courtney A. Young

Young became faculty at Montana Tech as an ABD postdoc (1993) and professor (1994) when he completed his dissertation on the job. His broad background allows him to teach various subjects. Courses include mineral processing, characterization and analysis, hydrometallurgy, pyrometallurgy, materials handling, flotation, and energy resource processing as well as gold processing and fire assay. His approach to the latter two is innovative because he gets subject-matter experts from Newmont and local consultants as guest lecturers. Furthermore, fire assay is a five-day, hands-on short course for the world to attend.

His research has been broad with most projects being funded by industry, predominantly involving mining sustainability issues and critical materials: gold (Au) recovery, cyanide remediation, rare earth element (REE) ore testing, dust and spent pot-liner remediation, synthetic lunar soil, slag and tailings repurposing, ARD treatment, depressants in bulk copper-molybdenum separation, electrowinning energy savings, flotation modeling, iron production from slag, flowsheet design, Au and titanium dioxide (TiO_2) nanosynthesis, plastic recycling, sulfide surface reaction determinations, and REE recovery from secondary resources. Consequently, he is accomplished, having been recognized with Montana Tech's Research

In compliance with the SME Bylaws, upon board approval of the Nominating Committee's proposed nominees for officers and directors, the names and biographies of the nominees will be published in an issue of *Mining Engineering.* Any group constituting at least five percent (5%) of the members of the Society may, by written petition signed by all of such members, submit additional nominations for these positions for the upcoming meeting. Such nominations must be received by SME staff no later than 90 days from the date of this publication.

Award (2009) and Lifetime Distinguished Researcher Award (2016) as well as the SME/MPD's Antoine M. Gaudin Award (2020) and Henry Krumb Lecturer (2021), to name a few.

Throughout his career, he encouraged students to become SME members and attend the SME Annual Conference & Expo. He particularly speaks through his actions by presenting, publishing, chairing, organizing and participating. Regarding the latter, he is helping with the technical content of the XXXI International Mineral Processing Congress (IMPC) 2024 and looking forward to working on the SME Board of Directors beginning 2024.

JUSTIN ANDERSON is the vice president, Americas for Trident Royalties PLC, a diversified mining royalty company, where he is focused on sourcing and evaluating new investment opportunities. Prior to joining Trident in 2023, he was a senior vice president with McGriff Insurance Services' mining insurance practice, where he worked on developing comprehensive risk management and insurance solutions for mining companies. He spent more than a decade with Resource Capital Funds, a mining-focused private equity fund managing a large mining investment portfolio. He also worked as a mining engineer for several consulting companies.

Justin Anderson

Anderson earned his bachelor's degree in mining engineering and master's degree in mineral economics from the Colorado School of Mines, and he is a licensed Professional Engineer in Colorado.

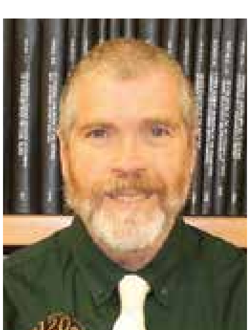
Anderson has been active in SME beginning in college, where he served in several leadership roles. Since graduation, he has been an active member of the Colorado Section, where he has held multiple leadership positions including chair, vice chair, treasurer and secretary. On a national level, he has served on the Finance Committee and Young Leaders Committee, including holding the chair position in 2011. Currently, he is chair of the Structure & Governance Committee and a member of the Audit Committee. Outside of SME, Anderson is a member of the International Organizing Committee of the World Mining Congress.

In 2015, Anderson was awarded the SME Mining & Exploration Division Outstanding Young Professional Award and Colorado School of Mines Young Alumnus Award.

Coal & Energy Division officer nominees

CHAIR

PAUL W. CONRAD is a professor of mining engineering at Montana Technological University. After graduating from high school, he worked in an underground coal mine for two years with his father, making him the third generation in his family to work in that same mine. He has both a B.S. and an M.S. degree in mining engineering from the Pennsylvania State University and a Ph.D. degree in mining engineering from the University of Kentucky. He is a registered Professional Engineer in Pennsylvania.



Paul W. Conrad

Conrad has more than 38 years of engineering work experience in the mining, civil, hydraulic, environmental, construction, permitting and research engineering fields. This includes work at mining and construction operations, government agencies, consulting firms and academia. He has conducted research in reforestation, mine optimization and mine reclamation and has had numerous peer-reviewed publications with his graduate students and research collaborators.

Conrad has been active in the SME. This is his second time serving on the SME's Coal & Energy (C&E) Division Executive Committee, and he has routinely chaired technical sessions at SME conferences for the C&E Division. He is currently a member of the SME's Mining and Mineral Processing PE Exam Committee, is an ABET program evaluator for mining engineering programs and is a former member of the *Mining Engineering* Peer Review Editorial Board.

VICE CHAIR

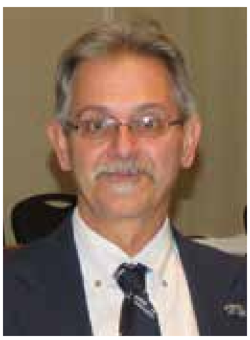
STEVEN J. SCHAFRIK is currently an associate professor of mining engineering and a faculty fellow of the James B. Beam Institute for Kentucky Spirits at the University of Kentucky. He is conducting research on applying advanced computing technologies to mining problems such as machinery automation, mine ventilation, dust control and underground wireless communication. Schafrik is the faculty advisor to the University of Kentucky RescueCats collegiate mine rescue team as well as the founding secretary/treasurer of the Eastern Collegiate Mine Rescue Organization.

Steven J. Schafrik

He has served SME on the Innovation Strategic Committee, C&E Division Executive Committee, Annual Conference & Expo Program Committee, C&E Mine Safety Committee, *Mining Engineering* Committee and Central Appalachian Local Section Executive Committee, of which he is a past chair.

SECRETARY/TREASURER

EDWARD F. ZEGLEN JR., P.E., has more than 42 years of experience in the coal mining industry and is currently working as a mining engineering consultant. Zeglen was previously the chief engineer with Alpha Natural Resources, Pennsylvania Services Corp., where he covered approximately 20 mines and held ventilation training classes for those operations. He also worked for GMS in various capacities including project management, mine coordinator and shift foreman, mine examiner and chief mining engineer.



Edward F. Zeglen Jr.

Zeglen has performed ventilation troubleshooting at company-affiliated mines in Pennsylvania, West Virginia, Kentucky, Alabama, Virginia, Utah and Colorado as well as in seven coal mines in New South Wales, Australia.

He has a bachelor of science degree in mining engineering from the Pennsylvania State University (Penn State) and is a registered Professional Engineer in Pennsylvania. Zeglen currently holds Mine Foreman certificates in Pennsylvania and Utah. He has been active in mine rescue for 33 years and is currently the coach/mentor of the Penn State student team. Zeglen currently serves on the board of directors for the Pittsburgh Coal Mining Institute of America (PCMIA) and is a past chair of the Pittsburgh Chapter of SME.

PROGRAM COMMITTEE CHAIR

SAM BAKER is a mining engineer at Rosebud Mining Co., a leading underground metallurgical and thermal coal producer in western Pennsylvania. He is responsible for underground directional drilling, multiple-seam mining analysis and ground control, methane mitigation and special projects. A graduate of the Pennsylvania State University with a B.S. in mining engineering, Baker has been active in SME since his freshman year of college. Since then, he has served as a C&E Division representative on the Young Leaders Committee (YLC), as vice chair of the YLC and as a C&E Division technical session chair, and he is a member of the board of the SME Pittsburgh Section.

Sam Baker

PROGRAM COMMITTEE VICE CHAIR

JIM HAUGHEY, P.E., is the business development director for Komatsu's underground soft rock division with a focus on industrial minerals' applications. He is responsible for customer development strategies, corporate office engagement and application engineering.

Jim Haughey

A 30-year Komatsu veteran, Haughey has held technical and product management positions on many of the Joy products and has been significantly involved in the application of such equipment in different markets and minerals. A graduate of Grove City College, he holds a bachelor of science degree in mechanical engineering and is a Professional Engineer in Pennsylvania.

Environmental Division officer nominees

CHAIR

ANNELIA TINKLENBERG is a senior hydrogeologist at INTERA Inc. She is a licensed Professional Geologist and has more than 15 years of experience in hydrogeological investigations and site characterization in support of mineral development projects and mine closure and reclamation. Her technical background and project experience includes designing and leading groundwater and surface water investigations, managing drilling programs, leading hydrologic testing, and characterization and closure of uranium mine and mill sites. Tinklenberg has been active in SME for several years and has served on the Environmental Division Scholarship Committee and as Program Committee Chair.

Annelia Tinklenberg

VICE CHAIR

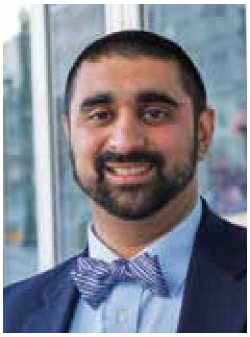
OMAR SMITH is a lead consultant at WSP. He has more than 15 years of experience supporting the mining industry on a variety of projects at numerous properties throughout Arizona, New Mexico, Nevada, Mexico and South America. Smith has a strong civil-engineering technical background with proven professional skills in site civil design, hydrologic and hydraulic engineering design, three-dimensional computer-aided

Omar Smith

design, construction quality assurance and quantity takeoff/cost estimates. Smith has served on the SME Tucson Section board for the last 12 years and is currently serving as the immediate past chair. He is also serving his second term as a member of the SME Structure & Governance Committee.

SECRETARY/PUBLICATIONS

AMAR R. PATEL is a senior air quality scientist at Barr Engineering in Salt Lake City, UT. He received a B.S. in chemistry from Tulane University with a minor in finance. Patel started his career with Freeport-McMoRan at the Morenci Mine in Arizona before joining Barr in 2016. At Barr he currently supports the mining, manufacturing and refining industries as a technical advisor and project manager. During his career, Patel has been involved in numerous projects focused on air quality, water quality, permitting, compliance and wildlife. He has served on the SME Young Leaders Committee since 2019, in subcommittee leadership roles and as an SME division/strategic committee representative.



Amar R. Patel

PROGRAM CHAIR

HEATHER HALDERMAN is a senior project manager with Knight Piésold. She has more than 26 years of experience in civil and environmental engineering, including environmental compliance, site investigation, remediation, feasibility studies, mine planning and closure, tailings management system integration, Global Industry Standard on Tailings Management auditing, and hazardous-waste projects. She has extensive experience in project management and execution, including regulatory analysis and negotiation, permitting, data interpretation, cost estimating and risk analysis. Halderman has served as chair on several Environmental Division committees and is currently the Program Planning Chair.

Heather Halderman

PROGRAM PLANNING CHAIR

GENEVIEVE M. SUTTON, P.E., is a two-time graduate of Missouri University of Science & Technology (Missouri S&T, formerly University of Missouri-Rolla), with B.S. degrees in metallurgical engineering and in mining engineering. She has worked in aggregates, coal and metal mining over a 20-year career in operations, engineering, environmental compliance and project management.

Genevieve Sutton

Sutton has been with The Doe Run Co. since 2011, filling various key roles in the environmental and remediation departments. She is currently its remediation business manager, overseeing all active remediation projects including the Old Lead Belt, Viburnum Trend, Glover and Herculaneum sites. She regularly participates in community engagement activities to promote the public perception of mining and is involved in a committee to enhance the working partnership between Doe Run and Missouri S&T. In 2015, she was invited to participate on the Missouri S&T Mining Engineering Department's advisory board, and was inducted into the Mines and Metallurgy Academy in 2017.

Sutton has NCEES Professional Engineer licensure in mining and mineral processing. She has been an SME member at the local-chapter and national levels since 1997, and she has served as chair of the local section for multiple terms, on the SME Structure & Governance, Products & Services and Association Growth strategic committees, and on an ad hoc committee to improve relations between local sections and national SME. She is currently serving as chair of the reformed SME PE Committee.

Health & Safety Division officer nominees

Pedram Roghanchi

CHAIR

PEDRAM ROGHANCHI is a Freeport-McMoRan Endowed Assistant Professor of Mineral Engineering at the New Mexico Institute of Mining and Technology (New Mexico Tech).

His research interests encompass several areas of mining engineering. including occupational health, dust control, mine ventilation, surface and underground mining. He is director of the Occupational Health and Safety Lab (OHSL) at New Mexico Tech. This laboratory conducts several health and safety projects related to occupational health; respirable dust; particulate toxicity and respiratory deposition; dust suppression systems; automation; unmanned aerial vehicles; and hazard mitigation.

Roghanchi is a co-author of more than 40 peer-reviewed journal and conference publications.

VICE CHAIR

KIMBERLY WALSTER, CMSP, is mine safety manager

Kimberly Walster

at Prairie State Generating Co. in southern Illinois. In addition to being a Certified Mine Safety Professional (CMSP) and Certified Occupational Safety Specialist (COSS), Walster holds certifications in leadership psychology from Cornell University and in management from the University of Notre Dame.

At Prairie State her focus is on the CORESafety Health and Management System, including continuous improvement of safety processes and risk management. As an on-site emergency medical technician (EMT) and cardiopulmonary resuscitation (CPR) instructor, she is passionate about sharing knowledge on best practices in the mining industry.

PROGRAM CHAIR

AMY J. RICHINS received B.S. and M.S. degrees in mining engineering from the University of Utah. In 2019, she received the Robert S. Shoemaker Ph.D. Fellowship Grant and is now completing that degree at the University of Utah.

Amy J. Richins

Richins was with FLSmidth Minerals for several years holding many different roles, including project manager and flotation products specialist, and is presently property and range manager for Circle R Livestock LLC, a producer of grass-fed beef cattle. She has authored three book chapters, several conference papers and many conference presentations. She is particularly interested in mineral processing, health and safety management, leadership and communication, and innovative teaching and training methods.

Richins has been a member of SME since 2006, and has been a member of the Health & Safety Division since 2015.

SECRETARY/TREASURER

ADAM GREGOR is the nominee for Secretary/ Treasurer of the Health & Safety Division.

Industrial Minerals & Aggregates Division officer nominees

CHAIR

NATHAN MANSER is a senior lecturer of mining and geological engineering at Michigan Technological University. His teaching and research activities focus on developing "mines of the future" by proving novel and improved technologies that reduce carbon and use water more effectively for the extraction, recovery and management of critical elements from mineral resources. Currently, he has investigations ongoing related to decarbonized lithium separations from hard-rock and clay hosts using biologically engineered approaches.

Nathan Manser

Manser is a registered Professional Engineer in the state of Michigan and has been chair of the Upper Peninsula Section of SME since 2019.

VICE CHAIR

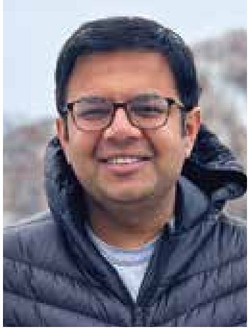
GAURAV SONI is a proposal manager (plant solution) with Metso Outotec in Denver, CO. He graduated with an M.S. in mining and mineral engineering from Virginia Tech in 2013 and B.Tech. in mineral engineering from IIT(ISM), Dhanbad in 2009. He is a certified project manager with Project Management Institute (PMI). He is currently pursuing a weekend program for an MBA at Booth School of Business (University of Chicago).

Gaurav Soni

Before joining Metso Outotec, Soni worked at Tata Steel and Imerys. His work experience has been focused on business development, supply-chain management, large Capex cost analysis, project execution and operation.

SECRETARY/ PUBLICATIONS

TUSHAR GUPTA is senior metallurgical engineer—research at MP Materials in Mountain Pass, CA. After graduating with a Ph.D. in mineral processing and extractive metallurgy from the University of Kentucky, his work as a research scientist at Columbia University in New York City focused on innovation in fine particle flotation for base metals.



Tushar Gupta

With a passion for making the most of natural resources through innovative extraction techniques, his current role is in research and development for characterizing and reprocessing rare earth tailings as feedstock for producing saleable rare earth concentrates. In this role, he serves as the technical lead for process innovation and development, working hands on to improve resource utilization. His strong academic background, coupled with his research and industry experience, has equipped him with a comprehensive understanding of the rare earth industry.

Gupta's dedication and contributions to the field earned him the SME Raja V. and Geetha V. Ramani Graduate Scholarship award in 2021 and SME Mineral & Metallurgical Processing Division Scholarship for outstanding graduate in 2020.

PROGRAM CHAIR

HIMESH PATEL is a metallurgist/project manager at McClelland Laboratories Inc., based in Nevada. He is responsible for project management, quotation, research, testing and reporting. Patel has more than five years of research and industry experience. Before joining McClelland Laboratories, he worked at Kinross Round Mountain, Freeport-McMoRan and India Power Corp.

Himesh Patel

Patel is an active member of SME and the Industrial Minerals & Aggregates Division (IM&AD). He has been serving on IM&AD technical and scholarship committees since 2020 and was on the SME/NSSGA Student Design Competition Committee in 2021. He is an alumnus of SME's Young Leaders Committee (Class of 2019) and has been secretary of the Nevada MPD Subsection since 2021. Patel has published several articles in various conferences and journals.

Patel received his M.S. in metallurgical engineering from the University of Nevada, Reno, and a dual degree in mineral engineering from the Indian Institute of Technology (Indian School of Mines), Dhanbad. In 2016, he was awarded a student exchange fellowship at Universidad Politecnica de Madrid (UPM) under the ERASMUS+ program. He is passionate about educating the public concerning the minerals industry.

Russell Winn

FGIM STEERING COMMITTEE CHAIR

RUSSELL WINN is an industrial minerals geologist with 16 years of experience in mining and exploration. He is a senior geologist with Permian Basin Materials in Odessa, TX. Winn has been a member of SME for 15 years and served in various capacities within the IM&AD and SME.

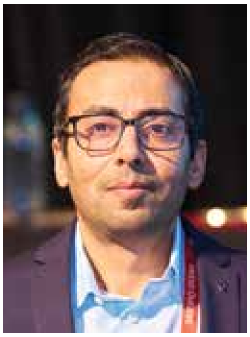
TECHNICAL COMMITTEEE CHAIR-ELECT

JACK SACKRIDER, P.G., is a geologic consultant with a focus on environmental and economic geology as it relates to construction aggregates, industrial minerals and associated industries. As a Professional Geologist licensed in the state of Texas, he has performed an array of tasks, primarily related to geologic exploration, modeling and calculations of economic aggregate reserves; geologic assessments over the Edwards Aquifer; and sensitive recharge feature training of mine and quarry staff. Sackrider also volunteers his experience with industry and the community through organizations such as SME and educational events like the Texas Hydro-Geo Workshop.

Jack Sackrider

SCHOLARSHIP COMMITTEE CHAIR

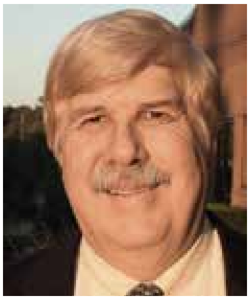
RAGHAV DUBE graduated with an M.S. in mining and mineral engineering from the University of Kentucky in 2012 and with a bachelor's degree in mineral engineering from Indian School of Mines in 2009. He is currently working as technology manager—flotation in Metso Outotec. Dube has more than 11 years of experience in the mineral processing industry, including laboratory test work, pilot plant operation, modeling and simulating plant flowsheets, and the startup and commissioning of greenfield plant projects.



Raghav Dube

MEMBERSHIP COMMITTEE CHAIR

STEVEN STOKOWSKI, a registered Professional Geologist, is the owner and materials geologist of Stone Products Consultants. His primary professional interest is industrial minerals, especially aggregates. He has an M.S. in geology from the South Dakota



Steven Stokowski

School of Mines and Technology and a B.S. in geology from George Washington University.

Stokowski is the recipient of the 2014 Herbert C. Hoover Award from the Washington D.C. Section of SME, the 2017 Robert W. Piekarz Award from SME and the 2020 Chair award from the Industrial Minerals & Aggregates Division of SME. He is a past chair of the Washington D.C. Section of SME, and the current program chair of the Georgia Section of SME. He has presented 10 papers at SME annual conferences, chaired five SME symposiums and sessions, presented five papers at past Forum on the Geology of Industrial Minerals (FGIM) meetings, which are now part of IM&AD, chaired an FGIM meeting and is the co-author of two chapters and edited three other chapters in *Industrial Minerals and Rocks*.

Stokowski joined SME in 1978 and has since participated in numerous committees. He is registered or certified as a geologist in Georgia, Maine, Virginia and other states.

Mineral & Metallurgical Processing Division officer nominees

CHAIR

JAEHEON LEE is an associate professor in the Department of Mining Engineering at the Colorado School of Mines (CSM) and associate director of the Kroll Institute for Extractive Metallurgy. He is a faculty member of the National Science Foundation (NSF)-funded IUCRC Center for Resource Recovery and Recycling as well as the Department of Energy (DOE)-funded research consortium Critical Materials Institute. He received his B.S. and M.S. degrees in metallurgical engineering from Korea University and his Ph.D. in materials science and engineering from the University of Arizona.

Jaeheon Lee

Lee has more than 20 years of industrial and academic experience with Newmont, Barrick, the University of Arizona and CSM. He has worked on various projects globally and is an expert in ore characterization, metallurgical study and project management for base metals and precious metals. Lee also has extensive experience in the bioleaching and biooxidation of sulfide minerals with various strains of microorganisms. He has been working on alternative lixiviants for precious metal extraction and new leaching systems for refractory copper sulfides. Mine tailings is one of his new areas of interest; he is a faculty member of the Tailings Center at CSM and participating in the BHP Tailings Challenge. He is currently working on several projects, including lithium-ion battery recycling using environmentally friendly chemical systems, and precious metals recycling from scrap, catalysts and electronics using new lixiviant systems. Lee is also participating in the Carbon Ore, Rare Earth, and Critical Materials (CORE-CM) projects funded by the DOE to seek a solution to extract rare earth elements and critical minerals from coal and its byproducts.

SME has been a big part of Lee's career. He received the prestigious SME Career Development Grant in 2018 and Freeport-McMoRan's Academic-Industry Mining (AIM) Fellowship in 2017 and 2018.

ASSOCIATE CHAIR

TARUN BHAMBHANI is principal scientist at Solvay Mining Solutions, where he has been for the last 15 years, engaged in the development of novel reagents to solve challenging separations and enable step change in flotation outcome. His contributions include the development of novel collectors for gold, platinum-group metals and oxide copper, modifiers for problematic gangue and selective separations of sulfides, and novel frothers. His efforts to set up collaborations between vendors, mining companies and academia have translated into much improved understanding of mechanisms governing mineral separations, and solutions for treating complex ores.

Tarun Bhambhani

Bhambhani has lectured extensively on the role of chemistry in flotation at many mining companies and their processing plants. He has organized several SME Mineral & Metallurgical Processing Division (MPD) technical sessions and symposia, and served on research, membership and scholarship committees. He was a co-organizer of the Sulfide Flotation Symposium at the Extraction 2018 conference and is a co-chair for the XXXI International Mineral Processing Congress (IMPC) 2024 to be held in Washington, DC. He has authored more than 40 papers, holds six sets of patents, is on the editorial board of SME's *Mining, Metallurgy & Exploration* journal, and received the MPD's Outstanding Young Engineer Award in 2013. He holds a bachelor's degree in mining and minerals engineering from Virginia Tech and a Ph.D. from Columbia University.

FIRST VICE CHAIR

AARON NOBLE is a professor and incoming department head in the Department of Mining and Minerals Engineering at Virginia Tech. His instruction and research are in the general areas of mineral processing, process economics and mine environmental management. He has

Division Officer Nominations


Aaron Noble

published more than 40 journal papers and has received three U.S. patents for innovative process equipment.

Noble has a B.S., an M.S. and a Ph.D. all from Virginia Tech and all in mining and minerals engineering. He is a licensed Professional Engineer in the Commonwealth of Virginia, and he currently serves as an associate editor on the editorial board of SME's *Mining, Metallurgy & Exploration* journal. He is an inaugural recipient of the SME Academic Career Development Grant (2015). Other notable awards and honors include the J.W. Woomer Award (2019), the MPD Outstanding Young Engineer Award (2018), the Rossiter W. Raymond Award (2017), the Stefanko Best Paper Award (2014) and Henry Krumb Lecturer (2016 and 2018).

SECOND VICE CHAIR

KIMBERLY MILLS is a senior metallurgist at Forte Dynamics Inc., based in Lakewood, CO. She earned her B.S. and Ph.D. degrees from the Colorado School of Mines (CSM) in metallurgical and materials engineering. She has significant experience in hydrometallurgy, including pressure oxidation, in situ leaching, dump and heap leaching, bioleaching, solvent extraction and electrowinning, as well as ion exchange. Her experience spans many commodities, including base, precious and battery metals, rare earths and industrial minerals, and she is a Qualified Professional in processing.


Kimberly Mills

Mills received the 2014 MPD Outstanding Young Engineer Award. She currently serves as vice chair of SME's Council of Education, has served on several MPD award committees, is a past chair of SME's Student Member Affairs Committee and is helping to organize the Extraction 2025 and Copper 2025 conferences. She also serves as a member of the CSM Mining Engineering Department Industry Advisory Council and is an affiliate faculty member of the Kroll Institute for Extractive Metallurgy.

SECRETARY-TREASURER

NICK GOW is a senior study manager for Paterson & Cooke in Golden, CO. He earned B.S. degrees in metallurgical engineering and chemistry and an M.S. in metallurgical engineering from Montana Tech. He received his Ph.D. from the University of Montana in 2015 with a focus on blending chemistry and mineral processing.

Gow is a diverse metallurgist with 15 years of experience based in early-stage project metallurgical development and late-stage/brownfield process optimization. His experience comes from numerous years of hands-on metallurgical testing focused on the impacts of geometallurgical considerations, including design and due diligence of metallurgical testing campaigns for processes including comminution, gravity, flotation and leaching of base and precious metals with a focus on bridging the metallurgical needs of a site to relevant and realistic analytical testing. He spent the last several years creating a mineral processing consulting laboratory, ensuring quality work in a timely manner. He routinely conducts analytical and metallurgical audits for operations domestically and internationally.


Nick Gow

Gow currently serves as chair of the SME Metallic Design Competition and co-organizer of the upcoming Hydrometallurgy 2023 and World Gold 2025 conferences. He is a Mining and Metallurgical Society of America (MMSA) Qualified Professional for mineral processing, Professional Engineer, CN code auditor, research associate at the Colorado School of Mines and recent recipient of the Ivan Rahn Education Award.

TECHNICAL PROGRAM ASSOCIATE

JIM WICKENS obtained his B.A.Sc. in mining and mineral process engineering from the University of British Columbia in 1987. He has spent most of his career in operations with Placer Dome and Barrick Gold in Canada and the United States.

More recently, Wickens has had the opportunity to diversify his experience working for Weir Minerals and McClelland Laboratories as a private consultant and is currently vice president, operations at Augusta Gold Corp. Wickens is active at the SME section level, serving as a past chair of the Nevada Mineral Processors subsection.


Jim Wickens

In 2022, Wickens was awarded the SME President's Citation for Individual Service for his work pioneering the Nevada Mineral Processors Subsection.

MEMBERSHIP ASSOCIATE

ADAM HOUSE is the process optimization lead for Paterson & Cooke. He received a B.S. in metallurgical engineering from Montana Tech. While working full time, he later received his M.S. in project engineering and management from Montana Tech.

House began his career working as a metallurgical technician at the Center for Advanced Mineral and Metallurgical Processing (CAMP). He then joined Newmont and gained invaluable experience working at its Western Nevada operations in metallurgy, operations and projects, including commissioning and startup roles for both the Phoenix concentrator and heap leach-SX/EW (solvent extraction/electrowinning) projects. He later transferred to Newmont's corporate office, providing project and operations support. Since 2015, House has served in consulting roles to global mining operations. He specializes in operational optimization and debottlenecking, but has provided extensive design support, project management, commissioning support and owner's team support.

House has served in multiple roles within SME, including as a member and chair for the Robert H. Richards Award Committee and the MPD Plant Design Unit Committee.

He is a member of the Responsible Mining and Underground Construction Strategic Committee and serves as secretary for the Colorado MPD Committee. He has authored several technical papers and served as a technical session chair for multiple annual conferences.


Adam House

Mining & Exploration Division officer nominees

CHAIR

DON DWYER of Elko, NV is the general manager of Orla Mining's South Railroad Project. He earned a B.S. in mining engineering from the Missouri University of Science and Technology (Missouri S&T, formerly University of Missouri-Rolla). He is an experienced mining industry professional with more than 20 years of experience leading openpit and underground mines.


Don Dwyer

Dwyer began his career at Vulcan Materials Co. in Alabama and eventually moved to Washington state, holding technical and operational roles with Teck Cominco American at the Pend Oreille underground mine. For more than 15 years, he has resided in Nevada working in leadership roles at various Barrick operations and at SSR's Marigold mine.

Dwyer is a member of the Mines and Metallurgy Academy advisory board at Missouri S&T. His involvement in SME started with the student chapter at Rolla and has since included mentoring young professionals, serving on the Mining & Exploration (M&E) Division Executive Committee, strategic committees, and program planning for the MINEXCHANGE 2023 SME Annual Conference & Expo.

CHAIR-ELECT

JENESSA HAARALA is a principal mining consultant at Haarala Mining in Utah, where she provides underground mine design and project scheduling services. Since starting her own consulting business in 2021 she has worked on polymetallic underground projects in Montana and Missouri. Prior to consulting, she worked in various engineering and supervisory roles in Nevada, New Zealand and Utah.

Haarala has 18 years of experience as an underground mining engineer. She holds a B.S. in mining engineering from the University of Nevada, Reno and is a Registered Member of SME. Since joining SME as a student, she has been an officer of the Northeastern Nevada Section, served as a program area manager for the M&E Division, served on the Sustainable Development Committee and received the M&E Outstanding Young Professional Award in 2018. She is a member of Women in Mining and is passionate about promoting inclusion in the mining industry.


Jenessa Haarala

VICE CHAIR-PROGRAMS

DANIEL ROSENBACH is the president of Petra Drilling Supply, providing tooling solutions to the geotechnical, construction and mining industries. He has been involved in the mining industry for 18 years and graduated from the Colorado School of Mines in 2011 with a B.S. in mining engineering.

Rosenbach has remained an active member of SME since he first joined SME in 2005. He has presented a paper on total drilling costs, chaired three technical sessions, was an M&E program area manager for the technology sessions


Daniel Rosenbach

in 2018, and participates on multiple scholarship and award committees within SME. In 2021 he was appointed to the M&E Executive Committee. One of his goals is to keep the next generations of miners involved in SME, and he makes an effort to mentor multiple students each year.

VICE CHAIR-PROGRAM PLANNING

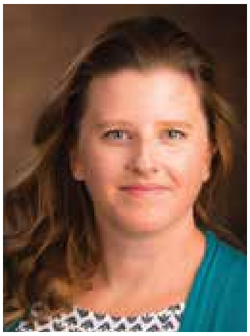
LIA WALKER is the manager of innovation for Freeport-McMoRan Inc., where she is the business leader for integrating data-driven innovation and technology transformation into the company. She leads highly engaged business teams to leverage Agile and change-management techniques to deploy technology and data-science solutions that amplify business growth and profitability.


Lia Walker

Walker has an M.S. degree and 27 years of experience in the mining industry, functioning in various roles throughout her career. Some of her key contributions are innovation engineering, quality leader, inventor, digital-solutions innovator, change-management advocate, enterprise product management and accomplished Agile coach. Walker is committed to SME's vision and has served in diverse positions.

ASSISTANT VICE CHAIR-PROGRAM PLANNING

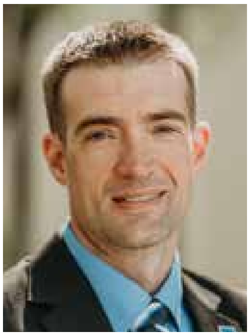
KATIE ROBERTSON has more than 15 years of experience in openpit and underground hard rock mining in the Western United States, primarily in gold and copper. She received her B.S. in mining engineering from Michigan Technological University (MTU) and MBA from the University of Utah. Her involvement in SME started as a student at MTU and since then she has been involved in the Young Leaders Committee, eventually serving as chair; multiple technical sessions, as speaker and chair; and recently as M&E operations program manager. She is currently the manager, integrated planning and systems, at Rio Tinto Kennecott Copper, where she oversees the optimization of business value from mine to finished product, working closely with technical, operational, commercial and finance teams.


Katie Robertson

SECRETARY

RUSSELL SHEETS has more than 18 years of experience supporting the mining industry. His mining career began with a few summers in underground coal in western Colorado and continued in the Carlin Trend in northern Nevada for 13.5 years.

For more than four years, Sheets' current role as a senior geotechnical engineer with Barr Engineering Co. has provided him with the opportunity to support various surface and underground operations across metals, rare earths, coal and aggregates. He received his B.S. in geological engineering from Montana Tech, where he has served on the Geological Engineering (GeoE) Industry Advisory Board for many years, including as chair for the past few years.


Russell Sheets

Sheets subsequently earned an M.S. in geological engineering from the University of Wisconsin. He has been a member of SME since 2005, and a Registered Member since 2014. He has been both a technical speaker and chair/co-chair for several years. In 2023, he served as the M&E program area manager for geosciences.

WAAIME Division officer nominations


Lydia Hull

CHAIR/SCHOLARSHIP CHAIR

LYDIA HULL received her R.N. degree in 1973 and remains active in that capacity. Her family's roots in mining began with both grandfathers, father and husband. She became active in WAAIME when family responsibilities allowed and has worked in many capacities locally and on the national board as well. She has worked continuously with the scholarship committee for the last 30 years. Her passion is dedicated to helping students obtain funding to further their careers in the extractive industries as well as obtaining degrees in these areas to teach the future generations. She looks forward to the new positive changes that are happening with WAAIME.

EXECUTIVE COMMITTEE

KATHERINE PINOCHET is a 35-year-old former WAAIME scholarship recipient who holds a B.S. and a professional degree in geology from Universidad de Chile.

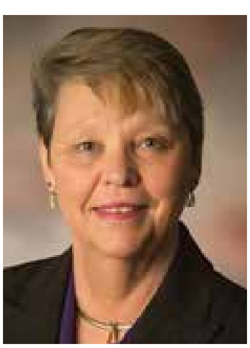
After graduating in 2013, Pinochet worked for five


Katherine Pinochet

years in the field of geological hazards applied to land-use planning. Since then, she has been a member of the Santiago de Chile section of WAAIME, serving in various roles. In 2018, she traveled to the United States for the first time to the WAAIME Midyear Meeting in Pittsburgh, PA, where she met Winnell Burt, Hull, Blanche Blattner, Jean Davin and other WAAIME members, who motivated her to become even more involved in WAAIME. Since 2020, she has been fulfilling the role of international representative of the WAAIME Executive Committee. Her greatest motivation to serve is to help other students as WAAIME helped her, thanks to the willingness, effort and selfless service of the members of each section.

At the beginning of 2019, Pinochet ventured into the promising and challenging lithium industry and currently works as the project coordinator of the Hydrogeology Department at SQM, a Chilean company that is a major producer of lithium. In March 2023, she completed her role as a mentor in the Mentoring Program for Job Placement.

BARBARA FILAS is a licensed professional mining engineer and a veteran member of SME. She was the first female SME President in 2005 and was instrumental in forming its Environmental Division and Student Mentor Program. She is also a past chair of the WAAIME Division of SME. She has served on the boards of trustees of the SME Foundation and the American Institute of Mining, Metallurgical and Petroleum Engineers (AIME) and was vice president of finance for AIME.


Barbara Filas

Filas has hands-on experience with operating gold and coal mining and processing facilities; executive experience in consulting, public companies and nonprofits; and technical expertise in base and precious metals, coal, uranium and industrial minerals in various engineering and environmental capacities. She currently sits on the boards of directors of two publicly traded companies, volunteers as the nominations chair and chair of the board of governors for the National Mining Hall of Fame and was inducted into the National Academy of Engineering in 2022.

MARGARET MARY MELVIN MANSANTI (MARGIE) MANSANTI is a graduate of Idaho State University and completed her dietary internship at Miami Valley Hospital in Dayton, OH. She has been a registered dietitian and member of the American Dietetic Association since 1981.


Margaret Mansanti

Relocating with her husband John to different mining communities, she practiced in hospitals, nursing homes and private clinics. She taught nutrition at community colleges and was a substitute teacher for local schools. An advocate for education and literacy, she was active in local library programs and is a more than 35-year member of P.E.O., a women's philanthropic and educational organization. Mansanti served on the Humboldt County Hospital board and chaired the board through a bond passage and construction of a medical office building, hospital expansion and nursing-home addition.

After learning of the more than 100-year legacy of WAAIME and its scholarships to support the minerals industry, she became involved with WAAIME, reviewing scholarship applications. She became a member of the WAAIME Executive Committee in 2021, helping WAAIME to restructure the Division through the SME Board of Directors-approved omnibus resolution. She and her husband have returned to Montana where they have three children and six grandchildren.

SUSANA PALOMINO PARODI is an interior designer who has been involved with WAAIME since 2005 when she became the scholarship director for the Cajamarca Section. She served as president of that section from 2008 to 2014, served on the board of the WAAIME Lima Section as its scholarship director in 2015, was the president of that section in 2016-2017 and served as WAAIME vice president, scholarship director of the Lima Section in 2018.


Susana Palomino Parodi

Among her achievements with WAAIME, Palomino Parodi participated in the modernization of the WAAIME organization with the support of strategic partner EY Peru. She helped with the reorganization of the scholarship program, resulting in the increase of scholarship holders from two to three years in the last seven years and improved the administrative documentation regarding scholarship programs in order to facilitate the scholarship process.

She helped with the launch of a new WAAIME Coaching Program, including custom sessions and workshops with up to 64 scholarship recipients and with an agreement with the Instituto de Ingenieros de Minas del Perú (Peruvian Mining Institute) to grant facilities to WAAIME in their office building.

Palomino Parodi participated in the last four PERUMIN convention events with booth implementation, awarded scholarships in the South region and achieved affiliations of recognized companies in the mining, energy and petroleum businesses in Peru. More than $65,000 during the last seven years has been obtained for WAAIME.

Fine Grind

(Continued from page 103)

- **Myth 3: Geometallurgy is what geologists do every day.** This myth is often found in pecking wars with its sibling and rival myth: Geometallurgy is what metallurgists do every day. Both feed on the common belief among experts in one field that the other cannot really be all that complicated. These myths are easy to identify by lopsidedness: in each, one wing is a tiny fraction of the other's size. You see this myth any time you read a "geometallurgy" paper that consists of nine pages of pure geology plus two tacked-on tail sentences insisting that the findings have important implications for processing and that metallurgists should pay attention to them. Its opposite number is the common processing or extraction study that includes one XRD and one SEM analysis and therefore claims to be geometallurgy. Despite constant flapping and squawking, neither of these can get off the ground. For geometallurgy to take off and fly requires a good balance of metallurgy and geology.

Fine Grind serves as a forum for the presentation and discussion of facts, ideas and opinions pertaining to the interests and technology of the Mineral & Metallurgical Processing Division. Accordingly, all material published herein is signed and reflects the individual view of the authors. It is not an official position of SME or the division. Comments by readers will be referred to that division for response. The division chair in 2023 is David G. Meadows.

A concentrated blast of facts at close range will generally bring down myths 1 and 2. Myth 3 lives in siloes that block direct hits. But there is hope. On occasion, a rare few subscribers to myth 3 wander out of their protective siloes and approach other academic or industry departments. If the approached department is receptive, they may help the newcomer strengthen its weaker wing enough to fly. Moreover, the exercise often benefits their own weaker sides and helps them reach new heights. In the past, such collaborations have been rare, random and driven by individual initiative. However, today there are hopeful signs of deliberate attempts to foster real cooperation between geologists and metallurgists. If each side can leave out a few enticing breadcrumbs and open its minds and doors, it will go a long way to dispelling myth 3. That would make geology more useful, metallurgy better informed, and mining more efficient. ■

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1. Olson Hoal K, Frenzel M (2022) Ores drive operations – economic geology is the foundation of geometallurgy. SEG Discovery 129:30–43
2. Lotter NO, Baum W, Reeves S, Arrue C, Bradshaw DJ (2018) The business value of best practice process mineralogy. Minerals Engineering 116:226–238

Best Presentations

(Continued from page 103)

looks forward to more great presentations and recognizing the speakers of next year.

Every year, the winners will be nominated by the unit committees and approved by the MPD Executive Committee. The winners will receive an award certificate and be recognized in Fine Grind in *Mining Engineering*. ■

(Left to right) Daniel DeMiglio, Courtney Young and Kristine Murphy win the 2023 MPD Best Presentation Awards for comminution, flotation and plant design, respectively.

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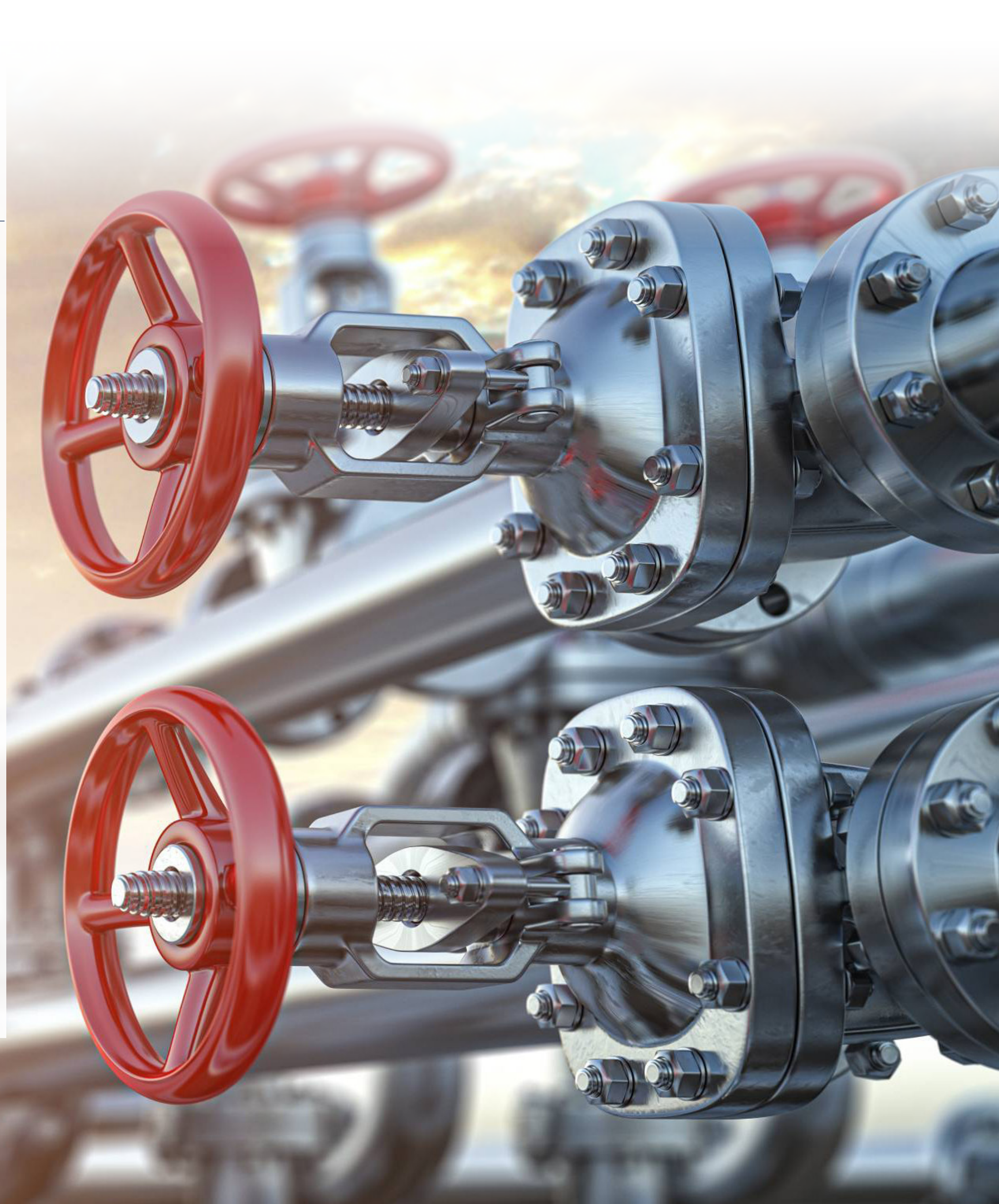

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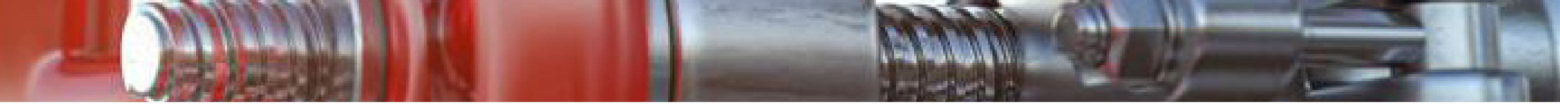

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Bolting applications in the mining industry can be especially challenging. You need a bolting solution that can be installed and removed safely and quickly. One that will keep your bolted joints tight through demanding operations and improve your bottom line. That's where Superbolt tensioners come in.

Superbolt tensioners are designed as direct replacements for standard bolting. They can be threaded onto a new or exiting bolt, stud, threaded rod or shaft. With Superbolt tensioners, bolting is safe, fast, easy and accurate – only hand tools are required.

Superbolt tensioners have been successfully implemented on leading OEM mining equipment such as rope shovels, draglines, haul trucks and much more.

Superbolt, Inc.
1200 Clifford Ball Drive
Clinton, PA 15026
T: +1 412 279 1149
E: bolting@nord-lock.com

Valley Forge & Bolt Mfg Co.
www.vfbolts.com/mining-industry/
Valley Forge has proudly manufactured both standard and custom fasteners in the mining industry for over 40 years. Our innovative solutions are manufactured in the USA including well-known technologies like the Maxbolt®- our visual load indicator in each fastener, which has long set the standard for bolted joint load-indicating solutions around the world.

Our innovative ideas are directed by continuous improvement, the simplification and accuracy of the installation of fasteners, and the resulting improvement in productivity and safety for our customers.

We are constantly developing new technologies to help our customers find solutions that optimize the integrity of the bolted joint. We are proud to continue our extension into the technology arena with cutting-edge upgrades to our core offerings. The RTM™ Meter Collection features wireless probes added to our SPC4® bolts that can continuously monitor fastener load in any application with industry-leading, unique features. This vigorous commitment to innovation continues to steer additions to these products with recent rollouts of a companion Android application available now on the google play store and on our site.

To learn more about specific developments to our products for the mining industry or access recent case studies visit: www.vfbolts.com/mining-industry/

Valley Forge & Bolt
4410 W. Jefferson St.
Phoenix, AZ 85043
sales@vfbolts.com
Toll Free: (800) 832-6587
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BORING EQUIPMENT

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Expander is an award-winning solution with over one million systems installed since 1985. The design is adaptable for any obstacle or application, and has been used on a variety of the world's largest Original Equipment Manufacturer machines.

Each Expander System comes with a full Lifetime Warranty. We guarantee your solution will perform as expected from the moment it is installed until the end of its intended lifecycle. Finally, a long-term permanent solution to pivot lug wear.

Contact:
Rod Whipple
MRO Manager – Expander – North America
Phone: +1 (928) 301-1013
Email: rod.whipple@nord-lock.com
Expander: 223 Industrial Street, De Witt, IA 52742

Northrop Grumman LITEF GmbH
Based on more than sixty years' history in the development and production of inertial sensors such as micro-electromechanical accelerometers and fiber-optic gyroscopes and an excellent reputation in the aviation and military industries, LITEF provides the innovative, handheld alignment tool LiPAD®-100.
The LiPAD®-100 is a battery driven hand-held gyrocompass that outputs the three spatial angles, North direction, pitch and roll angle simply and precisely. This handheld gyrocompass is designed for the mining, foundation, and special construction industries to perform quick and reliable alignment of equipment such as drill rigs or tunnel boring machines in above ground and underground applications.

The LiPAD®-100 offers Bluetooth® connectivity to communicate with a handheld device. An Android-based software app enables the operator to control the device and display the measurement data in real-time. All data can be recorded and exported for quality control or further processing.

LiPAD®-100 provides real cost savings versus standard surveying and alignment methods.

Loerracher Str. 18
79115 Freiburg im Breisgau

Germany
industrial@litef.de
+49 761 49010

EarthGrid
earthgrid.io
EarthGrid has invented plasma tunnel boring & trenching robots that are solar-powered, use no water, have zero emissions and can bore tunnels 100x faster at 1/10th the cost of conventional techniques. They are building a network of large, underground utility tunnels that improve infrastructure and rapidly accelerate the transition to 100% clean energy by enabling underground clean energy power lines, high-speed data, water, and wastewater, H2 pipelines, e-commerce parcel transportation via pneumatic tubes, etc. They have a BOOM model (Build, Own, Operate and Manage) to lease space to investment-grade utilities, and a BADASS model (Boring And Digging As a Simple Service) to charge per meter or cubic meter at costs of up to 80% below HDD, TBM, and conventional hard-rock trenching.

Contact info:
info@earthgrid.io
833-327-8441

Palmieri spa
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www.palmierigroup.com
info@palmierigroup.com
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BRAKES - DYNAMIC, FRICTION, DISK - BLOCK, MAGNETIC

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Dellner Bubenzer is focused on the design, production, and service of high-quality braking systems for both static and dynamic applications which involve the precise control of small to very large amounts of kinetic energy. Dellner Bubenzer manufacturers brakes designed for use on various pieces of mining equipment such as overland conveyor systems, bucket-wheel excavators, rail car dumpers etc. Dellner Bubenzer also provide an extensive line of pneumatic drum clutches & brakes for draglines and mining shovels. The Dellner Bubenzer extensive portfolio of brake products will provide you with a solution for all of your braking needs.

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Fax – 281-288-2114
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Fairfield, OH 45014
Telephone: 513-868-0900
Fax: 513-868-2105
E-Mail: tstoner@forcecontrol.com

Kobelt Manufacturing Co. Ltd.
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Kobelt designs and manufactures rugged, reliable braking systems for a broad range of applications in mining, material handling, oil & gas, transportation, material processing and the marine sector. Our strength is our ability to deliver bespoke braking solutions with very little lead time. Utilizing our experienced engineering team, an in-house foundry and extensive machining capability, we eliminate any lag time between design and manufacturing. Kobelt brake systems are used on overland conveyors, heavy equipment, marine shaft brakes, offshore turret winches, drawworks, cranes, steel uncoilers, paper converting lines and a variety of other applications. Kobelt is known for rugged and reliable products, trustworthy customer service and industry leading delivery times.

8238 – 129th Street
Surrey, B.C., Canada V3W 0A6
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Fax: +1(604) 590-8313
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Fax: (814) 472-7179

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Somersetinternational.com
412-576-4000
mbarish@somersetint.com
cnewport@somersetint.com

JOHNSON SCREENS

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www.johnsonscreens.com
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E-Mail: Info.us@johnsonscreens.com

COMMUNICATIONS EQUIPMENT

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everywherecomms.com

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sales@everywherecomms.com

Innovative Wireless Technologies

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sales@iwtwireless.com

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Northwest Towers designs and constructs complete mine-wide wireless networks. Projects are delivered from Northwest Towers in true turnkey fashion. System design, procurement, construction, installation, training, and 24/7 maintenance, all managed, hands-on by Northwest Towers. With years of experience in LTE, MESH, millimeter wave, microwave, WIFI, and 2-way radio, Northwest Towers applies the best suitable technology.

Networks by Northwest Towers support the most critical of applications and conquer the most challenging environments on the surface or underground. Systems are designed to provide fail-safe operation for the most critical of applications including full autonomy and safety. Northwest Towers is also available for routine maintenance and system upgrades.

12119 NE 99th Ave, Ste 2000
Vancouver, WA 98682
Telephone: +1 503-548-2005
Website: www.nwtowers.com
E-Mail: sales@nwtowers.com

MST Global

mstglobal.com

MST Global specialize in harsh industrial technology that empowers customers to unearth safety and productivity improvements. We believe that, without the right technology solution for a mine's unique situation, there is only partial components delivering partial results. Our disruptive digital vision for hardware and software embraces next-generation technologies and challenges paradigms to provide customers with value now and into the future.

With over 30 years at the face of underground operations around the world, MST Global is a trusted partner to Tier 1 and Tier 2 customers.

A customer-centered, flexible approach offers solutions designed with an open-standards protocol ensuring interoperability in a multi-vendor environment.

MST's suite of solutions are focused on improving and enhancing:

- connectivity (secure digital network, network capability extenders),
- safety (proximity detection, situational awareness, through-the-earth communication),
- tracking (visualization software, personal and asset tracking, collision avoidance),
- productivity (software providing communications, insights, monitoring and control).

13301 W 43rd Drive, unit 15, Golden, CO, 80403, United States
Telephone: +1 303 951 0570
Email: americasales@mstglobal.com

COMPUTER - HARDWARE AND SERVICES

Trimble Geospatial

https://geospatial.trimble.com

Trimble Geospatial provides solutions that facilitate high-quality, productive workflows and information exchange, driving value for a global and diverse customer base of surveyors, engineering, and GIS service companies serving mining owners, operators, and consultants. Trimble's innovative technologies include integrated positioning sensors, field applications, real-time communications, and office software for processing, modeling, and data analytics for slope stability, volumetrics, and construction as-built. Using Trimble solutions, organizations can capture the most accurate spatial data and transform it into intelligence to deliver increased productivity and improved decision-making. Whether enabling more efficient use of natural resources or enhancing the performance and lifecycle of mine infrastructure, timely and reliable geospatial information is at the core of Trimble's solutions to transform the way work is done.

Trimble
Riley Smith
Marketing Director, Monitoring, Mining, and Tunneling
riley_smith@trimble.com
10368 Westmoor Dr.,
Westminster, CO, USA 80021

Propeller

https://www.propelleraero.com

Propeller is an easy-to-use platform that combines the best GIS and survey technologies. We empower users to map, measure and manage their worksites like never before, powering over 52,000 users across 20,000 worksites in over 120 countries.

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Hexagon Mining division

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www.hexagon.com
T: +1.520.795.3891
E: info.min@hexagon.com

COMPUTER - SOFTWARE AND SERVICES

Airth.io

www.airth.io

Airth.io is a customer focused global mining technology company that provides solutions for miners by miners. The vendor-agnostic ecosystem of data-driven products connects planning, operations, mineral processing and finance on an integrated easy-to-use platform.

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Tucson, AZ 85740
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Eclipse Mining Technologies

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SourceOne® Enterprise Knowledge Performance System (EKPS) is a vanguard data transformation system that handles the vast amount of complex data generated by mines by using an ontology framework and knowledge graphs. SourceOne alleviates the need for manual data management by automating the organization and classification of your data for quicker and easier retrieval. It gives data meaning with context, relationships, and implications, transforming the most valuable asset you own into actionable knowledge.

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Tucson, AZ 85716
Phone: (520) 372-7345
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2015 Main Street, Vancouver, BC V5T 3C2
604-245-8266
info@actenum.com

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See our full listing on page 7
everywherecomms.com
Telephone: (207) 370-0499
sales@everywherecomms.com

Hexagon Mining division

www.hexagon.com
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Hexagon is a global leader in digital reality solutions, combining sensor, software, and autonomous technologies. Our technologies are shaping production and people-related ecosystems to become increasingly connected and autonomous—ensuring a scalable, sustainable future.

For the mining industry, this means a holistic, data-driven approach to integrating, automating, and optimizing critical workflows. From exploration and planning to drill and blast, material movement and survey and monitoring, these workflows are digitally transformed by the Power of One, a life-of-mine smart solution that connects sensors and software, infield apps and cloudware both in open pit and underground environments.

Hexagon (Nasdaq Stockholm: HEXA B) has approximately 24,000 employees in 50 countries and net sales of approximately 5.2bn EUR.

40 East Congress Street, Suite 300
Tucson, Arizona, 85701
United States
Contact Us
T: +1.520.795.3891

Micromine

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Micromine is a leading provider of innovative software solutions for the mining industry, offering a comprehensive range of products that cover the entire mining cycle. From geological exploration and data management to resource estimation, mine planning, and design, our solutions deliver cutting-edge capabilities. Our portfolio includes Micromine Pitram, a real-time fleet management and mine production system, and Micromine Alastri, an integrated open pit mine planning software.

With a global presence across 22 offices, we have established ourselves as an integral part of the mining sector. Operating in over 90 countries, we serve 50 active mine sites and have completed 3,000 diverse projects. Our advanced solutions provide mining operations with precise control, enhanced visibility, and optimized efficiency, driving productivity and success in the industry.

Discover the transformative power of Micromine at www.micromine.com

talpasolutions GmbH

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TALPA is an industry-leading provider of advanced industrial AI and IoT solutions. Our robust platform utilizes powerful AI and machine learning algorithms, combined with pre-trained data science models and industry-specific content, to transform vast amounts of data into actionable insights. By automating complex aspects of the industrial data science process, we enable businesses to quickly develop models that drive operational and financial outcomes.

With TALPA, organizations can easily aggregate data from diverse sources, including machine signals, enterprise systems, market information, and operational benchmarks. Our user-friendly framework empowers users of all technical backgrounds to leverage the platform's algorithms or configure their own, facilitating streamlined data analysis and decision-making.

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Clockwork Safety (CWS)

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"CWS Toolbox" is an enterprise risk & resource management software platform and comprehensive compliance services company specializing in MSHA regulated industries. We provide your organization with the tools and data to identify, control, and monitor risks with unprecedented "visibility" right to the worker level. Live, "leading" data on individual performance.

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Bradley M. Gibson, CMSP (USA 1087)
Founder & Chief Operating Officer
Clockwork Safety, Inc. – Integrated Management Solutions
brad@clockworksafety.com
+1 801 557 8236 m
337 S Main St, Cedar City, UT, 84720

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Contact: Antonio Gallovich
8333 NW 53 RD ST
SUITE 450
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CONSTRUCTION - CONTRACTING SERVICES

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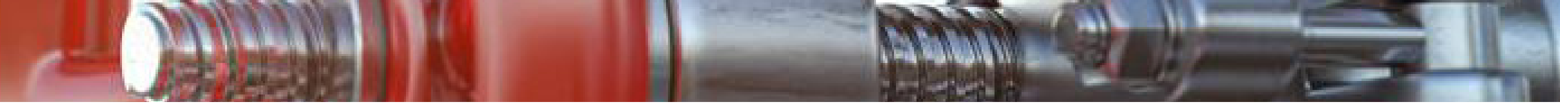

organizations with roots dating back to 1884. Our employee-owned organization operates through a network of subsidiaries in the United States, Canada and Mexico. We had 2022 revenues of $13.7 billion and employs 25,700 staff and craft employees.

We execute mining and mineral processing projects safely, on time and on budget. Since entering the market in the 1980s, our experienced project teams have constructed a wide variety of mining and mineral processing projects, including expansion or upgrade projects at operating plants and in some of North America's most remote locations. From greenfield startup to mining operations through final reclamation, Kiewit has the comprehensive experience, equipment and people for your mining and mineral processing project needs.

10055 Trainstation Circle
Lone Tree, CO 80124
Ph: (303) 649-6800
Meg.Anrezjewki@kiewit.com

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www.frontierkemper.com
Telephone: (877) 554-8600
information@frontierkemper.com

Iron Woman Mining Services, LLC

www.ironwomancon.com
Founded as a Native American-owned company in 1999, Iron Woman is an employee-owned general civil contractor with more than 300 employees, 15 crews, and more than 300 pieces of rolling equipment, including trucks, trailers, and yellow iron. Iron Woman Mining Services, LLC employs a proven staff of mining professionals who have first-hand knowledge of mining challenges and a collective pool of expertise that covers mine operations from hard to soft rock mining using both open pit and underground techniques. Customer service is our focus and we work with our clients to deliver our mining projects safely, on schedule and on budget.

Carl Crews, Vice President of Mining
ccrews@ironwomancon.com
Telephone: (719) 331-9306

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MATRIX SERVICE COMPANY, through its subsidiary – Matrix Service Inc. – is a leader in the design, construction, maintenance and repair of industrial infrastructure across North America. With specialized expertise in mining and minerals, we are proud of our reputation for delivering projects safely, with the highest quality possible, on-time and on-budget. We count a number of North America's most recognized mining companies among our clients. Matrix also provides industrial cleaning services.

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Fax: 406-586-3530
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Great Basin Industrial
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Phone: (801) 543-2100
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CDM Smith
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Boston, MA 02109
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Mahmood Khwaja, KhwajaM@cdmsmith.com, 617-777-3076

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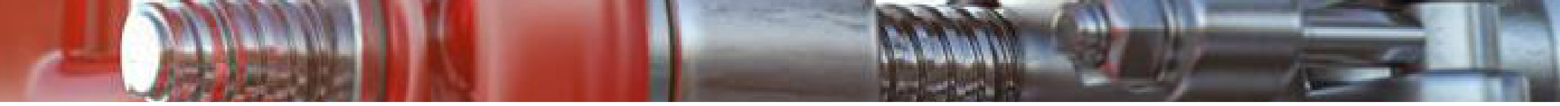

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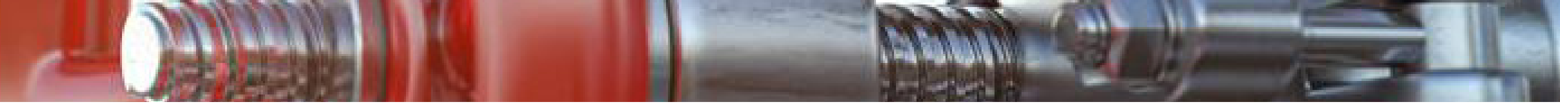

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Robert Valceschini, PE
Principal/Senior Engineer
Geo-Logic Associates
56 Coney Island Drive
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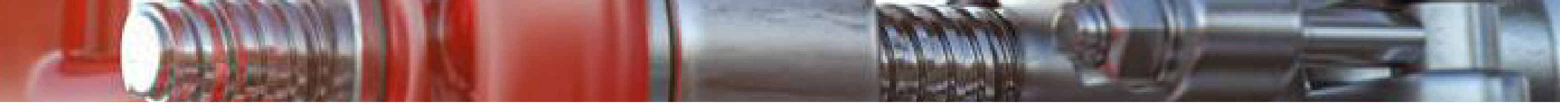

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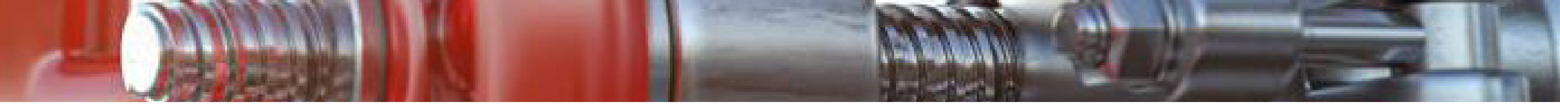

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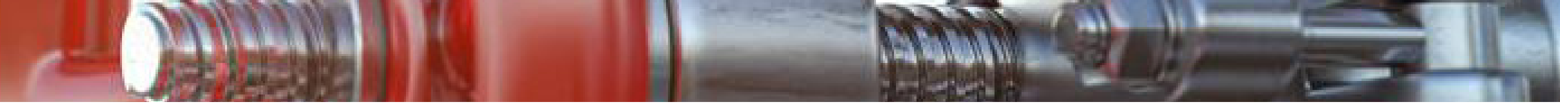

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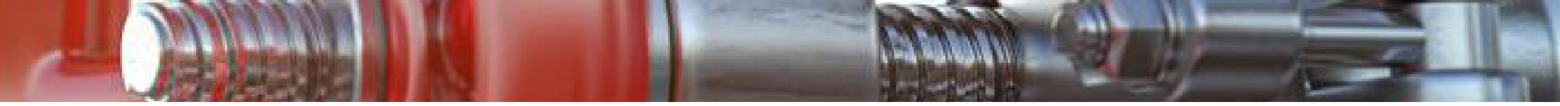

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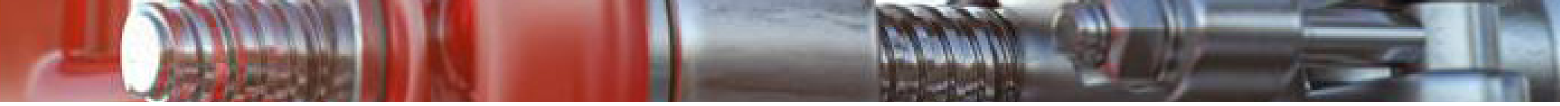

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Contact:
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Dr. Sanjay Srinivasan, Department Head, John and Willie Leone Family Department of Energy and Mineral Engineering
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The Mining Engineering Department has been serving the Mining Industry for over 100 years, providing high quality education of mining engineers, impactful research and industry collaboration. In addition financial support is available to qualified students through the Browning Scholarship during their undergraduate degree https://mining.utah.edu/scholarships/the-browning-scholarship.php. Graduate student education provides mentoring and financial support through research projects designed to improve technologies and approaches for more effective and sustainable mining. Our goal is to prepare graduates to work in any area of the mining industry, disseminate newly acquired knowledge via publication of original research, provide professional service to the mining industry and public to assist in the environmentally responsible and safe extraction of mineral resources, and inform the public at large about the importance of mining to society.

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Virginia Tech Department of Mining and Minerals Engineering

www.mining.vt.edu

Virginia Tech's Department of Mining and Minerals Engineering is one of the largest and most prominent mining-related programs in North America and enjoys a reputation as a global leader in the field, with a stated mission to serve society through education and innovation that supports the safe, efficient, and environmentally responsible production of energy and mineral resources. The department houses world-class facilities in a newly renovated Holden Hall, with over 100,000 sq. ft. of cutting-edge research, teaching and advising space. The Department is home to two renowned and highly productive research centers: the Virginia Center for Coal and Energy Research, and the Center for Advanced Separation Technologies. Its tenured and tenure-track faculty are globally recognized experts in mineral processing, geoenergy, and mine health and safety. A diverse research portfolio includes federal, state and privately funded projects, with annual expenditures averaging about $6,000,000 in the past eight years and a notable focus on capacity building and graduate student education.

Department of Mining and Minerals Engineering
378 Holden Hall, Virginia Tech
445 Old Turner St.
Blacksburg, VA 24061
Phone: (540) 231-6671
mineinfo@vt.edu

West Virginia University Department of Mining Engineering

https://mine.statler.wvu.edu/

The Department of Mining Engineering at West Virginia University provides educational programs at the bachelor's, master's and doctoral levels. Degree options at the undergraduate level include mining engineering, and dual degree programs in mining engineering and civil and environmental engineering, mining engineering and civil engineering and mining engineering and geology. At the graduate level, degrees are offered in mining engineering and mineral processing. Our mission is to produce graduates who are thoroughly prepared to meet the operational and engineering challenges of the mining industry, and to continue their studies in graduate programs. For more information about our Department, please visit https://mine.statler.wvu.edu/

Department of Mining Engineering
1374 Evansdale Drive, PO Box 6070
Morgantown, WV 26506
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Telephone: (304) 293-7680

Great Basin College

www.gbcnv.edu

Great Basin Colleges offers a range of training programs for the mines and other industries including Career Technical Education (CTE) in the following fields:

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- Manufacturing machinist (Pahrump)
- Electrical (Elko, Winnemucca and Ely)
- Instrumentation (Elko and Winnemucca)
- Land surveying & Geomatics (online)

In addition, various certificates are offered through the new Mining Center in Elko, and others are planned to encourage more people to enter the mining industry and study particularly geology, mining and metallurgy. Currently two high school dual credit certificates are being offered that will seamlessly transfer to Great Basin College or the University of Nevada Reno particularly for degrees in geology, mining and metallurgical engineering.

Main Campus:
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Main telephone: 775-3275002
www.gbcnv.edu
Contact:
A.J.S. (Sam) Spearing
Executive Director
sam.spearing@gbcnv.edu
Jessica Johnson
CTE recruiter and advisor
Jessica.johnson@gbcnv.edu

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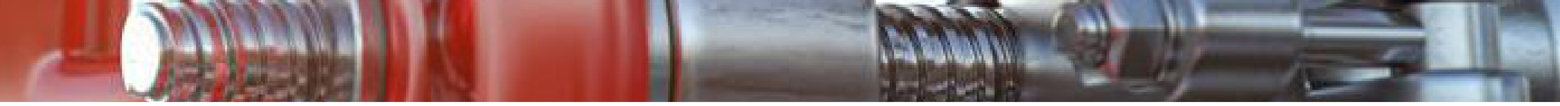

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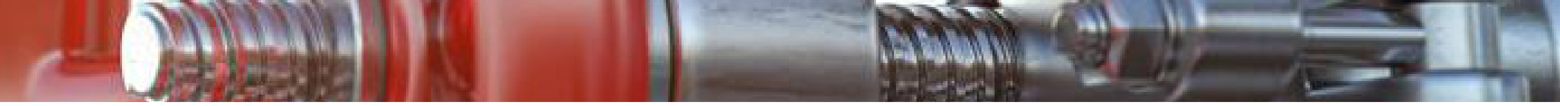

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Contact Information:
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Independent Mining Consultants Inc.

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www.imctucson.com
Telephone: (520) 294-9861
imc@imctucson.com

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GOVERNMENT AGENCY - ENTITY

U.S. Geological Survey (USGS) Mineral Resources Program (MRP)

https://www.usgs.gov/programs/mineral-resources-program

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Contact: Jim Mosley, MS., MBA., Program Analyst Energy & Mineral Resources Mission Area (EMMA), & MRP Outreach Coordinator
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DOVE Equipment & Machinery Co., Ltd.

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https://dovemining.com/
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GROUTING EQUIPMENT, SERVICES, AND MATERIALS

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Avanti International is an American owned and operated manufacturer of injection grouts located in Houston, TX. Since 1978, Avanti's injection grouts have been used worldwide in municipal, industrial, and geotechnical applications to stop leaks, stabilize soil, and control groundwater – permanently.

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Esri delivers groundbreaking geospatial solutions tailored for the mining industry. Our ArcGIS platform facilitates comprehensive spatial analysis, predictive modeling, mine planning, and asset management. Our customers also leverage the power of location intelligence to track real-time operations, optimize logistics, and assess environmental impact. These core technologies can be configured "out of the box" to address specific mining workflows. For example, our environmental tailings management solution provides storage facility stakeholders with increased operational visibility, workflow efficiency, and a single source of truth by integrating crucial monitoring information, geotechnical sensor data, and field inspection reporting on any smart device. In addition, ArcGIS offers cutting-edge cartography tools to simplify mine modeling and subsurface investigations. Esri's imagery solutions transforms UAV-captured data into turnkey professional-quality 2D and 3D information products. Harness the full potential of geospatial technology with Esri's mining-focused suite. Explore, innovate, and sustain with Esri.

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199 S.Taylor Ave, Louisville, 80027 CO 80027
USA
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talpasolutions.com
phone: +49 (0) 201 822 768 521
mail: info@talpa-solutions.com

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brad@clockworksafety.com
+1 801 557 8236 m

INSTRUMENTATION EQUIPMENT AND SERVICES

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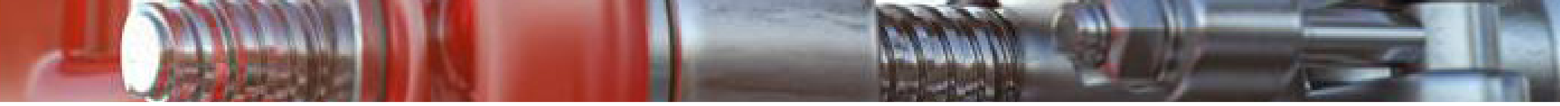

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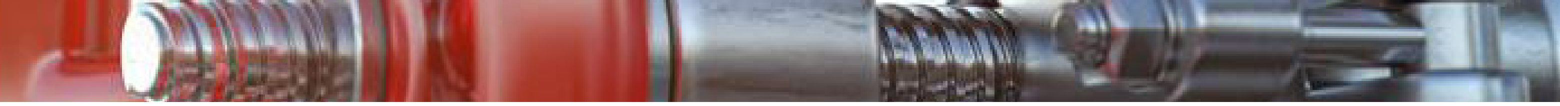

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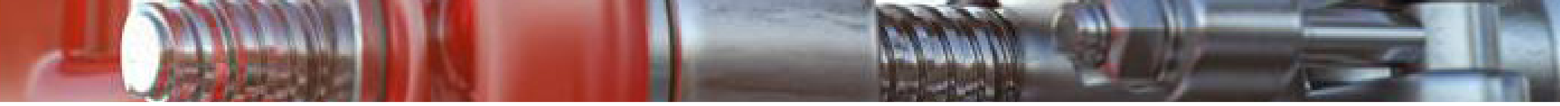

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Used within rotating machinery for mining and industrial applications, Voith Turbo ingenuity continues to push driveline reliability and performance to the next level. Products include hydrodynamic couplings, torque-limiting safety couplings, highly-flexible torsional damping couplings, torque diagnostic/condition-monitoring equipment, health-check site services, As a trusted long-term partner with a successful track record in the mining industry, we work closely with international OEMs, mine owners, and equipment operators to ensure that our systems meet industry needs and standards. Voith Turbo is where intelligent mining meets proven reliability.

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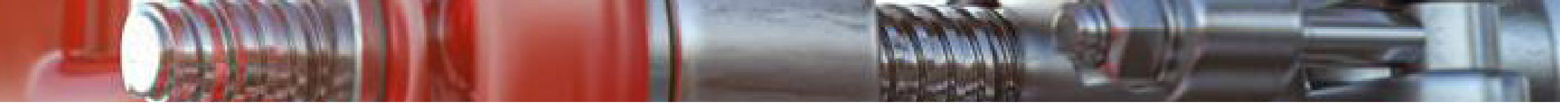

PRECAST CONCRETE LININGS

CBE GROUP

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CBE Group designs and manufactures segment moulds, automated plants for segment production and segment handling equipment for tunnel projects all over the world. The company ensures assembly of precast plants, staff training and maintenance worldwide. Its offices are located in France, with two production sites in France and China. Since its creation in 1987, the company has achieved 620 projects and produced more than 29 500 moulds. Recent achievements include: High Speed 2 (UK), HRBT (USA), Snowy Hydro (Australia), Grand Paris (France), Sao Paulo L2 (Brazil), Sydney Metro West (Australia), Shanghai Metro (China), Chennai Metro (India), CR105 (Singapour), and more.

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Since 1996, David R. Klug & Associates, Inc. has provided international and national manufacturers 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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David R. Klug & Associates, Inc.
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Jason Epstein
Director of Membership
jepstein@nssga.org
(703) 526-1071

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Atlas Equipment Co LLC

See our ad on p. 54

www.atlaseqco.com

Company is proud to offer high quality slurry pumps for industry's most demanding slurry applications. The Battle Mountain pumps drop into most existing installations and offer replacement units and parts for many existing pumps.

Products: Horizontal and Vertical Cantilever Slurry pumps in Hard Metal or Elastomer construction.

Quality: Atlas offers a 2 year Limited Warranty for defective materials and workmanship.

Delivery: Atlas has substantial inventory at its West Coast USA Assembly and Distribution Center. The Battle Mountain bare Pumps and Parts are stocked in the Vancouver and Seattle, WA Warehouses. These bare pumps are drop-in replacement and the parts are interchangeable with the Warman® AH, HH, L, M, G, and SP pumps. A source for Gallagher and ASH series pumps can be replicated as a drop in replacement pump with interchangeable parts. Or these pumps and other slurry pump brand applications can be upgraded with a current Battle Mountain pump.

Distribution/Support: Atlas Distributors are well qualified in Pump Applications and Pump Repair processes. We welcome all sales and distribution inquiries.

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CAID Industries

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https://www.samuel.com/our-businesses/caid-industries

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CAID provides turn-key engineered packages for the handling, measurement, and movement of fluids within several industries including mining & minerals, oil & gas, chemical processing, power, and municipal. Our Mine Technology segment provides fabrication support, service, and repair, to the solvent extraction and electro-winning processes including stainless steel cathodes to the copper industry.

We are ISO 9001 certified and we hold ASME Code stamps for pressure vessels, piping, and more.

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Hydro's core business of engineered repair and field service is bolstered by a wide range of other services designed to help end users improve their operational efficiency. These services are designed to reduce the total cost of equipment ownership by addressing factors that impact equipment availability, reliability, and performance. Some examples include field testing and troubleshooting, on-demand and in-person skill development, condition monitoring, system optimization, and expedited parts supply.

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ConMICO, Inc.

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For sewage bypass operations, construction site or mine dewatering or any other application where intermittent flow can be a problem, PAH Series pumps are dependable, versatile performers that help contractors and municipalities move large volumes of liquid – quickly. These pumps range in sizes from 4" (100 mm) to 16" (400 mm), provide flows up to 15,000 GPM (946.4 lps) and heads up to 575' (175.3 m). Units are available in a variety of materials and are equipped with the latest in Final Tier IV engine-driven technology.

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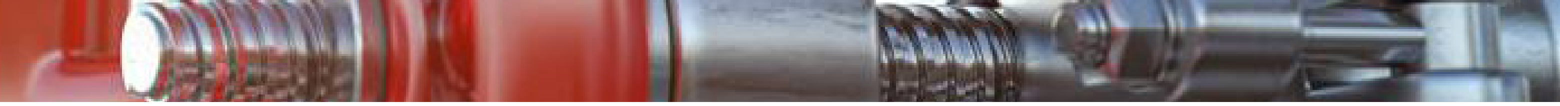
NETZSCH Pumps USA is the North American subsidiary of the globally operating group of NETZSCH companies. For over six decades NETZSCH has been manufacturing and supplying NEMO® Progressing Cavity Pumps and TORNADO® Rotary



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Schurco Slurry manufactures heavy-duty horizontal slurry pumps, vertical slurry pumps, replacement pump parts, and provides pump services to a wide array of markets worldwide. Schurco Slurry pumps and replacement parts for Warman® pumps are the industry's best source for supporting heavy duty centrifugal slurry pumps in industries like hard rock mining, mineral processing, power generation, aggregate production, or any type of slurry pumping application. Schurco Slurry focuses on delivering the lowest Total Cost of Ownership (TCC) of slurry pumping equipment by offering the best value and availability of slurry pumps and spare parts worldwide.

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Tsurumi Pump is a submersible pump manufacturer that supplies pumps worldwide for underground and open pit mine operations. Tsurumi pumps are capable of handling flows from 50 to 5000 gpm @ heads up to 750 feet. Parts are made of wear resistant materials capable of handling entrained solids commonly found in run of mine dewatering applications. Pump features such as dual inside mechanical seals (which do not require cooling from or come in contact with the abrasive liquid being pumped) is just one of the reasons Tsurumi Pump has become the pump of choice in mines throughout the world.

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Vertiflo Pump Company's vertical, horizontal and self-priming pumps are delivered fast, usually in half the typical lead time! Vertiflo's vertical sump pump line offers up to 3000 GPM, 250' Heads and 26' depth. The horizontal end suction pump line offers up to 3000 GPM and 300' Heads.

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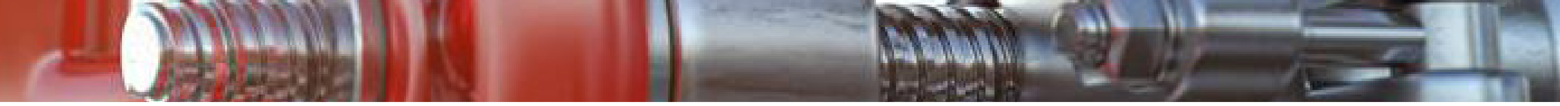
Vertiflo Pump Company, Inc. was established in 1979 to design, sell and build packaged lift stations. Since 1981, Vertiflo has concentrated on manufacturing vertical process pumps, sump pumps, end suction pumps and self-priming pumps in cast iron, stainless steel and special alloys.



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Watson-Marlow Fluid Technology Solutions

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Our peristaltic pumps can be installed in remote environments for abrasive slurry transfer without freshwater sources for seal or gland flushing. At chemical metering stations, our pumps can be employed without pressure or flow control ancillaries, bunding or screening equipment normally required to achieve safe, accurate results.

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The nature of abrasive, high-solid paste and aggressive chemicals present significant challenges to other positive displacement and centrifugal pumps recommended for hard rock and open cast surface operations. Our peristaltic pumps deliver substantial advantages for safely pumping viscous and abrasive paste or pulp and difficult fluids in mineral extraction processes such as dewatering and heap leaching.

Chuck Treutel
WMFTS Process Industries BDM and Marketing Manager
chuck.treutel@wmfts.com or info.us@wmfts.com to contact a local representative

Xylem

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Xylem is a leading global water technology company dedicated to providing services and solutions that solve water challenges across all industries, including water management, water quality and sustainability for mine operations. For us, supporting open pit, underground and processing operations isn't about offering a few key pieces of equipment and leaving you to figure out how to integrate them into your operation. Xylem is committed to providing everything you need to transport, treat and test water throughout exploration, development, operation and reclamation. Then we put it together in new, more meaningful ways to make your job easier, and your mine more efficient.

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Contact: genevieve.castillo@solvay.com Genevieve Castillo

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Nalco Water has been a global leader in water treatment and process optimization for the mining and mineral processing industry for over 50 years. We help mining customers meet their most pressing challenges by providing diverse products, on-site service, and technology to increase productivity, improve efficiency, decrease downtime, reduce total cost, and protect vital water resources. With our global network of technical experts, research and development laboratories, and world-class training, we provide our customers with unparalleled service and results.

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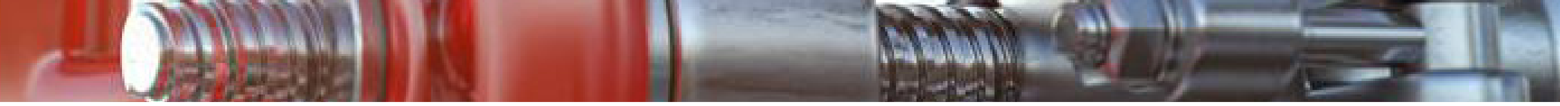

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ROOF - GROUND SUPPORT

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JENNMAR is a global, family-owned company that leads the way in ground control technology for the mining, tunneling, and civil construction industries. Since 1972, our mission has been focused on developing and manufacturing high-quality ground control products. We design and manufacture a wide range of reliable ground control products, including bolts, beams, channels, trusses, resin, rebar, and so much more. We take pride in creating products that enhance safety and efficiency in the mining, tunneling, civil, and construction industries.

Understanding the ever-changing and demanding conditions above and below ground, we have built the richest portfolio of diverse and complementary brands. JENNMAR sets the standard in every industry we serve, and as we continue to grow, our unwavering focus remains on the customer. Our commitment to our customer is guided by three words: SAFETY, SERVICE, and INNOVATION. It's these words that form the foundation of our business. It's who we are. For a comprehensive list of our brand portfolio, please visit our website at www.jennmar.com.

258 Kappa Dr
Pittsburgh, PA 15238 USA
Telephone: (412) 963-9071
Fax: (412) 963-9767
info@jennmar.com

Williams Form Engineering Corp.

www.williamsform.com

Williams Form Engineering Corporation has been providing threaded steel bars and accessories for rock, soil and concrete anchors, post-tensioning systems, and concrete forming hardware systems in the construction industry for over 105 years.

Our rock and soil anchor product line includes our Spin-Lock mechanical rock anchors, polyester resin anchors, multiple corrosion protection anchors, soil nails, strand anchors, Manta Ray soil anchors, Geo-Drill Hollow-Bar anchors, and micropiles. For concrete anchoring we offer Spin-Lock anchors, undercut anchors, reusable anchors and cast-in-place anchors. We also have a full line of All-Thread Rebar for tiebacks, micropiles and post-tensioning.

Williams Form Engineering Corp.
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Belmont, MI 49306
616-866-0815
williams@williamsform.com

MINOVA

MINOVA

MINOVA AMERICAS
www.minovaglobal.com

Minova's purpose is to preserve and enhance the value of assets both production and structural. We

provide safety critical products and solutions that deliver safe ground support and drive productivity for our customers. Our portfolio comprises steel and polymer based bolting systems, capsule and bulk cementitious and resin grouts for anchorage, seals, void control and backfilling, injection resins for water stopping, flotation reagents for ore processing and sprayed coatings for structural and water control. We have >140 years global experience and manufacturing on five continents, with research and development in North America, Australia and Europe. Minova's core industries are underground mining, tunneling and surface ground engineering.

150 Summer Court
Georgetown, KY 40324
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For over 50 years Alpine has been a trusted supplier of equipment for the construction, underground, and environmental sectors. We are specialists in hydraulic drum cutter attachments with our premier ROCKWHEEL product line, allowing for rapid and precise removal of rock and concrete, and filling the niche between bucket excavation and heavy hammers. We also offer the most comprehensive line of excavator mounted SOIL MIXING attachments for soil remediation, stabilization, and solidification activities. New to our product line are the Hartl ROCKCRUSHER and ROCKSCREENER Buckets for on-site material processing. If an off-the-shelf tool won't do the trick, job-specific customization is always an option. Alpine's experienced team will always strive to identify the optimum solution for your project, and is always available for technical support, service, and parts. All Alpine products are available on a rental basis with purchase option.

SAFETY EQUIPMENT AND PRODUCTS

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Carroll Technologies Group

https://www.carrolltechnologiesgroup.com/

Carroll Technologies Group is a leading provider of Communications, Electronics, and Safety Equipment for the tunneling and mining sectors. We distribute products for over 80 manufacturers, repair/calibrate over 75% of those products, and have a service team on hand to help facilitate those needs. Our company is dedicated to give you a service model 24/7 and we focus on the individual needs of our customers by providing a robust stock of the products they need at all times. Our number one goal is taking care of our customers and building a strong relationship. Customers trust us to supply all their needs with products supplied through companies such as MSA, PBE, Harrington, Industrial Scientific, NLT, Samson, Eaton, and so many more.

Josh Johnson
Sales Account Manager
Metal/Non-Metal Mining & Industrial
jj@carrollengineeringco.com
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BENETECH

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CAB Products

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PROVIX Inc. provides Proximity Detection and Collision Awareness & Avoidance Systems with mine management, position and tracking software. These systems meet EMESRT Level 9 regulations to autonomously stop or slow mobile and rotating equipment.

PROVIX also manufactures, assembles and installs custom camera systems for all mining applications, providing a safer, more productive operation. Wireless inspection camera systems integrate recording capability, remote monitoring, and enhanced lighting such as for stope, brow, pass, bin and drift inspection.

Digital or analog camera systems wirelessly transmit remote operations for loading pocket, chute, breaker, bin and conveyor systems, or mucking, drilling and bolting activities. Video systems are used on scoops, loaders, LHDs and drill rigs to haul-truck drivers and control-tower monitors.

PROVIX also supplies broadband back-up alarms, the finest LED and HID equipment lighting, cabled communication, thermal cameras, and gas detection systems for mining, tunneling, and mine rescue. For more information visit Provix.net.

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Canada
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Dräger

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For more than 125 years, underground workers have depended on safety equipment and quality products from Dräger to protect their lives. Our technical solutions are all components of an integrated safety concept that is dedicated to the improvement of underground safety – this begins with respiratory protection and gas detectors for everyday workplace safety and extends to self-contained self-rescuers and refuge shelters for emergency situations.

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E-Mail: us-safety@draeger.com

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SAFETY IS ALL WE DO™

Driver Industrial Safety™

www.DriverIndustrialSafety.com

Driver Industrial Safety™ is a quality manufacturer of market-driven Safety Products for industrial and commercial industries. SAFETY IS ALL WE DO™. We are headquartered in Phoenix, Arizona (USA) with manufacturing and warehouse facilities in the US & Canada and sell through our global distribution channels. Driver Industrial Safety™ was originally founded in 2004 under our former recognized name SafetyWhips®.

Driver was founded on the basis that there is a critical need for well-engineered and dependable products for work site safety. Clients depend on Driver to keep their worksite safe. Our combined 100+ years in LED and electronics manufacturing provides the best engineered products available for worksite safety. Driver Industrial Safety™ products are still unmatched in performance and durability.

Our 5 branded product lines lead the industry in robust quality and engineering: NVIZN Identification Displays®, SafetyWhips® Warning Whips, Helios Warning Lights®, Toro® Heavy Duty Wheel Chocks, and Industrial Decals Co™.

EVERYWHERE Communications

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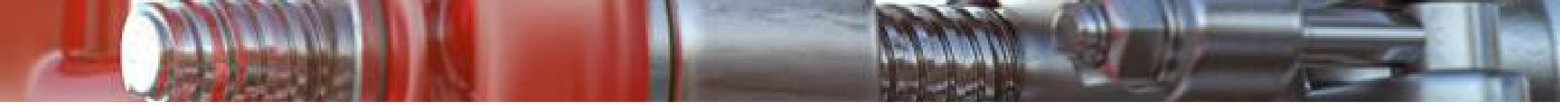
sales@everywherecomms.com



Strata Worldwide | Tunneling

www.strataworldwide.com/tunneling

Strata Worldwide, an international company established in 1992 and headquartered in the USA, supports the global tunneling industry with a selection of innovative safety technologies and underground networking systems. The company's mission is to ensure the day-to-day safety and effectiveness of underground operations. Strata's strengths lay in its broad product offerings, extensive underground experience, global presence, and attentive customer support.

A selection of the company's most prominent products includes proximity detection and collision avoidance systems for any and all types of equipment, underground communications and IoT networking, emergency refuge chambers, and a collection of specialized polymers and resins for construction and waterproofing.

Strata Worldwide maintains a successful track record by working closely with customers and fully understanding individual project needs. On-site and remote service capabilities provide ongoing support to ensure long-term system success.

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Superior Glove

www.superiorglove.com

Superior Glove is a leading innovator in the design and manufacture of safety gloves and sleeves. Since 1910, we have been protecting workers across the globe with specialized hand and arm protection for every major industry. Superior Glove products are engineered at our headquarters in Ontario, Canadawith teams and production facilities across Canada, the United States, Mexico, and Central America.

Why Superior Glove?
Protection workers want to wear

Workers shouldn't have to choose between comfort and safety. We innovate to fit the protection they need into comfortable safety gloves and other PPE they'll want to wear.

North American Innovation
We research, design, and test our products at our Canadian headquarters to ensure safety, effectiveness, and quality.

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See our full listing on page 42
www.x-glo.ca
don@x-glo-na.com
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MST Global

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Copper State Bolt & Nut Co

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SAMPLE DEVICES

Geotech Environmental Equipment, Inc.

Geotech Environmental Equipment, Inc. offers a range of products designed to meet the specific needs of the mining industry. These include fluid level monitoring instruments, metals detection with XRF technology, filtration for trace metals analysis, and air quality instrumentation. These tools provide accurate and reliable data to ensure safe and efficient mining operations while minimizing the environmental impact. Geotech's comprehensive suite of products helps mining professionals effectively monitor and manage critical aspects of their projects, resulting in improved productivity, compliance with regulations, and protection of the environment.

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Since its inception, Derrick® Corporation has expanded its product portfolio to serve a variety of challenging markets within the Mining & Industrial, Oil & Gas Drilling, and Civil Construction industries. Derrick remains committed to providing the latest technological enhancements that evolve alongside industry best practices and market developments – allowing end users to maximize resource efficiency for a greener world. For more than 70 years, Derrick has been leading the Mining & Industrial market in the design and manufacture of high-frequency vibratory screening machines and patented screen surfaces. With a pioneering spirit driving innovative solutions, the organization is continuously in the forefront advancing the field of fine particle and solid-liquid separation technology. Known worldwide for their high-capacity and superior separation efficiency, Derrick products are used successfully around the world. Its advanced technology allows processors to screen a wide variety of wet or dry fine materials in the range of 6.2 mm to 45 µm. Derrick's global family – comprised of employees, sales representatives, and distributors – are strategically positioned worldwide to provide superior customer service and technical support to customers around the globe. Our success is fully dependent on people. Priority one is to serve our global families; our tenured employees, multi-national partners, and surrounding communities.

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Fax: (716) 683-4991
info@derrick.com

Fluid Systems, Inc

www.fluidsystems.com

Fluid Systems is a developer and manufacturer of process technology to the mining, industrial, environmental and oil/gas industries for the past 40 years. We also design and manufacture stainless steel and urethane screen panels for FSI equipment along with other OEM replacement screen panels.

Fluid Systems technical expertise lies in our ability to design and develop equipment, systems, plants, 3d modeling, finite element analysis (FEA), package integration, installation, and commissioning. We have a line of equipment for all wet or dry applications. If you need more capacity, higher efficiencies or finer cut points from the same machine inquire about our HI-E technology. The HI-E Kit Option generates more energy on the screening area only and comes on all new FSI equipment as well as refurbishments.

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GENERAL KINEMATICS

See our ad on p. 63

www.generalkinematics.com

General Kinematics is one of the world's largest suppliers of vibratory processing equipment. GK is a significant contributor to the technical advancement of equipment design and application in the mining industry. GK serves a worldwide customer base through engineering-oriented sales representatives who cover industrial markets throughout the United States. International markets are serviced from subsidiary operations and through a combination of representatives, manufacturers, and strategic alliances with industry-specific organizations in other strategic locations. Today, over 50,000 General Kinematics units have been installed.

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Fax: 815-479-9428
E-Mail: info@generalkinematics.com

Polydeck

www.polydeck.com

Polydeck is the leading provider of modular synthetic screen media for the aggregate, energy & industrial, and mining industries. Our core competencies center around the ability to couple custom designed screen media products with screening application solutions that reduce costs and increase efficiency.

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Federal Screen Products, Inc.

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Federal Screen is a custom manufacturer and fabricator of wedge wire screens, delivering high-quality products and unmatched customer service. We provide filtration solutions that help lower maintenance costs and maximize systems efficiency for mineral processors.

We manufacture the most comprehensive range of screens for refining applications and specific machines, including large diameter, one-piece construction screens, providing an alternative solution to wire mesh and perforated metal filters. Wedge wire screens offer increased strength, higher flow rates, and reduced pressure loss while maintaining clog-free filtration greater than conventional metal filters. With the best delivery times in the business, you can count on us to help keep your project moving forward.

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JOHNSON SCREENS

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As the manufacturer of stainless steel and polyurethane screening systems, Johnson Screens offers the most comprehensive, innovative range of screen surface media and mining screening equipment in the industry.

Johnson Screens has developed world-class proprietary Vee-Wire® and polyurethane manufacturing processes. Our comprehensive range of products and services is well positioned through in-house product innovation, fit-for-duty material selection, mineral sizing, cleaning, and dewatering know-how.

Our screening systems:

- Remove moisture in coal preparation, which lowers coal heating value. Also, too much moisture leads to handling/freezing problems and increased transportation costs.
- Improve density media recovery in coal preparation to optimize process costs.
- Satisfy classification and purity specifications dictated by the metals and minerals markets.
- Ensure correct particle reporting will maximize asset efficiency in your downstream processes.
- Eliminate pegging and blinding (near-size material nesting in the screen openings) that improves process production yield and efficiency.

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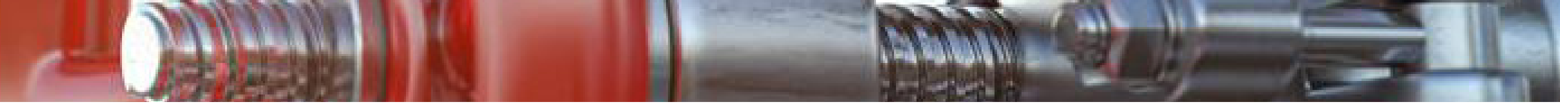

Schenck Process

www.schenckprocess.com

Schenck Process is recognized around the world as your strategic partner and the engineering experts in material handling, mineral processing and precision weighing technology for the mining industry. Collaborating closely with our customers, we commit to the real challenges to ensure their business remains in front of the varying mining cycles and trends. This dedication is achieved through our innovative designs, investment in research and development and our comprehensive engineering ability to improve efficiencies through higher reliability, accuracy and reducing operational costs when you invest in our robust vibrating screens and feeders, weighing, train loading system, dust collection, pneumatic injection, conveying solutions and screening media technology.

The advantages when you team with Schenck Process, we bring our global knowledge base from many industries supporting customers through the whole lifecycle of our products, with access to our in-house engineering teams, worldwide manufacturing locations, field service technicians, and aftermarket parts support to respond quickly to your needs no matter where you are located around the world.

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E-Mail: americas@schenckprocess.com

SCRUBBERS

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Email: sales@westpromachinery.com

SEALS

GCP, a Saint-Gobain company

https://gcpat.com/

The DE NEEF® portfolio from GCP, a Saint-Gobain company, provides waterproofing injection solutions that stop leaks under any circumstances and in any application - foundations, infrastructure and more. The major advantages of DE NEEF® products include the fact that they are easy to use, are not diluted, and can be applied quickly and reliably. The portfolio is mostly based on single-component, closed cell, hydrophobic polyurethanes, which are both durable and lasting. Therefore, leaks that are stopped once will remain stopped. For taking care of leaks that slow down the progress of a job site, endanger the future of a construction, or prevent full use of a building, DE NEEF® has become the world's most trusted brand.

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Maccaferri

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Maccaferri is a leading global company in civil engineering solutions based in Italy. The company has been providing innovative and sustainable solutions to various engineering challenges for over 140 years. They specialize in the design, manufacture, and supply of geosynthetics, geotechnical, and hydraulic products and solutions for the construction industry, including retaining structures, erosion control, soil reinforcement, and drainage systems.

With a strong focus on research and development, Maccaferri has developed cutting-edge technologies to offer solutions that are not only efficient and cost-effective but also environmentally friendly. They have a global presence with operations in over 100 countries and have completed thousands of projects worldwide. The company is committed to quality, safety, and sustainability, and their solutions are designed to meet the specific needs of their clients, from small-scale projects to large infrastructure developments.

Email: info.us@maccaferri.com
Phone: +1 301 223 6910

AVANTI INTERNATIONAL

see our full listing on page 39
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SEGMENT ACCESSORIES

Technical Tunnelling Components Ltd

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TTC has over 40 years' experience of manufacturing and supplying segment accessories including, connection bolts and sockets, grout/lifting socket assemblies, segment packers, grummets and other ancillary items, along with the award winning Dowelock connection, alignment and shear system, making TTC a true one stop shop for segment accessories.

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SEPARATORS AND CONCENTRATORS

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Eriez and Eriez Flotation offer best-in-class magnetic and flotation separation, material handling and metal detection systems to concentrate ores, recover coarse or ultra fine particles, remove tramp metals, and convey or feed heavy material. Eriez Mining equipment includes: Coarse and fine particle flotation columns, and mechanical cells, Wet Drum Separators that provide continuous recovery of magnetite or ferrosilicon in heavy media operations and/or concentration of ferrous and weakly magnetic ores, Suspended Electromagnets to remove damaging tramp metals from conveyed material, Metal Detectors built to handle harsh environments that can detect tramp and non-magnetic metals as small as ½ inch, Heavy Duty Feeders for low-horsepower, high-capacity mechanical feeding of bulk materials in volumes up to 2250 tph. In addition, customers can count on Eriez' Five-Star Service for a 24/7 service hotline, original OEM parts, on-site field service, equipment remanufacturing and full "as new" warranties.

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SCHAUENBURG Maschinen- und Anlagen-Bau GmbH

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TOMRA Sorting Mining

https://www.tomra.com/en/sorting/mining

TOMRA Sorting Mining provides proven sensor-based sorting technology for efficient material separation in various mineral and ore applications such as in the processing of gold, diamonds, gemstones, industrial minerals, and metal recovery from slag. World-wide, numerous sorting systems are already contributing to more energy-efficient and cost effective pre-concentrations as well as material recovery. TOMRA's sensor-based solutions help to extend the life of mining operations and increase the value of the deposit.

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SHAFT DRILLING AND RAISEBORING EQUIPMENT

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SHOTCRETE EQUIPMENT, SUPPLIES AND SERVICES

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Normet Americas Inc.

Normet is an industry-leading technology company offering continuous improvement to underground mining and tunnelling processes for increased safety, productivity and profitability. We work in close collaboration with our customers and utilise our process expertise amassed over thousands of mine and tunnel projects all over the globe into concrete actions and financial results for our customers.

We have a broad underground offering, including equipment for concrete spraying and transport, explosives charging, scaling, lifting, installation works, and logistics. We supply construction chemicals for sprayed concrete, admixtures, injection systems for ground and water control, waterproofing systems and additives for TBM technology. We have high quality and innovative rock reinforcement products that reduce the risk of accidents in challenging rock conditions. Our services are to ensure safety and productivity for our customers throughout the lifecycle this includes the supply of spare parts, rental equipment, remanufacturing and upgrades, field services, training and more.

Normet Americas, Inc.
1414 S Gladiola St | Salt Lake City, UT 84104 | United States of America
Tel. +1 801 5964700

Sika Corporation

usa.sika.com/STM

For more than a century, Sika has been pioneering underground construction and continues to be involved with the most challenging tunneling and mining projects ever built. We continue to forge ahead to bring modern day shotcrete, tunneling and mining technologies a step above the rest.

Focused on the entire North American continent, our Sika Shotcrete, Tunneling and Mining (STM) team incorporates the credibility of King Shotcrete with the global experience of Sika. Speak to one of our technical representatives today regarding our comprehensive portfolio of products which include pre-packaged shotcrete, fibers, liquid accelerator, grout, paste backfill, Sika® Aliva® equipment, asset maintenance and infrastructure repair. Sika specialists and our technical support team can advise and help meet challenges with the right solution.

Sika has subsidiaries in 101 countries around the world and manufactures in over 300 factories. Its 25,000 employees generated annual sales of CHF 9.24 billion in 2021.

Sika Corporation
201 Polito Avenue
Lyndhurst, NJ 07071
(800) 933-7452
robertson.kevin@us.sika.com

MASTER BUILDERS SOLUTIONS

www.master-builders-solutions.com/en-us

Master Builders Solutions is the world leader for reliable, customer-oriented product solutions to the underground mining sector. For more than 100 years, our innovations have become today's industry benchmark; we supply customized solutions that perform in the ever-changing geological environments and challenging underground conditions. Today we continue to support the underground mining sector with technological advancements that can directly enhance safety and improve productivity for a sustainable mining future.

The MasterRoc® product range is comprised of market-leading innovations and application expertise for the mining and tunneling industries. Our reliable, customer focused solutions include several outstanding technologies for:

- Shotcrete
  Accelerators and Fibers
- Rock Bolting Resins
- Injection
  Chemical Grouts
  Cement Grouts
- Chemical Technologies for Mine Backfill
- Admixtures for Concrete
- Thin Spray-on Liner (TSL)

23700 Chagrin Blvd.
Beachwood, OH 44122
Telephone: 216-839-7500
Fax: 216-839-8830
E-Mail: james.lindsay@masterbuilders.com

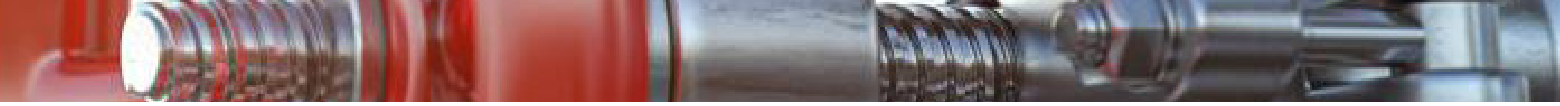
Shotcrete Technologies, Inc.

www.shotcretetechnologies.com

Shotcrete Technologies, Inc. is a Colorado Company with a global reach that supplies mining, tunneling and infrastructure projects with quality Shotcrete Products and Services. Our service starts long before the spraying begins. With 40+ years of global experience, expect our professionals to be involved from start to finish on your Shotcrete project. Our products and services include:

STI Shotcrete Equipment, including our industry standard; Shot-Tech Robotic Arm, which can be mounted on many types of carriers.

STI Shaftlining, a robotic system for lining/repairing



shafts and tunnels. This new process is quick, non-disruptive, efficient and all at a lower cost than conventional techniques.

STI Shotcrete Accelerators and admixtures, including our well-known Shotset 250 accelerator and STI Alkali Free.

Technical Support Training: STI's team of professionals understand, support and add value to every aspect of your shotcrete application.

Auxiliary Equipment: pumps, hoses, everything you need for a complete system.

1431 Miner St. / P.O. Box 3274
Idaho Springs, CO 80452 USA
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CREG TBM Germany GmbH

See our full listing on page 71
creg-germany.com
Phone: +49 211 522 889 00
Email: info@creg-germany.com

ConMICO, Inc.

See our full listing on page 38
www.conmico.com
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SLURRY SERVICES AND MACHINES

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sales@atlaseqco.com

SCHAUENBURG Maschinen- und Anlagen-Bau GmbH

Schauenburg-mab.com

Efficient separation plants form the basis for the successful use of fluid-assisted mining methods for tunneling, microtunneling, horizontal directional drilling (HDD) and diaphragm wall construction. Worldwide, the specifications for construction companies when using bentonite flushes and suspensions are becoming more and more demanding. On the one hand, this concerns ensuring the rheological properties of the rinses used during operation and, on the other hand, the disposal of the used rinses. SCHAUENBURG MAB supplies complete systems for the treatment of these slurries, which have been in use worldwide for many decades. Our systems for slurry treatment are continuously optimized for the various applications based on many years of experience. Thus, we can support our customers with our plants to meet these requirements sustainably and economically.

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SOIL AMENDMENTS / FERTILIZERS

Rocky Mountain Bio Products

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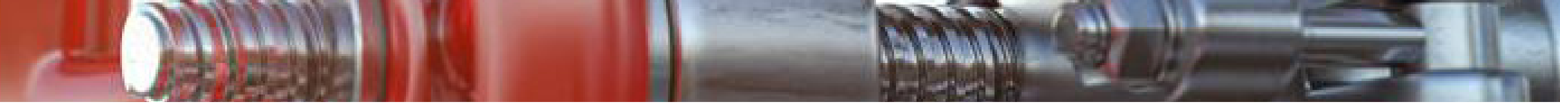

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Our flagship product, Hovermap, is a smart mobile scanning unit that combines advanced collision avoidance and autonomous flight technologies to map hazardous and GPS-denied environments. Hovermap is uniquely versatile, it can be handheld, drone-or vehicle-mounted to map challenging, inaccessible areas. With a wide range of applications, Hovermap is being used by customers around the world.

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Whether it's a subway tunnel in London, a hydroelectric plant on the Amazon river, the Gotthard Base Tunnel in Switzerland or a high-speed rail route in China: Construction projects of this magnitude are nothing unusual for Amberg Technologies AG. The Swiss company is one of the global leaders specializing in user-friendly surveying solutions. Geophysicists and surveyors as well as software and hardware engineers at the headquarters in Regensdorf design customized solutions for georeferenced data capture and processing in infrastructure installations. The company offers its customers field-proven products as well as customer-specific services for railway surveying, tunnel surveying and tunnel seismic.

The Amberg Tunnel surveying solution from Amberg Technologies supports tunnelling in all construction phases. The different system solutions in Amberg Tunnel combine precise measuring instruments with task-specific software. Significant improvements in efficiency are realised, especially in tunnel navigation, tunnel profile measurements, tunnel scanning, geotechnical analysis and as-built tunnel analysis.

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+41 44 870 92 50
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Frontier Precision is a distributor of geospatial survey and mapping products, unmanned aerial and ROV products, as well high precision satellite imagery and software. We are an employee-owned company, with over 35+ years of experience working in mining environments. Since our founding in Bismarck, ND in 1988, we've expanded our footprint to South Dakota, Minnesota, Colorado, Alaska, Montana, Idaho, Hawaii, Oregon, Washington, Florida, and Texas. Additionally, Frontier provides service in the states of Wyoming and Utah, along with our remote Frontier Precision Unmanned specific offices in Ohio, North Carolina, Florida, and Arizona. We pride ourselves on offering unmatched customer service with industry experts who always find a solution to fit your needs.

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STT Storage & Transfer Technologies

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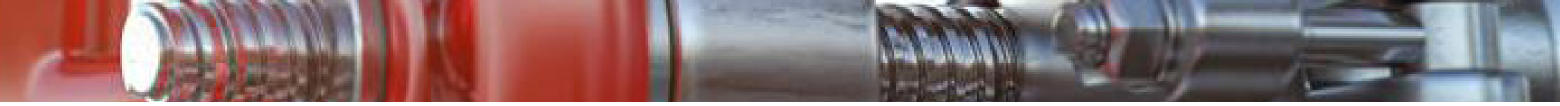

consultancy and our expertise is at the intersection of execution, leadership and operations. We believe that execution is the difference that makes the difference in converting goals into results.

Our ideas work: it's that simple. They come from our own experience: what we've seen work, and what we've successfully done ourselves. The techniques and practices are simple: instead of programs or processes that create more work, our tools are simply things that leaders do to lead — better. The tools can be immediately put into practice and will start making a difference immediately.

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TERRATEC
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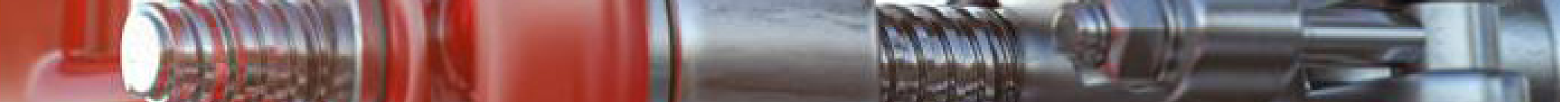

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Frontier-Kemper's Mine Development Division provides comprehensive, mine development services to our owners and partners. With techniques such as Blind Drilling, Raise Boring, Conventional Shaft Sinking, and Slope Construction, Frontier-Kemper has developed underground mines for coal, salt, copper, gold, and other minerals throughout North America.

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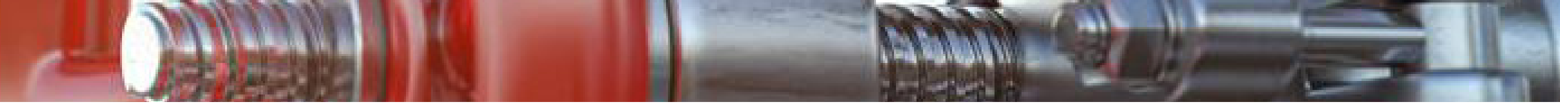

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All mining sectors feeling the same pressures

William Gleason
Editor

The Industrial Minerals & Aggregates Division (IM&AD) of SME has once again provided excellent editorial content for the July issue of *Mining Engineering*. The activities of 48 industrial minerals are summarized and much like last year, the issues impacting this sector are the same as those impacting every other mining sector: namely, supply-chain and demand issues driven by geopolitical, technological and societal pressures.

In a world that is working to meet aggressive timelines to decarbonize, the mining industry will be a key player. At the tip of that spear are the critical and strategic raw materials needed for everything from batteries in electric vehicles to advanced technologies. In the foreword to the Industrial Minerals Review Mike O'Driscoll, director and co-founder of IMFORMED Industrial Mineral Forums & Research Ltd. notes that in addition to accelerating actions from government and state organizations downstream activity by corporations is well under way.

While not included in the U.S. Geological Survey's (USGS) Critical Minerals List, copper is experiencing similar trends. The red metal is crucial to the global energy transition and demand is expected to increase dramatically as the world strives to meet carbon reduction goals.

While the debate for its inclusion on the USGS list will likely continue, (see Marc LeVier's President Page in the June 2023 issue of *Mining Engineering*) some of the largest mining companies in the world are already taking aggressive actions to position themselves in the copper sector.

In recent months, Newmont completed its $19.2 billion acquisition of Newcrest Mining that not only solidifies Newmont's position as the world's top gold miner but also adds a significant amount of copper reserves.

Rio Tinto's investment to expand its underground mining operations at its Kennecott operations is nearing $1 billion. Its recent $498 million investment in the North Rim Skarn project will commence in 2024 and is expected to ramp up over two years, to deliver around 250 kt (275,000 st) of additional mined copper over the next 10 years.

Antofagasta applied for an environmental permit to extend is operations at its Zaldivar copper mine through 2051 with an estimated $1.2 billion investment. And Barrick Gold is reported to be looking to expand its copper operations as well.

I recently asked Newmont about the trends that led to Newmont's acquisition of Newcrest. Daniel Horton, vice president, finance, treasurer and investor relations, said, "Societal pressures include those from investors who demand a transition to decarbonization while maintaining a profitable business. This influence not only guides Newmont to long-life, Tier 1 assets with some exposure to copper to help with the transition, but also to operate in stable jurisdictions where support for decarbonization will be strong from governments and communities.

"The technological megatrends are changing the ways we work and encouraging automation in the mining industry. In order to embrace the adoption of technologies that help drive sustainable efficiency in our mines, our operations need to have scale and mine-life to underpin these investments. Shorter mine lives do not provide the foundation to make these improvements necessary to enhance safety, sustainability and profitability in gold mining.

"Geopolitical instability is an important influence on investment decisions," Horton continued. "With the risk of nationalization, political instability or social unrest, it is more important than ever to understand the risks associated with each jurisdiction and your ability to safely and responsibly manage those risks. Where we operate continues to matter."

Many of these issues also influenced the activities of the 48 industrial minerals reviewed in this issue.

I would like to express my gratitude to Jim Norman, vice president of Tetra Tech, who has led the effort to gather and review these submissions since 1985. I would also like to extend my thanks to the dedicated technical committee members of SME's IM&AD who have contributed to these articles. Special recognition goes to the technical committee chair Dr. Tushar Gupta, senior metallurgical engineer-research at MP Materials, who is primarily responsible for the impressive number of articles, and Himesh Patel, metallurgist/project manager at McClelland Laboratories Inc.; Aneesh Kona, senior mining engineer at Pike Industries, CRH Co.; Kinsley Costner, mine engineer at Intrepid Potash; Mustafa B. Igdelioglu, senior structural engineer at Barr; Jack Sackrider, project geologist at Westward Environmental Inc. and Ahmed Nawab, graduate student at the University of Kentucky.

Lastly, I want to express my appreciation to Lee Bray and his team at the USGS National Minerals Information Center for providing many of the reviews featured in this issue. ■