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Industrial Minerals 2020 Review
Dynamic failure case study
Increased recovery rates at Hudbay Constancia

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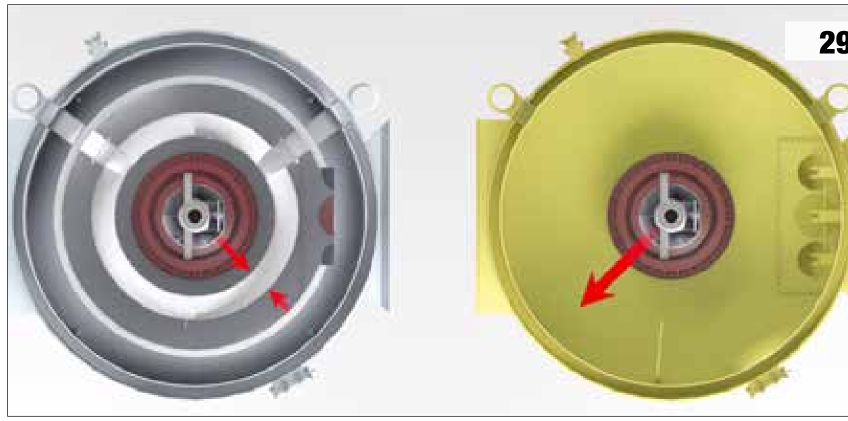

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According to the U.S. Geological Survey, the value of output of industrial minerals and materials from mines in the United States was $54.6 billion. In this issue, 43 various authors provide a summary of 43 minerals that are the building blocks of society. This issue also features coverage of coal and mineral processing technologies. Cover photo courtesy of Mike O'Driscoll.

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The value of professional associations;

Its an important part of one's professional career

William W. Edgerton
2021 SME President

SME is one of four member societies within the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME). The other member societies are: Association for Iron & Steel Technology (AIST), the Society of Petroleum Engineers (SPE), and the Minerals, Metals, and Materials Society (TMS). This year, AIME is celebrating the 150-year anniversary of its founding, in 1871, by 22 (actually 23) mining engineers in Wilkes-Barre, PA. Current AIME President and former SME President George Luxbacher continues to provide readers of Mining Engineering the history of AIME. In this issue he writes about the Institutes second 50 years, the time frame of 1922-1971.

Recently, a number of representatives from SME, including myself, and four ex-SME presidents (Barb Arnold, Luxbacher, Raja Ramani and Nikhil Trivedi) travelled to Wilkes Barre, PA to participate in the unveiling of a plaque honoring this 150-year anniversary. This event was organized by leaders from SME's Pennsylvania Anthracite section, illustrating how much SME contributes to AIME. Other participants included Congressman Matt Cartwright (D-PA), the Mayor of Wilkes-Barre, George C. Brown, Mark Riccetti from the Luzerne County Historical Society, and the executive directors of both SME and AIME, Dave Kanagy and Michele Lawrie-Munro. It is worth noting that SME has a history of providing leadership to AIME: In addition to the current AIME president, Luxbacher, sixteen other SME presidents have served as president of AIME since SME's founding in 1957. This leadership has resulted in the continuation of a vibrant AIME that confers awards and scholarships, documents its historical heritage, participates in the United Engineering Foundation (UEF), and partners with other associations in producing collaborative programs.

Being a member of a technical society is an important part of one's professional life. It helps you stay current with technology, it allows expansion of your network and facilitates relationship-building, and it provides educational offerings. All of these are essential elements in advancing one's career, and are the reasons why participation in a technical society is a critical aspect of career development.

An equally important element is the historical context of such organizations. This manifests itself in the concept of giving back to organizations. As we age, we recognize the factors that have made us successful, and we look for ways to pay this forward for the benefit of others who come after us. This is a major way that the future growth of our industry is ensured.

Again, I congratulate the Pennsylvania Anthracite Section for an outstanding effort in organizing the unveiling of the new plaque, and the luncheon presentations. This event crystallizes the importance of SME's local sections to our mission. ■

Safety Share — Haul trucks and other large surface mining vehicles are capable of destroying smaller vehicles that cannot be seen by the operator. Traffic controls, training and avoiding distractions are key to enhancing safety. Collision warning and avoidance systems can also help.

Key safety practices

- Communicate and verify with all equipment operators any planned movements and location upon entering or exiting a work area.
- Ensure all persons are trained to recognize workplace hazards. Specifically, train equipment operators on the limited visibility and blind spot areas that are inherent to the operation of large equipment. Do not drive or park smaller vehicles in mobile equipment's potential path of movement.
- Instruct all operators on the importance of using flags or strobe lights on the cabs of their vehicles to make haulage truck operators aware of their location. Flags must be high enough to be in the view of equipment operators.
- Install and maintain collision avoidance/warning technologies on mobile equipment.

U.S. Mine Safety and Health Administration

Federal task force will focus on supply chain issues

THE BIDEN administration announced the creation of a new federal task force that will aim to address near-term supply chain issues affecting a number of industries, including mining.

The U.S. Department of Commerce released the findings of its 100-day review of U.S. access to critical products and minerals used for everything from medicine to electric vehicles.

The supply chain task force will look to identify specific violations that have contributed to a "hollowing out" of supply chains that could be addressed with trade remedies, including toward China, senior administration officials told Reuters.

Officials also said the Department of Commerce was considering initiating a Section 232 investigation into the national security impact of neodymium magnet imports used in motors and other industrial applications, which the United States largely sources from China.

In a statement, the White House said the Biden-Harris Administration has already begun to take steps to address supply chain vulnerabilities including working with companies that manufacture and use semiconductor chips to identify improvements in supply chain management practices that can strengthen the semiconductor supply chain over time.

The Department of Defense (DOD) also announced an investment in Lynas Rare Earths for the expansion of the largest rare earth element mining and processing company outside of China to provide the raw materials necessary to help combat the climate crisis.

"These efforts are critical because, as the COVID-19 pandemic and resulting economic crisis have shown, structural weaknesses in both domestic and international supply chains threaten America's economic and national security," the statement from the White House read. "While amplified by the public health and economic crisis, decades of underinvestment and public policy choices led to fragile supply chains across a range of sectors and products. Unfair trade practices by competitor nations and private sector and public policy prioritization of low-cost labor, just-in-time production, consolidation, and private sector focus on short-term returns over long-term investment have hollowed out the U.S. industrial base, siphoned innovation from the United States, and stifled wage and productivity growth."

Among its goals, the task force will work to secure an end-to-end domestic supply chain for advanced batteries. The Department of Energy (DOE) will release a National Blueprint for Lithium Batteries to codify the findings of the battery supply chain review in a 10-year, whole-of-government plan to urgently develop a domestic lithium battery supply chain that combats the climate crisis by creating good-paying clean energy jobs across America. DOE will host a Battery Roundtable, including representatives from each segment of the battery supply chain, to discuss the blueprint.

DOE's Loan Programs Office (LPO) will immediately leverage the approximately $17 billion in loan authority in the Advanced Technology Vehicles Manufacturing Loan Program (ATVM) to support the domestic battery supply chain. ■

Peru's presidential election could impact mining industry

THE MINING sector in Peru was holding its breath while awaiting the final outcome of its presidential election that saw a slim lead for socialist candidate Pedro Castillo.

On June 11, with 99.6 percent of the votes counted, Castillo held a slim lead of about 60,300 votes or 50.2 percent of the vote. Castillo, the former teacher and union leader, has pledged to rewrite Peru's decade's old constitution and take up to 70 percent of profits from mining firms operating in the copper-rich country.

His opponent Keiko Fujimori, a market-friendly conservative has contested the early results of the election and has alleged fraud.

Reuters reported that Peru's market and mining watchers are wary of a presidential election victory for Castillo, but see a potential silver lining: a sharply split vote could hinder his plans for dramatic reforms.

A final tally may take days to arrive and there could be challenges to the results.

"The only positive factor - even if Castillo wins - is that the result of the election shows you that the country is very divided," said Guillaume Tresca, senior emerging market strategist at Generali Asset Management.

"And with a divided congress it will be very hard for him to implement structural and disruptive reforms."

Whoever wins the presidential vote, Peru will have a deeply fragmented legislature with ten diverse political parties, none of whom hold a majority. Castillo's Free Peru socialists will have the largest bloc, followed by Fujimori's conservatives.

Peru's congress has relished clashing with the presidency in the past. Last year, it pushed through a controversial impeachment process against then-President Martin Vizcarra that forced him to step down and sparked deadly protests.

Roque Benavides, chief executive of local miner Buenaventura, told Reuters that miners could agree to things like voluntary contributions to finance local infrastructure projects but more drastic measures like nationalizations would derail investments.

"I think that neither of the two candidates can impose their position and therefore I think that the idea of them making dramatic, drastic changes is very debatable," he said.

Francisco Acuña, a Santiago-based analyst at mining consultancy CRU, said it was quite likely the new government would need to negotiate and reach consensus with companies. ■

Rio Tinto Kennecott partners with BYU researchers;
Teams will focus on sustainable reclamation solutions

RIO TINTO Kennecott and Brigham Young University (BYU) researchers are joining forces to develop innovative and sustainable solutions to improve reclamation at the Bingham Canyon Mine near Salt Lake City, UT.

In June 2020, a group of students and professors from the BYU Department of Plant and Wildlife Sciences broke ground on four research projects on land areas surrounding the mine with the goal to increase plant diversity and stability and enhance the aesthetics of areas visible from the Salt Lake Valley.

BYU associate professor of plant and wildlife sciences Matt Madsen said: "This partnership is helping Rio Tinto Kennecott to continue improving the quality of its reclamation efforts and give our students the opportunity to learn skills that will benefit them in their future employment. The restoration we are doing in these areas can benefit Utah's land and community by bringing back native vegetation, improving the site for wildlife habitat, air quality and the viewshed here in Utah.

"We are proud of our commitment to the environment, and this partnership is an important step in advancing sustainable outcomes. Joining forces with BYU professors and students to apply the latest environmental research to further improve our effort is extremely rewarding."

Rio Tinto Kennecott managing director Gaby Poirier said, "this joint project is mutually beneficial for Rio Tinto Kennecott, BYU and our surrounding communities, and we hope this project will be a stepping-stone for future collaboration that helps improve reclamation work at other locations in Salt Lake City and more widely."

The partnership is employing 12 students on six different projects for the next three years, all of which contribute to land reclamation efforts. Study objectives include engineering seed coatings to increase seeding success, understanding the vital role of Curlleaf Mountain Mahogany, more effectively establishing perennial grasses and improving the viewshed of waste rock areas.

Alex Larson is one of two female BYU graduate students leading projects. Her Saints Rest Biodiversity Study is working to increase the diversity of plants on reclamation land by introducing shrubs and forbs that match the surrounding landscape, using a technique inspired by the process of how anti-epileptic medications work.

"When anti-epileptic medications are taken, the compounds that treat the symptoms are embedded in a biodegradable polymer, essentially a biodegradable plastic, which dissolves after ingestion, so it slows the release of the medication and increases its effectiveness," said Larson. "We are applying this same method to seeds. We have a biodegradable biocompatible polymer coating embedded with a growth hormone wrapping the seeds we are planting. This coating will help increase the germination success on the site

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Global competition launched to electrify mining fleets;
Global Mining Guidelines Group will develop solutions

Newswatch contents

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14 Indigenous groups reject cultural heritage bill

16 Wyoming Innovation Center breaks ground in Gillette

THE GLOBAL Mining Guidelines Group (GMG) has introduced an international initiative aimed at developing effective solutions for mine electrification and decarbonization and opening new pathways for integrating innovations from other sectors into the mining industry.

BHP, Rio Tinto and Vale have launched the Charge On Innovation Challenge, a global competition to promote collaborative efforts on reducing carbon emissions from mining operations. Facilitated by Austmine, the leading not-for-profit industry association for the Australian mining equipment, technology and services (METS) sector, this is a global challenge for technology pioneers to develop new interoperable solutions that can assist in the electrification of mobile mining equipment in order to help reduce consumption of diesel fuel and significantly cut emissions, securing safety, productivity and operational improvements.

Addressing climate goals needs to be at the core of the mining industry's efforts. This initiative will be a great opportunity for key stakeholders to bring forward new ideas and encourage innovative technology developments to help solve one of the greatest challenges facing mining today.

The deadline for submitting an expression of interest is June 30. For further details on requirements visit www.chargeoninnovation.com and participate in global decarbonization efforts. ■

Industry Newswatch

Energy transition could lead to smaller mines;

Report finds new opportunities could be on the horizon

A NEW REPORT from accountancy firm PwC suggests that as the world begins to transfer to cleaner energy production the world’s biggest miners should consider developing smaller deposits to make the most of the commodities expected to be in demand in the future.

Large mining companies have tended to seek the biggest, low-cost, long-life deposits, such as top global miner BHP Group’s iron ore operations in Western Australia that have already been running for more than half a century.

In the report, PwC writes the global energy transition has opened up opportunities as power grids decarbonize and as demand grows for battery raw materials like nickel, cobalt, lithium as well as copper for electric vehicles.

“The way battery minerals present themselves geologically doesn't necessarily lend themselves to a multi-decade horizon,” PwC Australia Global Mining leader Paul Bendall told *Reuters*. “That might mean the top miners need to recalibrate their investment criteria.”

Battery minerals represented less than 3 percent of the top 40 miners’ total revenue in 2020, the PwC report showed, but there are ample opportunities for that to share to increase, including through buyouts.

Miners have developed significant warchests as governments around the world invested heavily in infrastructure to overcome the disruption caused by COVID-19, sending prices sky high.

As well as investing in renewable power generation alongside their mines, some firms may move into processing, Bendall said.

A representative from Tesla told an Australian mining conference that environmental, social and governance (ESG) would be a major consideration in how new energy supply chains develop.

Tesla plans to spend $1 billion a year on Australian minerals thanks to its reliable mining industry and responsible production practices.

However, mining companies need to take the safety mindset they have spent the last few years instilling into their work culture and apply that to integrating ESG, the PwC report said.

According to MSCI ratings, only four of the Top 40 are considered leaders in managing the most significant ESG risks and opportunities, PwC noted. ■

Rio Tinto: Innovation for reclamation

(continued from page 10)

compared to what would exist naturally.”

Fellow graduate student Holley Lund is spearheading the Yosemite Waterboxx Study nearby. Her team is working to grow woody species that match the surrounding hillsides. Waterboxx irrigation technology maintains moisture in the soil during dry periods of the year so that seedlings can establish in the rocky soils. By the end of the project, they will have planted 656 shrubs and trees.

“Restoration has been done on this site before,” said Lund. “It looks great during parts of the year; however, these particular species go dormant, turn brown and stand out from the native hillsides during other seasons. Our goal is to establish a woody species that will match the green textures of the surrounding mountainside, help with erosion and provide food for wildlife.” ■

Indigenous groups reject cultural heritage bill;

Proposed bill in Western Australia aims to protect heritage sites

A PROPOSED BILL to protect cultural heritage in the state of Western Australia is flawed and should not be presented to parliament according to five Indigenous groups who said they had not been properly consulted over the bill's revisions.

Reuters reported that a national Indigenous group said if the bill was passed it would risk further damage to cultural heritage, citing the destruction of two rock shelters in Juukan Gorge by Rio Tinto in May 2020.

"If the bill continues in its current form, significant damage to Aboriginal heritage will absolutely occur and, as Juukan Gorge has proved, damage to Aboriginal heritage represents significant financial risk to miners and investors," National Native Title Council chairman Kado Muir said in a statement.

The destruction of the rock shelters at Juukan, which showed evidence of continual human habitation before the last Ice Age, led to a leadership overhaul at the world's largest iron ore miner and a national inquiry with the removal of top executives. Rio Tinto has issued an apology saying in part, "we fell far short of our values as a company and breached the trust placed in us by the Traditional Owners of the lands on which we operate. It is our collective responsibility to ensure that the destruction of a site of such exceptional cultural significance never happens again, to earn back the trust that has been lost and to re-establish our leadership in communities and social performance."

Rio Tinto's action was legal and was approved by the state minister of Aboriginal affairs under a process that does not allow Aboriginal groups to appeal.

The Western Australian government has not made public the results of consultation over the bill, undertaken in five weeks last year, said WA Alliance member Yamatji Marlpa Aboriginal Corp.

"Members do not believe sufficient time was allowed in this current phase for Aboriginal people to fully engage on the bill and its impacts on their heritage," it said in a statement.

The Western Australian state minister for Aboriginal Affairs acknowledged current laws were inadequate to protect heritage. Drafting of the bill was ongoing and a summary of submissions and responses would be made available when it was finalized, the minister said.

Changes to the bill include allowing traditional owners to appeal decisions made by the minister where currently only proponents may lodge an appeal.

The Kimberly Land Council called on the state government to recognize the right of Aboriginal people to protect their own cultural heritage and to protect the Martuwarra Fitzroy River.

They are concerned that state government water allocation plans will threaten culturally important sites and the local ecosystem. ■

Nuclear power plant to be built at former coal-fired plant;

Wyoming will remain as energy leader with new plant

WYOMING WILL WORK with TerraPower to build a next-generation, small nuclear plant at the site of a soon-to-be retired coal-fired power plant in the state.

Microsoft co-founder Bill Gates is the founder and chairman of TerraPower. He said that the plant featuring a sodium reactor and molten salt energy storage system will perform better, be safer and cost less than traditional nuclear power.

The *Associated Press* reported that TerraPower is working with Rocky Mountain Power, an electric utility serving Wyoming and other Western states, to put the Natrium reactor at one of four of the utility's power plants in Wyoming, with the location to be decided later this year.

"We think Natrium will be a game-changer for the energy industry," Gates said by video link to a news conference hosted by Republican Gov. Mark Gordon. "Wyoming has been a leader in energy for over a century and we hope our investment in Natrium will help Wyoming to stay in the lead for many decades to come."

Wyoming is the top uranium-mining state, and the reactor would use uranium from in situ mines that extract the heavy metal from networks of water wells on the high plains, officials said.

Wyoming also is the top coal-mining state. The U.S. coal industry has suffered a dramatic downturn over the past decade as utilities switch to cheaper and cleaner-burning gas to generate electricity.

The reactor proposal creates common ground between Wyoming, one of the most Republican states, and Democratic President Joe Biden's administration.

"The future of nuclear energy is here," U.S. Energy secretary Jennifer Granholm said by video link. "It's got a simpler design that will hopefully result in faster construction at lower cost. It's going to create a smaller footprint. It's going to be equipped with next-generation safety measures."

If it's as reliable as conventional nuclear power, the 345-megawatt plant would produce enough power for roughly 250,000 homes. The plant also would produce hydrogen, which can power trucks and other vehicles with fuel cells.

The plant will be a "multibillion-dollar project" with costs to be split evenly between government and private industry, TerraPower president and CEO Chris Levesque said. ■

Wyoming Innovation Center breaks ground in Gillette;
Center will search for new ways to utilize coal

THE WYOMING Innovation Center (WyIC), a new 5,500-square-foot coal commercialization facility that will promote the advancement of diversification of the energy sector broke ground on June 7 in Gillette, WY.

Energy Capital Economic Development (ECED) announced that the 9.5-acre site, located in northeast Wyoming's coal-rich Carbon Valley region, will be home to companies and researchers developing commodities like asphalt, graphene, graphite, agricultural char, carbon fiber and more — using coal and coal byproducts.

The state-of-the-art WyIC will feature two buildings and seven demonstration sites for pilot plants, for private companies and researchers to advance coal-to-product and rare earth element processes. The region holds 500 Gt (550 billion st) of recoverable coal, making it a desirable testbed for new and proven products made from coal.

The project, located on a reclaimed mine site, received a $1.5 million grant from the Wyoming Business Council, along with a $1.46 million matching grant from the U.S. Economic Development Administration (EDA). It also received funding from both the City of Gillette and Campbell County.

WyIC's first tenant is the National Energy Technology Laboratory (NETL), which focuses on applied research for the production and use of clean-energy resources.

"A main goal of the Innovation Center is to promote and advance the diversification of Wyoming's economy utilizing our wealth of raw materials," said Wyoming Governor Mark Gordon, whose state has been the leading coal producer since the 1980s. "Backed by state and federal resources, we're confident that the facility will facilitate the industry's sizable economic growth and Wyoming's undeniable leadership in coal processes and production."

Tenants at WyIC will focus on evaluating the commercial viability of high-value nonfuel, low- or zero-emissions products made from coal and extracting pivotal rare earth elements found in the fly ash of coal burned at local power plants. The region's Powder River Basin coal contains high extractable rare earth element content in portions of the coal seams and also particularly in the coal ash materials produced at power plants — used in nuclear reactors, cell phones, magnets, camera lenses, wind turbines, electric cars and more. (The United States currently depends on China for as much as 97 percent of its rare earth element sources.)

"Our goal at this new facility is to analyze the immense potential of rare earth elements and their commercialization — a process that could reduce U.S. dependence on foreign markets," said Tom Tarka, engineer at NETL. "Northeast Wyoming is a perfect location to begin these studies — with plenty of feedstock and a knowledgeable workforce."

Construction of the facility is expected to wrap in the fourth quarter of 2021. The completion of the facility will enable NETL's pilot test to proceed — slated for completion in the third or fourth quarter of 2023. ■

Mining companies seek input into Chile's new constitution;
Mining industry looks to protect copper production

THE MINING Council, a group in Chile that unites and represents large mining firms in Chile such as Anglo American, Antofagasta, Barrick and BHP has drafted a document outlining how those companies would like to progress under the new constitution that is being drafted there.

The rewriting of the constitution is the result of a broad political consensus agreed to after the violent social protests that broke out at the end of 2019 over inequality in a nation known for its decades-long embrace of free-market policies. An assembly of 155 members was formed to draft a new constitution for the country. On June 20, Chilean President Sebastian Pinera said the assembly to draft a new constitution for the copper-producing country, replacing the one inherited from the dictatorship of Augusto Pinochet, will hold its first session on July 4.

Chile is the world's top copper-producing nation and the mining firms working there will try to preserve growth of the sector, an industry leader told local media on Saturday.

Reuters reported that Joaquin Villarino, head of the Mining Council told local newspaper *El Mercurio* that it had written a document outlining how the companies would like to operate under the new constitution.

"There are some things that should be kept because they have been positive and have contributed to this country achieving levels of development that no other country in Latin America has," Villarino was quoted as saying in the newspaper story.

"It seems to us it would be a mistake to blur the things that have been positive," he said.

The document drawn up by the council addresses environmental regulations, which have been much debated in Chile, and the form in which mining companies interact with indigenous populations and the local towns where mines are located.

The initiative by the council comes at a time of historically high copper prices and as the copper and lithium mining industries are the focus of a nationwide debate on sales royalties. ■

US Secretary of Energy speaks of demand for **battery-manufacturing supply chain**

AT A ROUNDTABLE discussion that included Congressional as well as industry representatives, U.S. Secretary of Energy Jennifer Granholm spoke about the urgent and growing need to create an advanced battery manufacturing value chain within the United States.

The event was attended by Sec. Granholm, along with Congressman Mike Doyle of Pennsylvania's 18th Congressional District. Industry representatives from six private companies with a stake in the battery energy storage space also spoke briefly before answering questions from the Department of Energy (DOE) chief.

Energy Storage News reported that the event was hosted and presented by Kelly Speakes-Backman, the former chief executive officer of the national Energy Storage Association, now the acting assistant secretary and principal deputy secretary for energy efficiency and renewable energy at the DOE.

During the event Granholm, said that with technology being central to 21st century life, lithium batteries are essential components for the clean energy transition, job creation, industrial competitiveness and the fight against climate change.

With the United States targeting 100 percent clean electricity by 2035, the demand for clean energy technologies is growing. The major concern is that China is currently the only country in the world which has control over every tier of the supply chain for critical materials — including lithium.

China has 80 percent of the world's raw-material refining capacity.

The International Energy Agency (IEA) estimates the need for lithium will increase by up to 70 times over the next 20 years.

Fitch Solutions projects that for every 1 million electric vehicles (EV) on the road, the EV market will need 54 kt (60,000 st) of lithium. At that rate, the world will need between 1.8 to 4.5 Mt (2 to 5 million st) of high-grade lithium over the next five to 10 years.

Current production is estimated to be only around 74 kt/a (82,000 stpy) annually worldwide.

If the United States remains reliant on imports, the country will be unable to compete in the global market for clean energy technologies, which Granholm said will be a market worth at least $23 trillion by the end of the 2020s.

The recently released Federal Consortium for Advanced Batteries (FCAB) National blueprint for lithium batteries 2021-2030 sets out a whole of government approach for shoring up domestic battery production. This includes strategies for building out the domestic supply chain and Granholm called for national effort in U.S. policy, alongside "ingenuity and major investments" to start making batteries using U.S. labor.

Granholm also announced that the DOE's 17 national laboratories and DOE partnerships will receive $200 million funding over the next five years for EVs and batteries to complement $62 million pledged in April to support vehicle electrification. Also on the table is a $4 million prize through the Department's geothermal office to support lithium extraction processes using geothermal industry assets.

Granholm said that the challenge is "big and urgent" and the United States needs all of the help it can get to succeed. She said a big private-partnership announcement on the lithium battery supply chain is imminent. ■

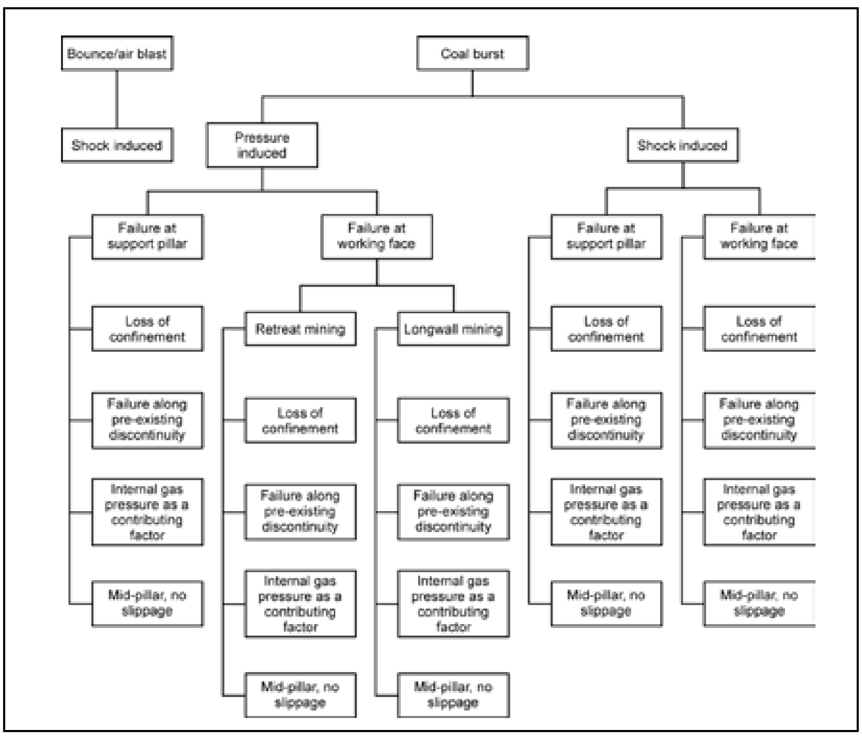
Dynamic failure classification within the context of regional geology:

A case study from the Uinta and Piceance Basins

by Heather Lawson, Maria Mastalerz and David Hanson

Figure 1

A hierarchical decision tree for dynamic failure classification developed by NIOSH in conjunction with the University of Utah Mining Engineering Department.



Dynamic failure may be defined as the abrupt, violent ejection of coal or rock within a working area of an underground coal mine (Peng, 2008). These events may occur with little or no warning. Despite evolving mining techniques and practices, dynamic failures continue to occur. Between 1983 and 2013, American coal mines have experienced nearly 400 cases of reportable dynamic failure accidents, resulting in more than 20 deaths, 155 lost-time accidents and an estimated 48,000 lost man hours. While these events are relatively rare in relation to other types of ground control accidents, they resulted in worker injury in greater than 50 percent of cases reported to the U.S. Mine Safety and Health Administration (MSHA) after the year 2000, and the fatality rate per capita for these events is more than 10 times that associated with roof falls (MSHA, 2020).

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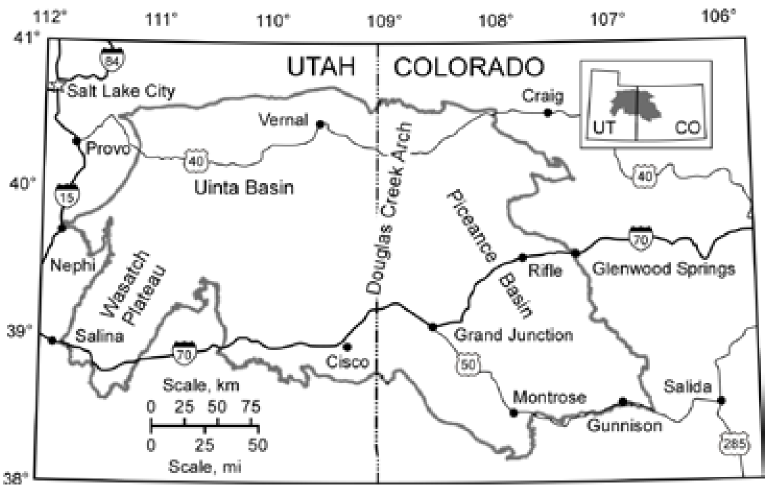
Dynamic failure events occur when mining-induced stresses exceed the bearing capacity of the coal seam or surrounding strata, such that the rock mass fails abruptly and energetically. However, the precise balance of risk factors and specific failure mechanism(s) vary from case to case. Lack of consistent hazard prediction may come in part from an oversimplification of dynamic failure phenomena: There is not one type of dynamic failure, but rather several — each with similar but distinct physical characteristics and driving causes. Efforts to categorize dynamic failure events were documented as early as 1918, when Rice (1935) proposed that dynamic failure in coal mines falls into two primary categories — pressure bursts and shock bursts. Brauner (1994) additionally identified dynamic failure events in which internal gas pore pressure plays a significant contributing role in gas outbursts. More recently, Iannacchione and Tadolini (2016) proposed an expanded classification scheme that considers both the event source and the characteristics of its manifestation. Vardar et al. (2018) echoed these observations, referring to these event subtypes as direct and indirect, akin to Rice's pressure and shock bursts, respectively. As noted by Hebblewhite and Galvin (2014) and Vardar et al. (2018), however, there is no consistent terminology with which to refer to different types of dynamic failure. This makes clear and consistent communication between dynamic failure researchers more challenging and may contribute to slower progress toward comprehensive understanding of dynamic failure root causes.

As noted by Hebblewhite and Galvin (2014), all dynamic failure initiation events are predicated by the existence of four co-occurring variables in the coal-associated clastic rock system:

1. The rock mass must be sufficiently stressed to produce failure.

Figure 2

The physiographic boundaries of the Uinta and Piceance Basins, in which the dynamic failure classification system has been applied (modified after USGS, 2002).



2. The system must be in some way unstable. Examples may include weak bedding contacts or the presence of soft mudstone layers that facilitate loss of confinement under load. Other examples might include proximity to faulting or floor or roof strata of some critical thickness, such that it is neither strong enough to withstand mining-induced loading nor weak enough to fail gradually and instead failing suddenly and with great force.
3. The rock mass must be able to store stress, which is then subsequently released in the form of kinetic energy, thus facilitating the expulsion of rock and coal into the working area. Factors that may contribute to this may include critically sized pillars; competent, poorly cleated coals; or strong, thick roof and/or floor strata.
4. There must be a triggering event or change in the ratio of load to capacity. Examples include the collapse of massive strata in the gob or changes in the localized stress regime.

The interaction of these variables in each case is unique and is likely to differ between events. By clearly demarcating the differences between types of dynamic failure events and their associated characteristics and geologic settings, we can begin to more effectively identify patterns in specific risk factors that contribute to these events.

Developing consistent terminology to describe unique event classifications is, then, an important first step in being able to discuss dynamic failure in a meaningful way. A preliminary classification system for dynamic failure events has been devised by the National Institute for Occupational Safety and Health (NIOSH), Spokane Mining Research Division (SMRD), in conjunction with the University of Utah Mining Engineering Department based on the characteristics of dynamic failure events described in the available literature and accidents reported to MSHA. The existing system represents a new classification scheme based upon the work of Whyatt (unpublished). The proposed classification system was developed through the systematic review of dozens of dynamic failure records and published cases and then establishing trends in event characteristics and apparent driving mechanisms. Physical characteristics considered include the source(s) of stressors, event location with respect to mining activities, volume of debris, violence of failure, primary source of damage (pillar, roof or floor), mining method, and other information contained in accident narratives. This study applies this newly developed classification scheme to a sample set of dynamic failure accidents and seeks to evaluate classification patterns within the context of regional geology to better understand how geologic risk factors may influence the failure mechanisms. If geologically induced risk can be clearly identified, site-specific mitigation techniques may then be enacted, ultimately leading to a reduction in the number of reportable accidents.

Methods

Development of a classification scheme. Development of the hierarchical classification decision tree (Fig. 1) was based upon physical characteristics and potential event sources, as identified through review of the available literature, historical dynamic failure reports and MSHA accident and fatality reports. Criteria considered for classification include the physical characteristics of the failure, proposed risk factors (by mine operators or MSHA officials, as indicated by published reports and accident narratives), geologic information, mining methods and mine design.

The classification decision tree is subdivided into several tiers, based on event characteristics:

- Witnesses explicitly mention an air blast. There is no indication of bursting behavior, however, either at the working face or at any distance from it in conjunction with the bounce or air blast.
- Workers and/or equipment are thrown or displaced by ground movement.
- There is mention of the massive collapse of strata in the gob or poor caving. This criterion, however, is not diagnostic as it is also associated with other failure types and mechanisms.

Coal

Figure 3

Seventy-four percent of reportable dynamic failure accidents occurring within the United States in 1983–2019 occurred in the Uinta and Piceance Basins, despite their consistently producing less coal from underground mines than the Appalachian Basin, suggesting some element of risk inherent in mines from this area (modified after Lawson, 2019).

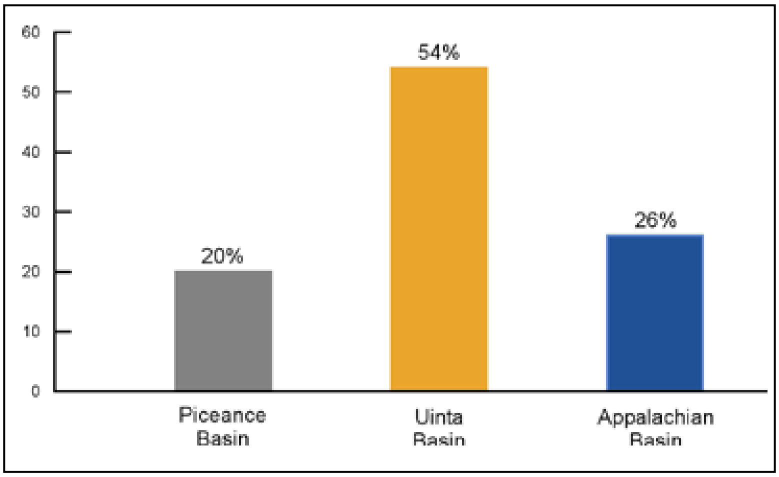


Figure 4

Underground coal production by basin from 1984 through 2018 shows that the Appalachian Basin has been the greatest producer of coal by underground mining in the United States. Data source: U.S. Energy Administration.

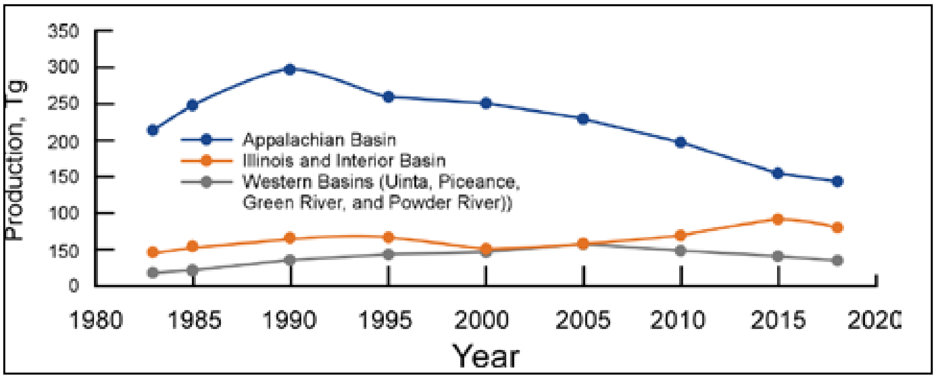
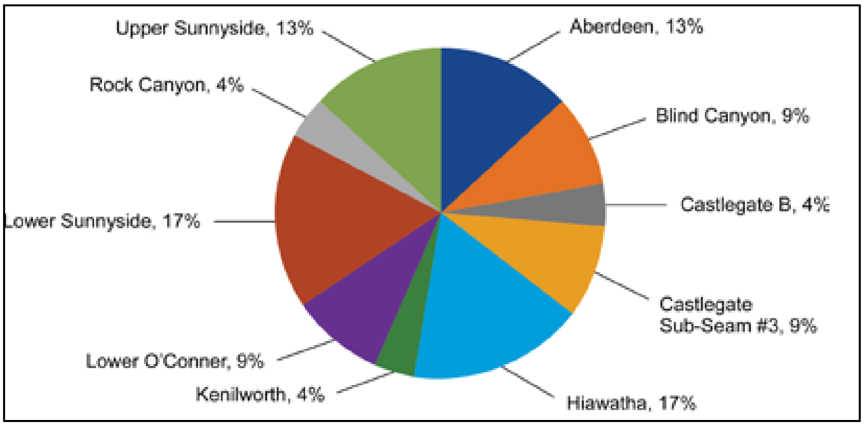


Figure 5

Distribution of dynamic failure accidents in the database by seam in the Uinta Basin.



Coal bursts can be identified by:

- Failure originating in the pillar or working face.
- Description of the accident as a burst or an outburst.

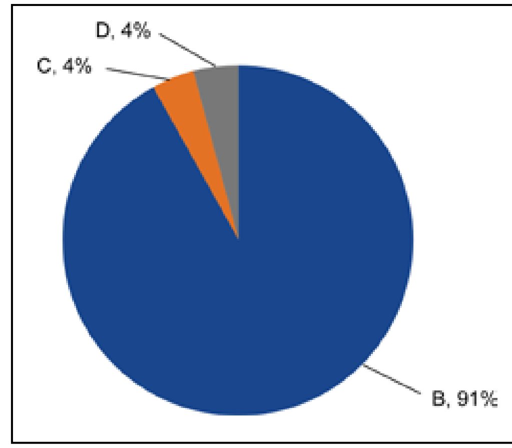
Although less common in the United States, dynamic floor heave and dynamic roof failures can be identified by failure originating in the floor and roof, respectively. These failures can be distinguished from typical floor heave and roof failure by both the severity and violent nature of the failure. It is important to note that considerable rib damage is also often associated with these types of failure.

Second tier. The second-tier classification addresses the question of why the event has occurred. Pressure-induced failures result from an excess of localized stresses, which ultimately exceed the pillar's bearing capacity. These failures are typically located at or near the working face. They may also, however, be associated with areas of faulting or other geologically anomalous conditions; in these circumstances, they may occur at some limited distance from the working area. Shock-induced failures, by contrast, are the result of the propagation of shockwaves through the intact coal as the result of the collapse of strata at some point distal to failure. Shock-induced bursts are produced by the massive collapse of strata in the gob, similar to an air blast or bounce, and may include all characteristics of those failure types. However, a shock-induced burst also involves the ejection of rock or coal into the mine workings, and it is this criterion that distinguishes it from a bounce or air blast.

These designations are by nature qualitative in the absence of first-hand evidence, as they are determined solely by evaluating MSHA-reportable accident narratives and Reports of Investigation. This qualitative nature introduces an element of uncertainty into accident classifications. However, supporting evidence for a pressure-induced burst might include mention of highly stressed coal, rapid topographic changes, steep seam dips, critically sized pillars or panels, and geologically anomalous conditions, etc.

Figure 6

Distribution of dynamic failure accidents in the database by seam in the Piceance Basin.



Supporting evidence for shock-induced bursting behavior may include mention of poor gob caving and strong sandstone roof units or strong sandstones close to the immediate roof.

Third tier. The third-tier classification addresses the question of where failure has occurred. Specifically, this classification tier takes into account where in the mine workings the dynamic failure event has occurred. This event characteristic is closely linked to the stress conditions active at the time of the event, local geology and mining method. These risk factors are closely linked to second-tier classification through clarifying the stress-inducing factors active in the mining environment at the time of the dynamic failure event. Identifying mining method is an important component in developing risk assessment strategies. However, this study focuses primarily on classification within the context of geologically induced risk: accurate, comprehensive evaluation of mining-induced stressors in each case requires more comprehensive assessment of variables than is available through many accident narratives and is beyond the scope of this investigation.

Fourth tier. The fourth-tier classification addresses the specific mechanism or how the failure manifests in terms of damage characteristics. Mechanisms include loss of confinement, internal pore pressure, movement along preexisting discontinuities, and the mid-pillar expulsion of coal that does not involve slip along bedding planes or other discontinuities. Loss of confinement may be suggested by symptomatic criteria such as:

- Explicit mention of slip along bedding contacts or bedding plane faults.
- Slip at the roof/pillar or floor/pillar interface.

Figure 7

Event-type classification of the events database as a whole, indicating that the dominant Tier 1 classification is coal burst.

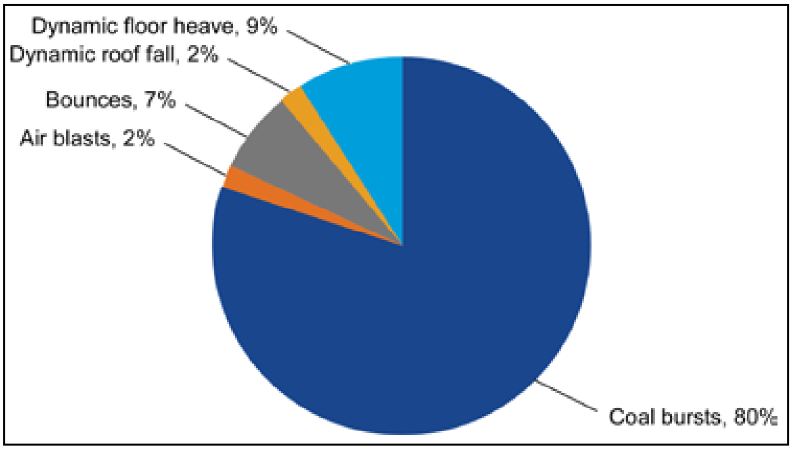


Figure 8

Categorization of driving mechanism in the events database as a whole, indicating that most events were induced by the buildup of excessive pressures in the rock mass.

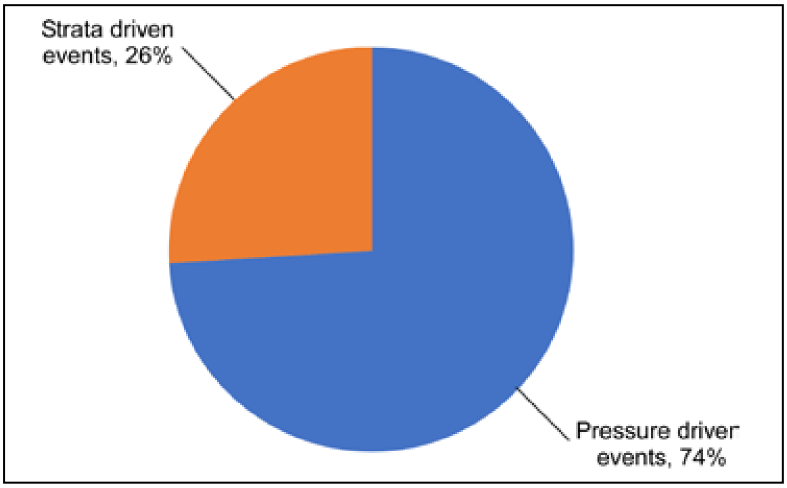
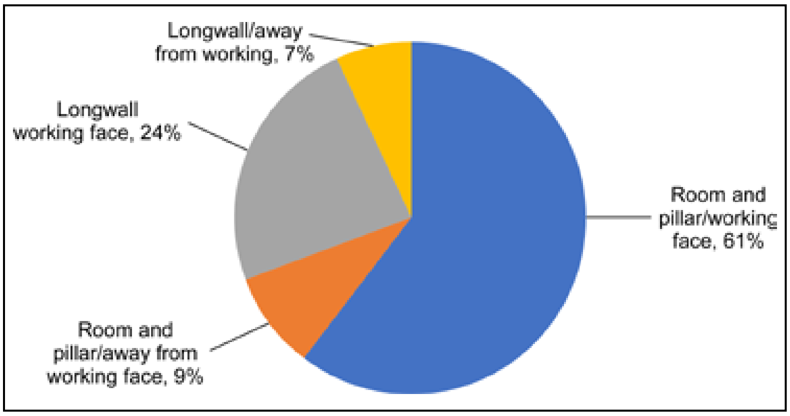


Figure 9

The types of mining represented in the database and the location of failure relative to the working face.



- Observation of red dust along failure planes.
- The presence of weak overlying or underlying mudstone or shale units and seam splits.

Internal pore pressure as a contributing factor in dynamic failure occurrence may be suggested by:

- Very fine debris size.
- Release of significant volumes of methane.
- Association with subsequent ignitions or explosions.
- Mention of preceding regular methane accumulations or gassy mine conditions.

Failure along preexisting discontinuities involves failure facilitated by the existence of faulting at the failure location. This may also include mention of features such as cleat swarms, which may indicate faulting that is not immediately visually apparent. Mid-pillar failures that do not involve failure along preexisting discontinuities or slip along bedding planes are determined by violence of failure, which is typically more pronounced than failure along weak or already extant planes, and process of elimination. The analysis of accident reports suggests that at this level failure commonly occurs through a hybrid mechanism, involving two or more classification categories. For example, an event may be classified as mid-pillar failure with no slippage while also exhibiting characteristics associated with influence by internal pore pressure.

Application of the classification scheme. Although reportable event narratives are relatively plentiful, accident reports for this study must include sufficient detail to apply the classification system. Most nonfatal MSHA-reportable events fail to meet this criterion. As such, the MSHA data used for this experimental application of the classification system are composed almost entirely of information harvested from MSHA Fatality Reports and Reports of Investigation that predate 1983. Prior to the current litigious mining climate, accident reports included much greater detail. A database of 46 dynamic failure events was constructed from historical (pre-1983) and more recent (after 1983) MSHA Fatality Reports occurring in the Uinta and Piceance Basins. Twenty-three cases in this database come from the Uinta Basin, and 23 from the Piceance Basin. Approximately 44 percent of the database is composed of historical events, ranging from 1945 through 1982. The remaining

56 percent occurred after 1983 and are considered modern events and are mostly documented by fatality reports. Consequently, this experimental application of a classification system is weighted very heavily toward fatal events and represents the deaths of more than 40 miners as a result of dynamic failure. The authors of this paper acknowledge that mining practices represented by the ample set are not representative of modern mining methods and practices. As this study focuses on the interaction between inherent geologic risk and dynamic failure manifestation, this does not invalidate the findings of this study. However, of necessity, the mining method cannot be accounted for in a meaningful way through these investigations in the absence of a similarly detailed body of nonfatal, modern dynamic failure data.

Study area

The Uinta and Piceance Basins are located in the southwestern United States and cover portions of Utah and Colorado (Fig. 2). They cover an estimated 64,000 km^2 (40,000 square miles) (Spencer, 1996) and hosts many of the coal deposits mined in the western United States (Hucka et al., 1997; Schultz et al., 2000). In fact, nearly all western U.S. underground coal mines currently in operation fall within the Uinta-Piceance Creek boundaries. Conjoined at the Douglas Creek Arch, the Uinta and Piceance Basins are two separate but related basins having unique physical boundaries, histories, and sedimentation patterns. This region was chosen to apply the newly developed classification system because it accounts for 74 percent of reportable dynamic failure events occurring from 1983 through 2019 (Fig. 3). The bulk of underground coal mining in the United States occurring between 1983 and the present has occurred in the Appalachian Basin (U.S. Energy Information Administration Coal Data, no date). The high rate of dynamic failure occurrence in the Uinta-Piceance Basin, despite lower overall underground coal production than the Appalachian Basin, suggests some element of inherent risk. Clarifying the link between differences in dynamic failure mechanism and regional geology may begin to shed light on what the nature of this inherent risk may be.

Coal seams represented in the compiled MSHA accident reports include the Colorado B, C, and D seams in the Piceance Basin, and the Kenilworth, Castlegate, Blind Canyon, Hiawatha, Lower O'Connor, Rock Canyon, Sunnyside, and Aberdeen seams in the Uinta Basin. The relative distribution of accident cases from each seam are illustrated in Figs. 5 and 6 and show that the vast majority of considered accidents (91 percent) from the Piceance Basin occurred in the Colorado B seam. Accidents reported from the Uinta Basin, by contrast, are distributed relatively evenly among several seams, albeit with the Hiawatha and Lower Sunnyside seams exhibiting the greatest number of reportable dynamic failures. The discrepancies in relative distributions of reportable dynamic failure events between these two areas may be attributable to differential rates of production from the seams in each respective basin — perhaps the Colorado B seam has been mined much more heavily than other seams in the Piceance Basin, while mining in the Uinta Basin occurred in many seams more or less evenly. Unfortunately, production data by coal seam are not available through the U.S. Energy Administration prior to 1983, and production from 1945 through 1982 is difficult to accurately track, so this cannot be verified. An alternative explanation may be that the Colorado B seam is particularly prone toward dynamic failure, suggesting seam-specific risk, whereas risk in the Uinta Basin may be more regional in nature.

Results and discussion: Evaluation of dynamic failure classification within the context of local geology

Application of the dynamic failure classification hierarchy to the selected dataset shows several trends (Table 1, see appendix).

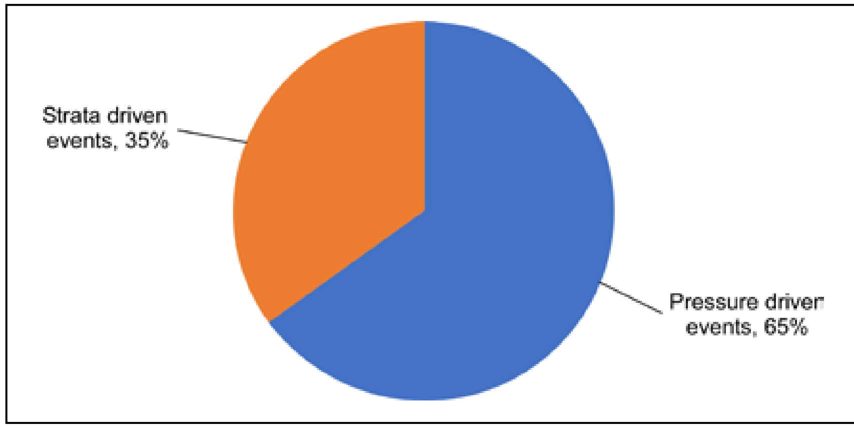
When considering the dataset as a whole, most events are classified as coal bursts caused by excessive pressures at the working face. Eighty percent of events in the database can be classified as coal burst events (Fig. 7). Dynamic floor heave events, involving the abrupt failure of floor strata which is then thrust upward into the working area of the mine, constitute 9 percent of events. Bounces constitute 7 percent of events. Dynamic roof-fall events, in which failure originates in the roof strata, but which differ from the more common roof-fall accidents in both energy and driving mechanisms, make up 2 percent of events in the database. Similarly, air blasts also constitute 2 percent of cases. Of these, strata failure is identified as the primary driving mechanism in 26 percent of cases. The remaining 74 percent are attributable to the buildup of excessive pressures in the pillar and/or working face (Fig. 8). Eighty-four percent of events occurred at the working face, while only 16 percent occurred distal to the face (Fig. 9).

These observations primarily reflect mining practices at the time of reporting, rather than geologically induced risk. As previously discussed, much of this dataset is derived from accident reports pre-dating 1983, prior to the widespread adoption of longwall mining in Western collieries. Moreover, much of this mining took place at excessive depths, ranging from approximately 460 m (1,500 ft) to 760 m (2,500 ft). Room-and-pillar mining at depths exceeding 300 m (1,000 ft) is acknowledged as a significant exacerbating factor in the occurrence of dynamic failure accidents (Iannacchione and Zelanko, 1995; Mark et al., 2003; MSHA, 2015). These practices are outdated and do not reflect modern mining in the Uinta and Piceance Basins.

However, with the understanding that pressure-induced coal bursts are likely to be less frequent in modern mining scenarios in the Uinta and Piceance basins, the relative distribution of these event types and mechanisms can help to clarify differences in geologically induced risk factors between the two basins. This is particularly true with respect to Tier-2 classification (driving

Figure 10

The distribution of driving force (strata-driven versus pressure-driven) in the Uinta Basin.



forces) and Tier-4 classification (specific failure mechanisms). We note, however, that events in the Piceance Basin come almost entirely from the Colorado B seam; as a result, it is possible that differences reflect disparities between depositional conditions between seams, rather than regionally associated risk. Nonetheless, several differences are apparent between events occurring in the two basins.

Failures driven by the massive collapse of strata, such as bounces, air blasts, and shock-induced coal bursts, are more frequent in the Uinta Basin (Fig. 10). Thirty-five percent of failures in the Uinta Basin can be associated with the collapse of strata, whereas only 17 percent of events in the Piceance Basin are associated with strata collapse (Fig. 11). This may suggest that thick competent strata are a more significant contributor to dynamic failure occurrence in the Uinta Basin than in the Piceance Basin. Pressure, however, is a significant contributor to failures in both regions.

Determining specific failure mechanisms from accident narratives carries a considerable element of qualitative analysis relative to other classification tiers, and, in many cases, could not be determined with confidence. Consequently, 30 percent of event mechanisms in the Piceance Basin and 17 percent of event mechanisms in the Uinta Basin could not be determined. The disparity in the number of cases wherein an event mechanism could not be determined stems from the preponderance of cases from the Dutch Creek mines in the Piceance Basin. Many historical accident reports from this area contained text stating that dynamic failure occurrence was not understood (an unavoidable hazard of mining) and, accordingly, contained fewer diagnostic details.

In the Piceance Basin, most dynamic failure events occurred as the result of a hybrid mechanism involving both significant internal gas pressures and loss of confinement at bedding plane contacts (Fig. 12). Red dust at failure planes was identified as a common feature of failures, as was excessively gassy conditions that resulted in small dynamic failure events with “nearly every cut” (Elam et al., 1985). Loss of confinement alone with no clear-cut contribution from internal gas pressure was identified as a contributor in one out of the 23 Piceance Basin cases (4 percent). However, this does not preclude the contribution of internal gas pressure but rather indicates a lack of sufficient information with which to make this claim. Nine percent, or two out of 23 cases, were facilitated by failure of the floor strata. This is similar to more recent failure mechanisms observed in the Piceance Basin (Lawson et al., 2012; Tesarik et al., 2013) in the B and D seams in Delta and Gunnison counties, CO.

The Uinta Basin, by contrast, shows a greater

Figure 11

The distribution of driving force (strata-driven versus pressure-driven) in the Piceance Basin.

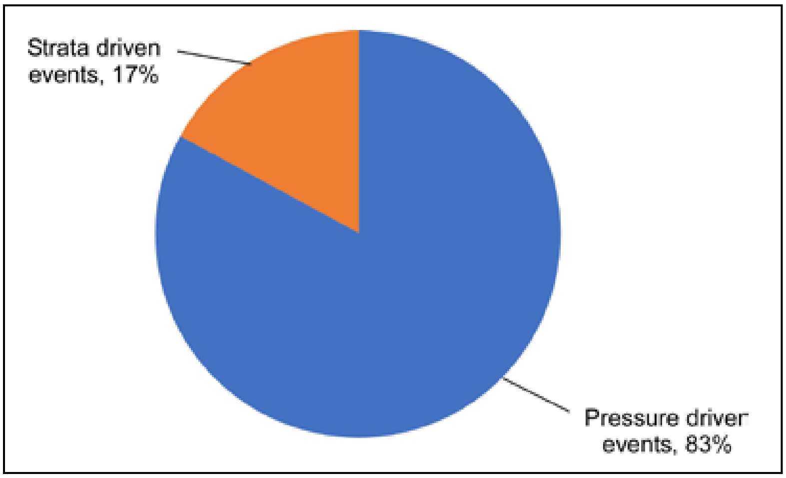


Figure 12

Specific failure mechanisms in the Piceance Basin (Tier 4).

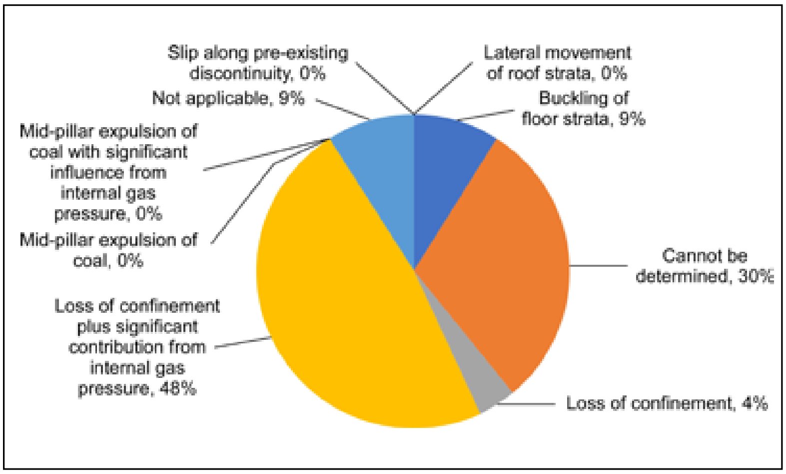
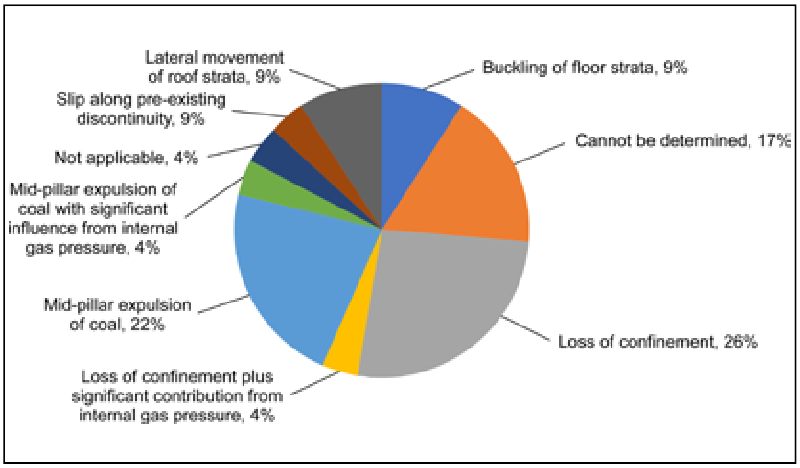


Figure 13

Specific failure mechanisms in the Uinta Basin (Tier 4).



diversity in failure mechanisms (Fig. 13). Loss of confinement was identified as a significant contributing factor in 26 percent of cases. Mid-pillar expulsion of coal having either no slip at coal/rock interfaces or excessive friction was identified as a significant contributor in 22 percent of cases. The determination between these two failure mechanisms was made using relative violence of failure, as indicated by the volume of ejected debris, and the type of surrounding lithology. As such, it is susceptible to evaluator bias. Lateral movement of roof strata and buckling of floor strata were both identified as significant facilitators of failure in 9 percent of cases each. While failures in the Piceance Basin show similar frequencies of floor failures, failures originating in the roof rock was unique to the Uinta Basin. One case was identified as the result of a hybrid mechanism involving both internal gas pressure and loss of confinement. There is some uncertainty in this designation — other dynamic failure events in the Uinta Basin in this dataset were also associated with the liberation of significant amounts of methane. However, the source of this methane was identified as sandstone units in the floor, which may have acted as a reservoir for underlying gas-generating deposits. The source of methane generation remains obscure. Similar to the Piceance Basin, buckling of floor strata was identified as the dominant failure mechanism in 9 percent of cases. Slip along a preexisting discontinuity was identified as the failure mechanism in one out of 23 cases (4 percent) in the Uinta Basin. This case is the only pressure-induced failure not occurring at the working face.

Massive strata collapse-driven events versus pressure-driven events and differences in the frequencies of mid-pillar failure mechanism versus loss of confinement failure mechanism. Differences in first and second tier classification in the Piceance and Uinta basins could be attributable to differences in the rates and environments of deposition between the two basins. Variable subsidence rates resulted in greater available accommodation space in the Uinta Basin and, subsequently, thicker accumulations of sediment (Osmond, 1964; USGS, 2002). Moreover, coals of the Uinta Basin are associated with coastal plain and deltaic facies of the Upper Cretaceous Mesaverde Group, with thick sandstone units overlying the coals (Osmond, 1964; Johnson and Roberts, 2002). Thick sandstone units are known risk factors for shock-induced failures and bounces (Rice, 1935; Whyatt, 2008; Whyatt and Varley, 2010).

The Piceance Basin, by contrast, subsided more slowly and, being closer to the Western

Cretaceous Seaway shoreline at the time of economic coal deposition, was subject to more frequent transgressive/regressive episodes during early sedimentation, resulting in interlayered packages of coarse- and fine-grained sediments. This may account for the dominance of the loss of the confinement failure mechanism in the Piceance Basin, as this pattern of sedimentation may result in frequent coal-mudstone contacts. Lithologic data available through the Pennsylvania State Coal Sample Databank suggest that the immediate roof lithology for seams in the Piceance Basin used for this study was universally classified as shale or mudstone. Contacts in the Uinta Basin, by contrast, are divided between coal-shale/mudstone and coal-sandstone. Direct contact with sandstone is less likely to facilitate failure through the loss of confinement mechanism owing to greater friction at the coal-rock interface, and stresses are likely to build in the pillar, ultimately releasing as a mid-pillar burst.

Gas-driven events in the Uinta and Piceance Basins

Differences in thermal maturity of economic coal deposits in the Uinta and Piceance basins correspond to observed differences in the relative prevalence of gas pressure as a contributing risk factor in dynamic failure events. Vitrinite reflectance values in the mined coal seams of the Uinta Basin range from as low as 0.30 to 0.70 percent, placing the rocks within the oil window and below. At greater depths, vitrinite reflectance may be significantly higher (USGS, 2002), which may contribute to methane seepage from floor units in some cases. However, no cases included in the test dataset were mined at these depths. In the coal seams represented in the event database, vitrinite reflectance ranged from 0.57 to 0.69 percent, as indicated by Pennsylvania State Coal Sample Databank records, well outside the gas-generating window. However, some cases do exist in the Uinta Basin in which gas is noted as a contributing factor regardless of the relatively low thermal maturity of these coal deposits. However, the reasons behind this phenomenon are not clear and may be due to the presence of microbial rather than thermogenic gas or may be a function of assumptions made by mine personnel at the time of the dynamic failure event or the qualitative nature of application of the classification hierarchy, or a combination of these factors. Ultimately, further research is required to identify causes behind these observations.

The coals of the Piceance Basin range in vitrinite reflectance from 0.58 to 1.59 percent. Only the Colorado B seam in the vicinity of Pitkin County, CO, occurs at the highest range of this spectrum, corresponding to the gas generation window, and, accordingly, all accidents in which gas pressure appears to have played a role come from this seam. The presence of gas in micropore structures of high-rank coal may have contributed to internal gas pressure in the Colorado B seam. This implies that the character of the seam itself is the most significant contributor to risk in this area; whereas, by contrast, events in the Uinta Basin are widespread and may be more influenced by stratigraphic risk factors.

Summary and practical applicability

Applying a dynamic failure classification scheme prototype to a database of events from the Uinta and Piceance basins demonstrates differences in the character of event manifestation between the two areas. These differences are attributable to sedimentation and thermal histories of mined coals in these regions. Observations suggest that:

- Dynamic failure linked with the massive collapse of strata, such as bounces, air blasts and shock bursts, may be the result of relatively rapid basin subsidence in conjunction with an inland depositional setting, resulting in thick competent lithological units surrounding the coal.
- The loss of confinement failure mechanism is prevalent in both the Piceance and Uinta basins in association with coal/mudstone contacts at the roof and/or floor and may have its origins in frequent transgressive/regressive events associated with the retreat of the Western Cretaceous Seaway. However, the relative prevalence of mid-pillar bursting with no slip in the Uinta Basin may be the result of the frequency of coal/sandstone contacts, which may be a function of the basin's relatively distant position from the shoreline and preponderance of more inland depositional settings.
- Gas-driven failures in the Piceance Basin correlate to high vitrinite reflectance in the Colorado B seam and suggest that the primary risk in this area derives to a greater extent from thermal maturity of the seam itself than strata-driven failures, as is the case in Uinta Basin failures.

The findings in this study are consistent with what might be expected in both regions. In the Uinta Basin, where strong lithology has long been indicated as a significant risk in dynamic failure occurrence, bounces, shock-induced bursts, and mid-pillar expulsion of coal are more

Appendix: Table 1

Results of the application of the hierarchical classification scheme to the selected dataset.

Event identifier	State	Mine name	Seam	Tier 1 event type	Tier 2 event source	Tier 3 mining method/ event location	Tier 4 event mechanism(s)
UT-1	Utah	Kenilworth	Kenilworth	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement, internal gas pressure
UT-2	Utah	Spring Canyon	Castlegate B	Coal burst	Massive collapse	Room and pillar/ working face	Mid-pillar expulsion of coal, internal gas pressure
UT-3	Utah	Bratzah #3	Castlegate Sub-Seam#3	Dynamic roof fall	Pressure	Room and pillar/ working face	Lateral movement of roof strata
UT-4	Utah	Price River #3	Castlegate Sub-Seam #3	Coal burst	Pressure	Longwall/ working face	Loss of confinement, methane at the time of event/ignition attributed to release through sandstone floor
UT-5	Utah	Deer Creek	Blind Canyon	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement
UT-6	Utah	Wilburg	Hiawatha	Dynamic floor heave	Pressure	Longwall/ working face	Buckling of floor strata
UT-7	Utah	Trail Mountain #9	Hiawatha	Bounce, initiating simultaneous coal outburst and roof fall	Massive collapse	Room and pillar/ working face	Lateral movement of roof strata and subsequent loss of confinement
UT-8	Utah	Belina #2	Lower O'Connor	Air blast	Massive collapse	Longwall/ working face	Not applicable
UT-9	Utah	Soldier Canyon	Rock Canyon	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement
UT-10	Utah	Deer Creek	Blind Canyon	Coal burst	Massive collapse	Room and pillar/ away from working face	Mid-pillar expulsion of coal
UT-11	Utah	Cottonwood	Hiawatha	Coal burst	Pressure	Room and pillar/ working face	Cannot be determined
UT-12	Utah	Skyline #3	Lower O'Conner	Coal burst	Pressure	Longwall/ away from working face	Slip along existing discontinuity
UT-13	Utah	Cottonwood	Hiawatha	Coal burst	Pressure	Longwall/ working face	Cannot be determined
UT-14	Utah	Aberdeen	Aberdeen	Coal burst	Pressure	Longwall/ working face	Mid-pillar expulsion of coal
UT-15	Utah	Aberdeen	Aberdeen	Coal burst	Pressure	Longwall/ working face	Mid-pillar expulsion of coal
UT-16	Utah	Aberdeen	Aberdeen	Coal burst	Pressure	Longwall/ working face	Mid-pillar expulsion of coal
UT-17	Utah	Sunnyside #1	Lower Sunnyside	Coal burst	Pressure	Room and pillar, location unclear	Cannot be determined
UT-18	Utah	Sunnyside #1	Lower Sunnyside	Coal burst	Massive collapse	Room and pillar/ away from working face	Mid-pillar expulsion of coal, regional fault activity cited as a contributing initiating event
UT-19	Utah	Sunnyside #2	Upper Sunnyside	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement
UT-20	Utah	Sunnyside #2	Upper Sunnyside	Coal burst	Pressure	Room and pillar/ working face	Cannot be determined
UT-21	Utah	Sunnyside #1	Lower Sunnyside	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement
UT-22	Utah	Sunnyside #1	Lower Sunnyside	Coal burst	Massive collapse	Longwall/ working face	Loss of confinement
UT-23	Utah	Sunnyside #2	Upper Sunnyside	Dynamic floor heave	Massive collapse	Longwall/ away from working face	Buckling of floor strata, roof fall and rib damage also accompany this event

Event identifier	State	Mine name	Seam	Tier 1 event type	Tier 2 event source	Tier 3 mining method/ event location	Tier 4 event mechanism(s)
CO-1	Colorado	Dutch Creek #2	B	Coal burst	Pressure	Room and pillar/ working face	Cannot be determined
CO-2	Colorado	Dutch Creek #1	B	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement, internal gas pressure
CO-3	Colorado	L.S. Wood	B	Coal burst	Pressure	Room and pillar/ working face	Cannot be determined
CO-4	Colorado	Somerset	B	Coal burst	Pressure	Room and pillar/ working face	Cannot be determined
CO-5	Colorado	Somerset	C	Bounce	Massive collapse	Room and pillar/ working face	Not applicable
CO-6	Colorado	L.S. Wood	B	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement, internal gas pressure
CO-7	Colorado	Dutch Creek #2	B	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement, internal gas pressure
CO-8	Colorado	Dutch Creek #1	B	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement, internal gas pressure
CO-9	Colorado	L.S. Wood	B	Bounce	Massive collapse	Room and pillar/ working face	Not applicable
CO-10	Colorado	Dutch Creek #1	B	Coal burst	Pressure	Room and pillar/ working face	Cannot be determined
CO-11	Colorado	Dutch Creek #1	B	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement, internal gas pressure
CO-12	Colorado	Dutch Creek #1	B	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement, internal gas pressure
CO-13	Colorado	Dutch Creek #1	B	Coal burst	Pressure	Longwall/ working face	Loss of confinement, internal gas pressure
CO-14	Colorado	Dutch Creek #1	B	Coal burst	Pressure	Longwall/ working face	Loss of confinement, internal gas pressure
CO-15	Colorado	Dutch Creek #1	B	Coal burst	Pressure	Longwall/ working face	Loss of confinement, internal gas pressure
CO-16	Colorado	Sanborn Creek	B	Dynamic floor heave	Pressure	Room and pillar/away from working face	Buckling of floor strata, internal gas pressure
CO-17	Colorado	Bowie #1	D	Coal burst	Pressure	Room and pillar/ working face	Cannot be determined
CO-18	Colorado	L.S. Wood	B	Coal burst	Massive collapse	Room and pillar/away from working face	Cannot be determined
CO-19	Colorado	L.S. Wood	B	Dynamic floor heave	Pressure	Room and pillar/away from working face	Buckling of floor strata, significant methane liberated during the event
CO-20	Colorado	L.S. Wood	B	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement, internal gas pressure
CO-21	Colorado	L.S. Wood	B	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement, internal gas pressure
CO-22	Colorado	L.S. Wood	B	Coal burst	Pressure	Room and pillar/ working face	Cannot be determined
CO-23	Colorado	L.S. Wood	B	Coal burst	Pressure	Room and pillar/ working face	Loss of confinement

frequent classifications. In the Piceance Basin, by contrast, these classification characteristics are less common and are superseded in prevalence by pressure-induced failures with slip at bedding contacts, often with gas as a contributing factor. Interestingly, these findings highlight the differences between regionally based risk factors in contrast to risk factors associated with the seam itself. In the Uinta Basin, risk is clearly dominated by stratigraphic features. In the Piceance Basin, however, risk was dominated by thermal maturity of the Colorado B seam, although other, more localized stratigraphically influenced risk factors were not insignificant. In terms of practical applications of these findings, the greatest benefit may stem from enhanced understanding of sources of dynamic failure risk and how these differ within the context of different geological settings. These geologic differences are relatively minor in this case, as the Uinta and Piceance Basins are genetically related and were, in fact, a single basin throughout much of their sedimentation histories (Osmond, 1964; Franczyk et al., 1992; Johnson and Nuccio, 1993; Johnson and Roberts, 2002). The most significant geologic differences in terms of dynamic failures in the Uinta and Piceance Basins appear to include differential rates of basinal subsidence, proximity to the Western Cretaceous Seaway during coal deposition, and differences in seam thermal maturity. These geologic differences are reflected in dominant modes of failure between these two regions and have implications toward the application of more targeted risk mitigation practices in these regions. Only by clearly identifying sources and mechanisms of dynamic failure risk can targeted risk mitigation be enacted. ■

Acknowledgements

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Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

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Copper and molybdenum recovery increased

by upgrading flotation cells with center launders at Hudbay Constancia

by Guillermo Bermudez, Peter Amelunxen, Marcial Medina, Mathew Taylor and Raghav Dube

Optimizing froth surface area throughout the flotation circuit has a critical impact on the process performance. Launders are an essential part of any flotation cell and with the correct design and orientation for specific application, optimal performance can be achieved. This article describes the launder improvement project undertaken at Hudbay Minerals Inc.'s Constancia copper concentrator, located in southern Peru. Each rougher line was upgraded by installing center launders in the last three out of seven Metso Outotec TankCells e300. Installation of the center launders took place in two stages. The first set of three center launders was installed in rougher line 1 during June 2019 and the second set of three was installed in November 2019. The staggered installation allowed for the evaluation of the metallurgical performance of line 1 relative to line 2. The results showed the implementation of the new launder design yielded a statistically significant recovery increase of 0.70 percent for copper (Cu) and 1.4 percent for molybdenum (Mo).

Introduction

Flotation circuits are increasingly designed using larger flotation machines. One reason for this trend is the demand from copper producers to treat larger volumes of ore due to a combination of declining head grades and the economic benefits of having a large-scale operation (Lynch, Harbort and Nelson, 2010). The larger machines require bigger motors, more wear-resistant materials, larger installations and novel maintenance strategies, bringing new challenges in design, performance and operation of large copper concentrators (Tabosa et al., 2016).

One of the first of these larger flotation machines was commissioned at the Kevitsa concentrator in Finnish Lapland in 2015. It was the first Outotec TankCell e500, and one of the challenges was that the significant distance of the launder from the tank centerline could lead to poor froth recovery (Murphy et al., 2015). Big flotation cell development has been a long journey. It was in the late 1980s that it was recognized by Outukumpu that flotation is essentially a two-subprocess operation (collection zone recovery and froth recovery), and maximization of the performance meant understanding and being able to maximize the performance of each flotation subprocesses (Gronstrand and Kujawa, 2009).

The two subprocesses are described by Falutsu and Dobby (1989), who proposed the two-zone model to estimate the total recovery in collection and froth zones as in the following equation. Flotation recovery based on two-zone model, excluding entrainment:

$$R = \frac{RcRf}{1 - Rc + RcRf}$$

Where R_c and R_f are the recoveries in the collection and froth zones, respectively. The flotation recovery calculation is shown schematically in Fig. 1.

In a flotation cell, the cross-sectional area above the froth cone is considered as the available froth surface area. Designing a flotation cell with a low froth surface area could lead to a situation where too much material will be transported over a limited froth surface area. Conversely, a flotation cell design with a high froth surface area could lead to a situation with insufficient froth flux to stabilize the froth, potentially leading to a significant proportion of hydrophobic material not reaching the concentrate launders. Solid particles are an important component of the froth structure (Espinosa-Gomez et al., 1998); too few solid particles will also lead to a lower froth stability and poor transportation of concentrate particles to the launder lip (Heath, 2013).

The froth transport characteristics of a flotation cell can be strongly correlated with flotation performance, as they affect the time that particles reside in the froth phase (and, therefore, the probability that they survive the

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Figure 1

Total recovery based on two-zone model.

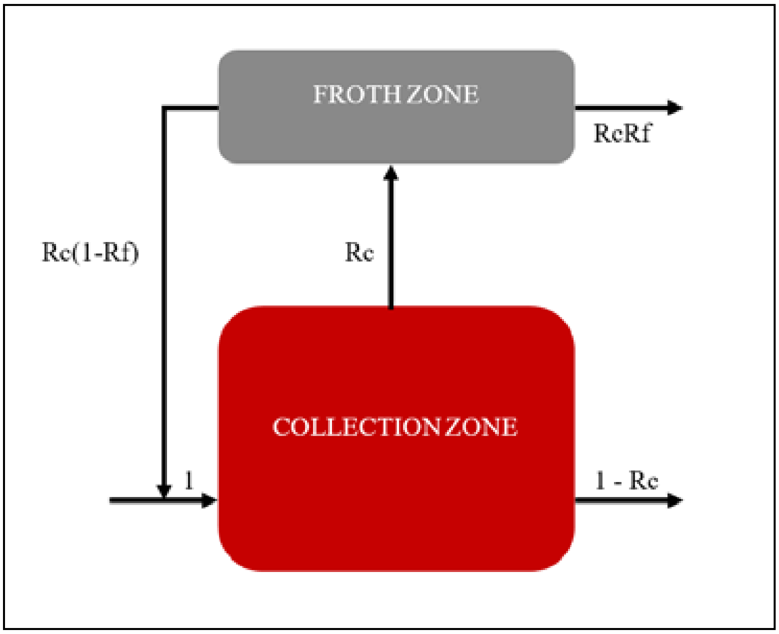


Figure 2

Froth transport distance effect over recovery (Contreras et al., 2013).

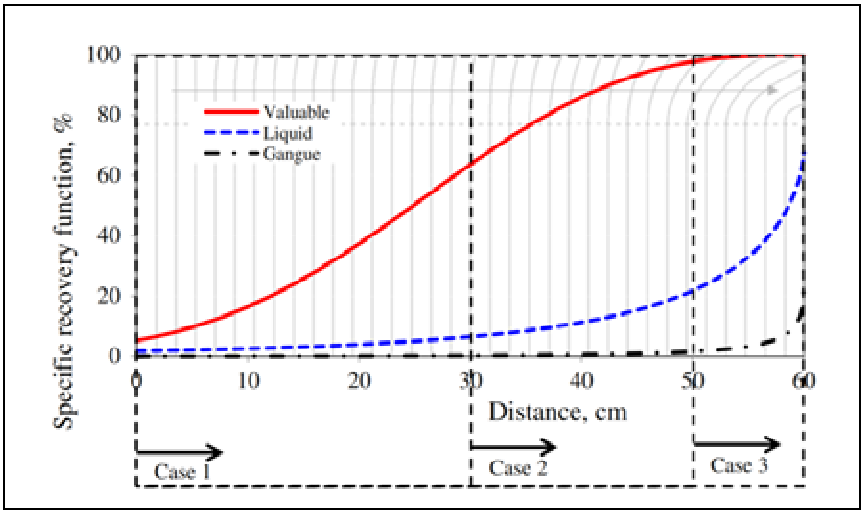
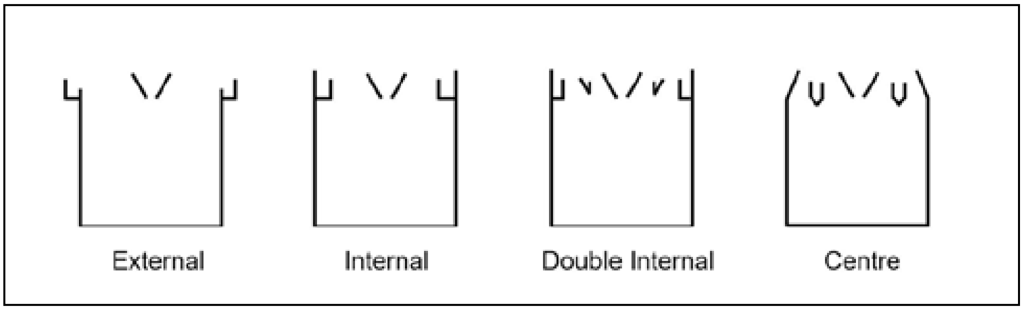


Figure 3

Different launder configuration examples.



froth phase; Li et al., 2014). In some cases (Fig. 2), the recovery of valuable minerals in can increase by nearly 30 percent when transport distance is shortened by just 30 cm (11 in.) (Contreras et al., 2013).

As the feed grade for each cell decreases downstream along a flotation row (i.e., by removal of hydrophobic mineral), it has been observed that the optimal froth transport parameters are significantly different for cells down the bank. This implies that having one type of launder arrangement for all the cells down the bank is not the best approach (Sherwin, 2019).

Froth removal in flotation can be affected by modifying the open froth area in the flotation cell. Figure 3 shows some launder configuration examples (Grau et al., 2019).

In a center launder, froth flows into both sides of the launder. Center launders can be used in addition to or instead of the peripheral launder (Coleman, 2009).

The Metso Outotec center launder design consists of a new froth cone, a center launder and an outer crowder. The center launder will collect all the froth that is being pushed by the froth cone in the inner area and by the outer crowder in the outer area.

Constancia concentrator

The Constancia operation, owned by Hudbay Minerals, is located in the southeastern Andes of Peru, in the department of Cuzco. Primary metal production is of copper, with secondary metals being molybdenum, silver and gold.

The grinding circuit consists of two lines, each with a SAG mill in closed circuit with screens, followed by a ball mill in closed circuit with hydrocyclones. The particle size of the cyclone product is controlled by an online particle size analyzer PSI300i. The design mill throughput was 78 kt/d (86,000 stpd) at a life-of-mine average grade of 0.41 percent copper, but since commissioning the mill has achieved sustained throughputs of 90 kt/d (99,000 stpd) at greater than 94 percent availability.

The flotation circuit consists of a copper/

Table 1

Froth surface and transport distance parameters before and after CL installation.

Before center launder installation		After center launder installation	
Froth surface area FSA (m²)	Transport distance TD (m)	Froth surface area FSA (m²)	Transport distance TD (m)
33.1	2.6	19.2	0.8

Figure 4

Froth displacement contrast between center launder (left) and peripherical launder (right).

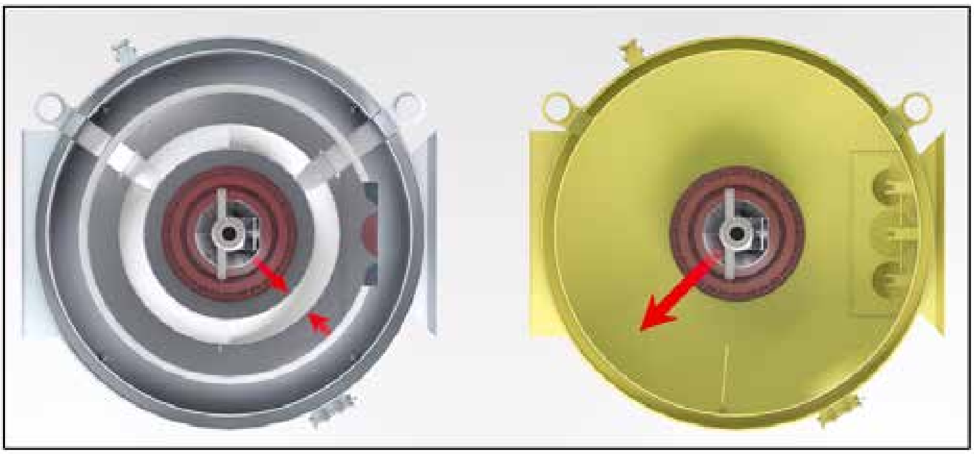
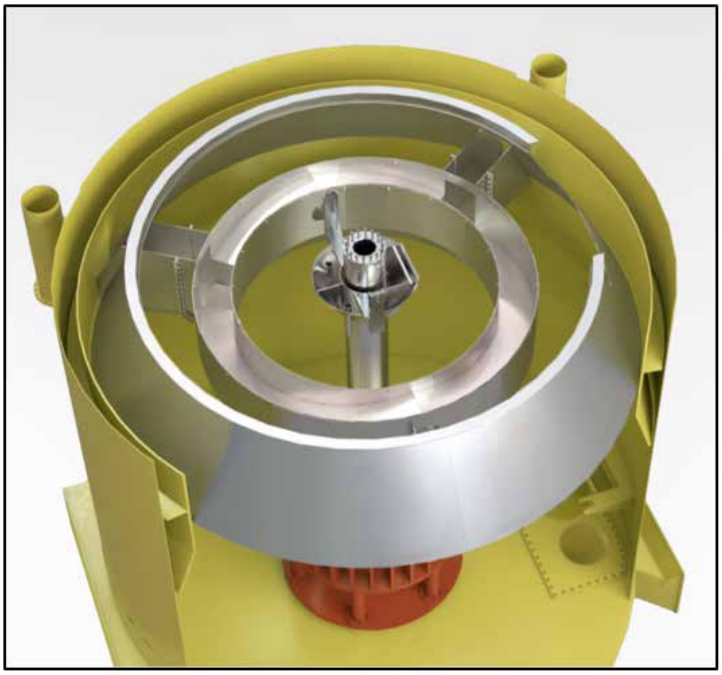


Figure 5

Scope of center launder installation (metallic gray).



molybdenum bulk flotation circuit and a molybdenum separation circuit. A flowsheet of the Constancia bulk Cu-Mo flotation circuit is shown in Fig. 6.

The rougher flotation circuit at Constancia consists of 14 Metso Outotec e300 TankCells with internal perimeter launders, configured in two flotation lines of seven flotation cells in each line.

Previous studies had identified the low froth carry rate as one of the major challenges in maximizing the copper recovery, especially in the last cells of the rougher row. A project was initiated to change the launder configuration of the last three roughers cells in each line from a radial launder configuration to launder configuration. This would reduce transport distance of froth to the launder and help froth crowding by reducing the effective froth surface area. The new launders were installed in line 1 during June 2019 and line 2 during November 2019. Overall froth surface area and transport distance were reduced by 42 and 69.2 percent respectively, modifications are detailed in Table 1.

Evaluation method

Direct comparison of a given line performance before and after the modification is not feasible because of noise introduced by natural variability in ore type, head grade, flotation feed particle size, tonnage, and reagent dosage during the ordinary course of operation of the plant. Nevertheless, these changes are applied equally to both flotation lines; hence, a statistical evaluation can be performed by comparing the performance of line 1 relative to line 2 before and after the launder upgrade.

The performance of each rougher line was determined based on the chemical assays of the 12-hour shift composite samples collected using the automated on-line sampling devices for feed and tails on both lines. The rougher concentrate is only collected as a combined rougher concentrate sample (i.e., the combined concentrate from both lines).

Sampling and assays

The rougher feed and tails streams were sampled using the installed MSA3 /140H metallurgical automatic sampler for both rougher lines.

Shift composites representing 12 hours of continuous plant production were assayed for Cu, Ag, Au, Mo, CuS, Zn, Fe and Pb.

Analysis

The Cu, Mo, Zn, and Pb raw shift assays for feed, tails and concentrates were balanced using the

Figure 6

Buik flotation circuit at Constancia.

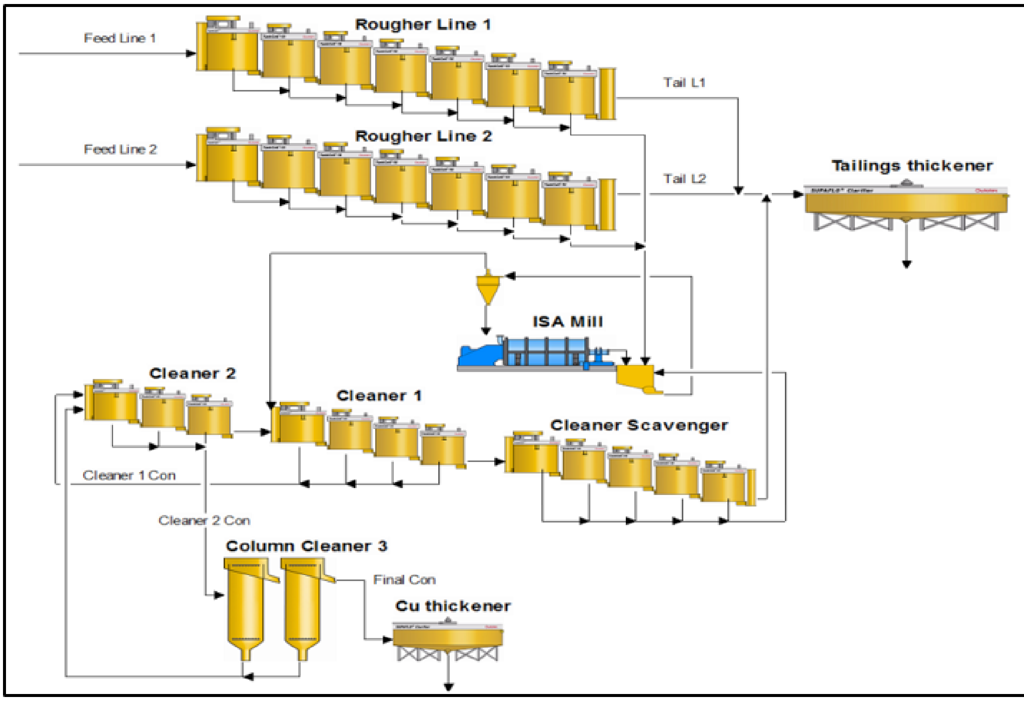


Table 2

Streams relative error by metal.

Stream	Tonnage	Cu	Mo	Zn	Pb
Feed	0%	5%	5%	5%	5%
Concentrate	5%	10%	10%	10%	10%
Tails	5%	3%	3%	3%	3%

method of LaGrange multipliers. Approximately 4 percent of the shift data points were excluded from the analysis because either the mill was not operating or one of the rougher lines was operating at less than 75 percent runtime during that shift. The balanced assays were used to determine the metal recovery. The following table shows the error model applied to the raw assays. The relative error of the concentrate was set higher because of the lack of separate concentrate assays for line 1 and line 2. The tailings assay was assigned a lower tolerance because it bears more significance on rougher recovery.

Recovery was calculated using the following two-product formula applied to the reconciled assays. Recovery calculation with *f* as feed grade, *t* as tails grade and *c* as combined concentrate grade.

$$R = \frac{c(f-t)}{f(c-t)}$$

Note that recovery is not additive; in this study mean recoveries are weighted by metal units in the feed.

Net recovery gain of line 1 relative to line 2 was calculated as per the following equation:

Net recovery gain =

$$(R_{L1After} - R_{L2After}) - (R_{L1Before} - R_{L2Before})$$

Where:

- $R_{L1Before}$ = Line 1 CU recovery (%) before installation
- $R_{L2Before}$ = Line 2 Cu recovery (%) before installation

Figure 7

Radial launder design before retrofit (left) and upgraded center launder (right).

- $R_{L1After}$ = Line 1 CU recovery (%) after installation
- $R_{L2After}$ = Line 2 Cu recovery (%) after installation.

Results and discussions

The net recovery gain for line 1 (after installation of new launders) relative to line 2 was 0.70 percent for copper and 1.40 percent for molybdenum. Note that the data also show that for both Cu and Mo there was a tendency of slightly better recoveries in line 2 relative to line 1. This is likely a result of differing grind size, caused by the grinding circuit configurations (liners, lifters, cyclones) in use during the time period in question. For this reason, the comparison must be done on a normalized basis; i.e. line 1 recovery relative to line 2 recovery. Summary statistics are shown in Tables 3 and 4 and presented graphically in Fig. 8.

The two-sample t-test analyzes the difference (Table 5) between the averages (means) of two samples, in this case the retrofitted cell and original cell. The samples do not need to be of

Table 3

Net copper recovery gain during the evaluation period.

	Line 1: metal (Cu) weighted recovery (%)	Line 2: metal (Cu) weighted recovery (%)	Delta recovery, % Cu
After, metal weighted	86.13	85.87	0.26
Before, metal weighted	86.64	87.08	-0.44
Net recovery gain			0.70

Table 4

Net molybdenum recovery gain during the evaluation period.

	Line 1: metal (Mo) weighted recovery (%)	Line 2: metal (Mo) weighted recovery (%)	Delta recovery, % Mo
After, metal weighted	54.25	52.45	1.80
Before, metal weighted	58.16	57.76	0.40
Net recovery gain			1.40

the same size. The P (T<=t) value obtained for this comparison was much lower than 0.05 and hence it indicates that the differences between weighted mean recovery are statistically significant for both copper and molybdenum recovery.

For the typical, life-of-mine head grades and operating throughputs of the Constancia concentrator, the recovery improvements achieved above translate into a pay-back period of approximately six months at current metal prices.

Conclusions

The center launder installation in the last three cells of the line 1 rougher row at Constancia decreased the froth transport distance and facilitated concentrate overflow, resulting in 0.70 percent increased copper recovery and 1.4 percent higher molybdenum recovery when calculated on a metal-weighted basis from statistically

Table 5a

Two-sample t-tests for Cu.

Copper recovery of L1 minus L2 — weighted mean (% rec difference)			
	Before crowder	After crowder	Delta (% rec)
Mean	-0.44	0.26	0.70
Variance	2.11	2.18	
Observations	290	307	
Hypothesized mean difference	0		
df	594		
t Stat	-6.27		
P (T<=t) one-tail	3.38E-10		
P critical one-tail	1.65		
P (T<=t) two-tail	6.76e-10		
t critical two-tail	1.96		

reconciled production assays. Based on nominal head grades and ore treatment rates, the payback period was approximately six months. In addition to the improved economic performance, intangible benefits include lower energy consumption, water usage, and environmental impact per unit of metal produced; these were not quantified as part of this study. ■

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The authors of this paper would like to acknowledge all the people who have participated in the study, development, installation and optimization of the new center launder configuration in Constancia mine. We would also like to thank the metallurgical and projects teams of Hudbay Minerals for facilitating and collaborating in the progress of this project and for allowing us to publish this paper together.

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Table 5b

Two sample t-tests for Mo.

Molybdenum recovery of L1 minus L2 — weighted mean (% rec difference)			
	Before crowder	After crowder	Delta (% rec)
Mean	0.41	1.81	1.40
Variance	70.67	29.08	
Observations	290	307	
Hypothesized mean difference	0		
df	488		
t Stat	-2.23		
P (T<=t) one-tail	1.31E-02		
P critical one-tail	1.65		
P (T<=t) two-tail	2.63E-02		
t critical two-tail	1.96		

Figure 8

Net copper and molybdenum recovery gains during the evaluation period.

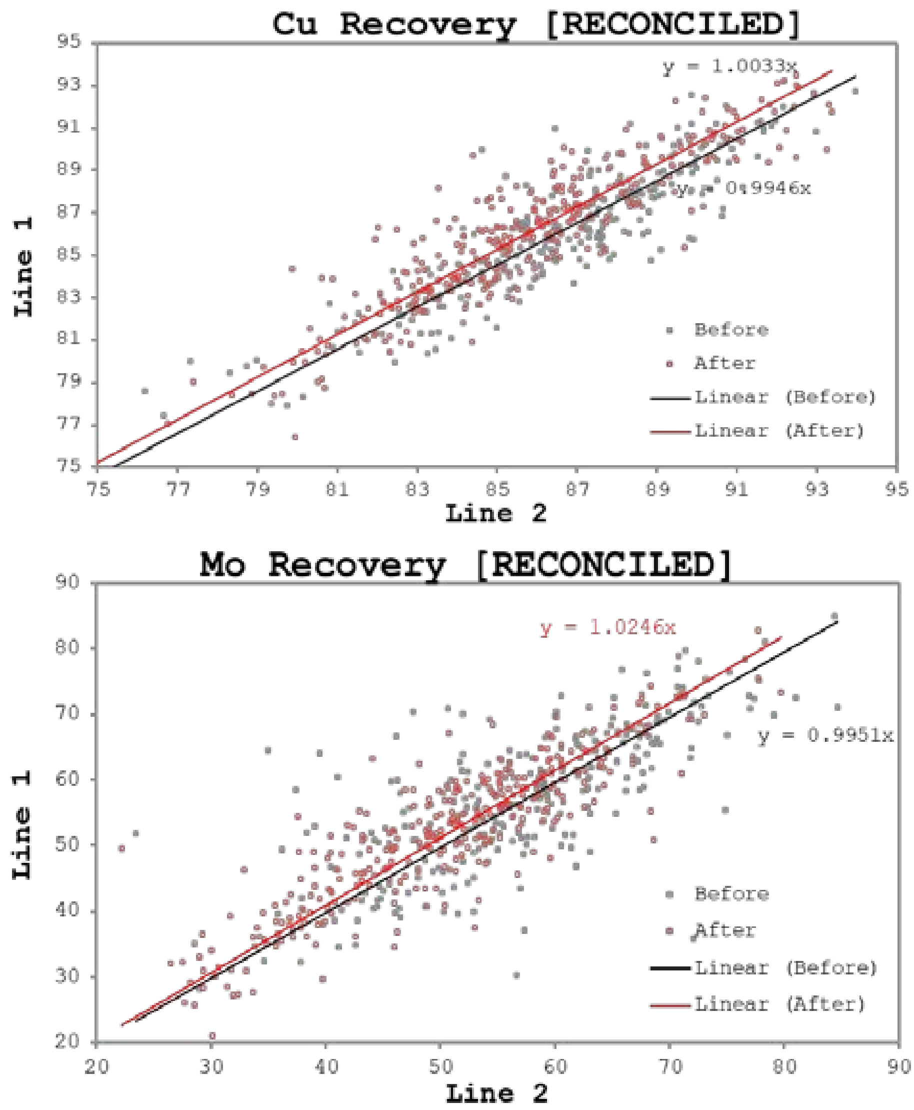

ABB launches new condition-monitoring digital service **for predictive maintenance of conveyor belts**

ABB HAS launched ABB Ability Condition Monitoring for belts, an advanced digital service to enable mine operators to track the speed, misalignment, damage, thickness and wear, slippage and temperature of conveyor belts in real time, and therefore anticipate maintenance, avoid unplanned downtime and improve belt reliability and lifetime.

Belt damage can cause significant production time loss in mines and processing plants with in-person inspections typically carried out to determine the condition of conveyor belts. The new ABB Ability Condition Monitoring for belts offers a complete overview of the assets' condition through continuous monitoring of belt health, generating alarms and warnings in the event of deterioration. By moving from preventative to predictive maintenance, it enables operators to avoid the costly failures that can occur between physical inspections, and personnel can be removed from dangerous areas.

The technology is based on sensors installed in strategic points of the conveyor belt equipment and is specifically designed to withstand harsh environments while monitoring asset health and condition.

ABB Ability Condition Monitoring for belts provides easy access to informative dashboards. Fault-trend analysis, event alarms, data logs and reports can be monitored for single or multiple conveyors and by remote connection, SMS text message and email.

"Real-time monitoring of the actual belt performance prompts the necessary corrective actions ahead of failure or further and more costly damage," said Eduardo Botelho, Global Material Handling Service product manager, ABB. "With equipment condition continuously assessed, operators can plan necessary maintenance only when certain indicators give the signal that the equipment is deteriorating, and the probability of failure is increasing. It will consistently catch misalignment or speed issues online, long before failure, and pre-empt issues such as falling material, energy waste, excessive belt wear, rupture or fire."

The solution can work as a stand-alone option or can be integrated into any control system, being interoperable with existing maintenance tools and infrastructure. KPIs can be customized, based on customer's needs or pain points. ■

Report identifies major carbon reduction opportunities;
Global mining to shift away from fossil fuels

A NEW REPORT commissioned by the Weir Group plc, analyzes mine energy data from more than 40 published studies to give a comprehensive understanding of where energy is consumed in mining and minerals processing. The report finds that the global mining industry must move away from legacy systems and processes if it is to meet the challenge of decarbonization. The report identifies ways the industry can aid the transition to net zero emissions needed to limit temperatures in line with the Paris Agreement.

The report suggests there are technologies available today that could make a significant difference to this trend. For example, it highlights that comminution (i.e., crushing and grinding processes) is the single biggest user of energy at mine sites, typically accounting for 25 percent of mining's final energy consumption. This is equivalent to the power used by 221 million typical UK homes, or about 1 percent of total consumption globally. Comminution is therefore a natural target for the most impactful energy savings opportunities.

"The mining industry is central to economic development globally, with critical minerals enabling the low-carbon transition required in the rest of the economy. But the environment in which it will operate in future will be very different from the past, requiring comprehensive change and investment," Weir Group chief executive Jon Stanton said. "In short, mining needs to become more sustainable and efficient if it is to provide essential resources the world needs for decarbonization while reducing its own environmental impact. This report is an important contribution to that debate that we hope will spark thoughtful conversations around the world on the way forward."

Small improvements in comminution technologies can lead to relatively large savings in both energy consumption and greenhouse gas emissions. For example, a 5 percent incremental improvement in energy efficiency across comminution could result in greenhouse gas emissions reductions of more than 30 Mt (33 million st) of carbon dioxide equivalent. The replacement of traditional comminution equipment with new grinding technology also reduces indirect emissions in the mining value chain, for example by removing the need for the manufacture of emission-intensive steel grinding balls.

Of the remaining energy consumption by the mining industry, diesel in varied forms of mobile equipment accounts for 46 percent, electricity in mining (ventilation) for 15 percent and "other electricity" for 14 percent. ■


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Industrial Minerals review 2020

by Mike O'Driscoll*

Responding to challenges and change

At this time last year, I commented on a "2020 Vision for Industrial Minerals" being shaped by the COVID-19 pandemic which was just hitting its stride in causing tragedy and mayhem around the globe. Industrial-mineral supply chains and markets were not immune from the fallout.

Fast-forward 12 months, and while we are not out of the woods yet, market recovery is underway. During 2020-2021 industry response to challenges and change wrought by the pandemic and other factors, although not without difficulty, has been refreshingly proactive.

In summarizing this activity, a "Rule of Six Influencing Factors" can be broadly ascertained as steering the outlook for industrial minerals:

1. Industrial-mineral "Criticality" + "Essentiality"
2. China in change.
3. Emergence of high-tech growth markets.
4. Accelerated recycling.
5. Environment.
6. Corporate and government readjustment.

1. Industrial-mineral "Criticality" + "Essentiality"

Perhaps of greatest long-term significance was the "favor" that the pandemic impact dealt the industrial-minerals business, in that it both educated and reinforced the vital role of industrial minerals in industrial manufacturing processes and everyday products and applications.

As mineral supply chains struggled to meet market demand for most of 2020, industrial minerals' "essentiality" and "criticality" soon became apparent and has since informed consuming industries and governments worldwide of their vulnerable supply lines and overreliance on limited overseas sources.

This has naturally given a boost to the development of new and alternative sources of minerals in high demand worldwide, such as First Bauxite LLC's new high-purity raw refractory bauxite mine in Bonasika, Guyana and Ares Strategic Mining Inc.'s Lost Sheep Fluorspar Project in Delta, UT.

Across the board, the impact of the pandemic on the ultra-important role of logistics in mineral supply was most evident, with ports congested and shipping disrupted, compounding material shortages and delivery delays.

As market recovery has stimulated demand for minerals, this issue has continued to plague the industry into 2021. It notably intensified in March with the Suez Canal blockage and further was strained by soaring freight rates adding to consumer woes as delivered mineral prices increased accordingly and shipping delays lengthened.

In early May 2021, Maersk, which handles about 20 percent of containers shipped, revealed that there were not enough ships available worldwide to meet the surge in consumer demand (all products), resulting in record-high freight rates, some 25-50 percent higher than in early 2020. One barite trader quoted China to Europe at US$6,000/20-ft container. This tight shipping situation is expected to last through 2021.

It is hoped that in the long term this recognition of industrial minerals' importance will assist in prudent strategic-sourcing decisions and investment in mineral development projects worldwide.

2. China in change

China will always have a major influence over industrial-mineral supply, owing to its abundant resources. However, changes are afoot that are transforming the trend of this influence. The primary factor is the country's fast-expanding domestic markets for industrial minerals, which is generating increasing mineral imports to China and thus consuming more domestic mineral production and reducing availability for export markets in the West.

Ongoing government environmental controls are causing certain mineral production centers (e.g., bauxite, magnesite, graphite) to close temporarily as they upgrade environmental anti-pollution equipment — particularly energy-intensive plants such as for mineral calcination and fusion — as well as overall mining restrictions.

Planned reforms to the structure of certain mineral production sectors will also change future supply scenarios, such as the rare earths sector and the magnesite sector in Liaoning, which is facing dramatic consolidation and streamlining — it is thought such actions will be rolled out to other mineral sectors.

A final note on China is to expect increasing activity by Chinese companies in overseas mineral projects, as has happened already with major rare earths projects in the United States, Vietnam, Greenland and Australia, and lately in fluorspar in the United States.

3. Emergence of high-tech growth markets

The emergence of high-tech growth markets is to become more mainstream, particularly in the "new energy" sector, e.g., lithium-ion batteries, electric vehicles, photovoltaic cells and wind turbines.

Demand for these markets' respective critical minerals is to increase (e.g., for lithium, graphite, rare earths) and has recently influenced the strategies of many mining groups and governments.

Much has been written elsewhere in this journal about the race for critical minerals, where to find them, and how to secure their supply chains — suffice it to say it is an area which will remain busy for many years, but must be accompanied by recognition and understanding of the processing stage of these critical minerals and their integration into their end-product manufacture.

4. Accelerated recycling

Driven by environmental protection, development of the circular economy, primary resource pressures, limited sources and cost of waste removal and storage, there will be continued activity in developing mineral recycling and strengthening this fledgling mineral sector.

Mineral-recycling technology is becoming more established and economic, while opportunities in this sector are increasingly identified and sought after, such as in waste supply, waste source partnerships with traders and recyclers, process and sorting technology innovation and market application development.

There will be more supply-chain cooperation in modifying mineral end-product formulations to ease end-of-life recyclability, and in public-relations terms, it will provide mineral suppliers and mineral consumers with a green portfolio.

Again, this trend is influencing both mineral companies' and government strategies going forward in their mineral-sourcing plans.

More miners are becoming involved in recycling tailings and other waste sources. Recent examples announced in 2020 included: LKAB, Sweden, US$1.2-2.4 billion over 15-20 years for rare earth elements (REE), fluorspar, gypsum, phosphorus from iron ore tailings; Rio Tinto, Canada, scandium oxide from ilmenite processing waste; Nutrien, USA, to supply 40 kt/a anhydrous hydrogen fluoride from phosphate rock processing fluorosilicic acid waste to Arkema (replacing U.S. fluorspar imports); Noranda Alumina, USA, to supply 60 kt/a bauxite residue to CemTech Materials.

5. Environment

The environment is clearly a common denominator for this Rule of Six Influencing Factors, but in addition to recycling and sustainable development of primary resources, there are two other key aspects affecting industrial minerals.

The first involves carbon dioxide (CO_2): whereby across the board the industry must reduce its carbon footprint, i.e., greatly reduce or eliminate CO_2 emissions. This is a huge challenge but one that is now occupying most mineral companies' future programs, whether it be switching energy source, installing CO_2 scrubbers or changing processing routes.

In Europe, for example, Carmeuse, Sibelco and Lhoist have all employed or plan to employ large solar-cell arrays, while European Commission (EC)-supported projects like low-emission-intensity lime and cement lead innovative solutions for carbon reduction.

In parallel to this, there is also an emerging market opportunity for certain minerals to be applied in carbon capture or sequestration technology. This is being looked at for magnesite, olivine and dunite, for example.

The second environmental strand for minerals is one that is already established but will certainly continue to grow: Minerals consumed in environmental applications such as waste/water treatment and antipollution applications, e.g., hydrated lime and magnesium hydroxide in neutralization, bentonite and zeolites in absorption.

On Jan. 1, 2020, a new limit on the sulfur content in the fuel oil used on board ships came into force by the International Maritime Organization, prompting almost overnight a sudden demand for marine SO_2 scrubbers that utilize magnesium hydroxide.

6. Corporate and government readjustment

Finally, in essence necessitated and steered by factors 1-5, mineral producing and consuming companies and governments alike have been forced to readjust or reset their forward programs and thinking.

Overall, this centers on a rethink in mineral sourcing and supply-chain strategy: Consideration of alternative sources to say China and exploring for new sources of supply both domestically and overseas.

Regarding the corporate world, a refocusing of the mineral supply chain has taken companies in several directions: Securing alternative supply sources through switching suppliers, signing offtake agreements in new mineral projects, and/or investing in such developments; vertical integration, while not for everyone, continues as an option for large mineral consuming companies as well as mineral distributors (e.g., leading mineral trader Possehl Erzkontor acquired major processor Mineralmahlwerke Hamm last year to expand its capabilities).

There has also been recent corporate restructuring in stripping down to the core business while at the same time starting development of critical mineral and recycling business units, leading examples include LKAB with its REE (and other minerals) from recycling, Rio Tinto in primary lithium mineral development and lithium and scandium oxide recycling from waste, Iluka in REE development, Schlumberger and Volkswagen going upstream to develop lithium minerals supply.

At the same time, there will continue to be more government and regional (e.g., EC) input with actions, legislation and even investment to advance recycling, CO_2 emission reduction, and exploration and development of critical minerals and other minerals in short supply.

Last year saw several key action plans launched and some already updated in 2021, particularly by the EC, Australia, Brazil, Canada, India and the United States. More will surely follow.

All told, this Rule of Six Influencing Factors certainly heralds a new era of industrial mineral exploration, sourcing and development for the 2020s.

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Editor's note: Throughout this review, measurements are expressed as metric units unless the author provided conversions.

ANTIMONY

by Nils Backeberg, Roskill Information Services

Native antimony metal is rare, and antimony generally occurs together with gold, lead, copper and silver. There are more than 100 antimony minerals, although the sulfide mineral stibnite is the main economic mineral. Antimony consumption is split into nonmetallurgical and metallurgical applications. The largest end use for nonmetallurgical antimony is in flame retardants, which accounts for around half of total antimony demand. For metallurgical applications, the major consumer of antimony is lead-acid batteries, which accounts for around a third of total antimony demand.

Consumption trends in these two critical applications for antimony thus shape overall demand dynamics. In both cases, a similar situation prevails — and despite overall demand steadily increasing — the antimony loading within these applications has been reducing, which has resulted in reduced overall demand for antimony. In flame retardants, this is mainly because of high antimony prices, prompting substitution of antimony, and legislative requirements forcing changes to flame-retardant formulas. In batteries, lead-calcium-tin alloys are increasingly being used instead of antimonial lead in battery grids for sealed-for-life maintenance-free automotive batteries, also called valve-regulated lead-acid (VRLA) batteries.

Antimony enters the supply chain either by mining (primary production) or recycling (secondary production). Owing to antimony's geological spread and association with precious-metal and base-metal deposits, antimony mining is widespread, although China dominates antimony mine production. While China remains the leading primary producer in 2020, declining reserves, market consolidation and regulatory inspections across China that have led to closures of facilities have caused a significant decrease in Chinese output from more than 80 percent of global production in 2010 to below 50 percent as of 2020.

Ores are mainly converted into antimony ingot, which forms the feedstock to produce refined antimony compound, including antimony trioxide used in flame retardants. While China has lost a significant market share in ore supply, the country remains the largest producer of ingots and trioxide (around two-thirds of global production in 2020). As a result, China has sourced growing volumes of primary antimony units through imports to keep up with declining domestic ore supply.

The three largest producers of mined antimony are all key suppliers to Chinese processing plants. Anzob in Tajikistan is the single largest antimony miner and accounted for about 13 percent of global supply in 2020. Anzob also produces antimony ingot at its mine site, which is supplied to Europe (mainly AMG in France and Umicore Belgium), but a large portion of its mine supply is exported to China. In Russia, GeoProMining and Polyus are the two major suppliers of ore to China. In 2018, Russian supply of antimony leapfrogged ahead of Tajikistan with Russian company Polyus, one of the world's leading gold producers, supplying by-product antimony from Olimpiada Mine for the first time, but output has declined since then and output from Polyus fell back behind that from Anzob in 2020.

The addition of ore supply from Polyus has caused some fundamental shifts in the antimony supply chain. Typical antimony concentrates imported into China, for which the processing plants had been designed, include either high-grade antimony with negligible gold, or high-grade antimony with high grades of gold. Most gold-bearing ores are sourced from Russia, Australia and Bolivia. The concentrates from Polyus, however, are of a much lower antimony grade, with significant gold by-product. Most ingot plants in China were not equipped to effectively process these ores over 2018 and 2019 and only a select few producers were able to consume this new high-volume source. By 2020, however, there had been growing investment by antimony ingot producers to upgrade facilities to be able to benefit from by-product gold flowsheets, including China's largest antimony producer Twinkling Star, which owns its own captive (nongold-bearing) mine but has chosen to supplement supply with imported feed. The switch to invest in gold recovery lines was spurred on in 2020 by the recovering gold price and has seen some familiar mine names reappear on the market, including Canada's Beaver Brook antimony mine and more recently Australia's Hillgrove gold mine.

A decade ago, around 90 percent of the concentrates processed in China were of non-gold-bearing ores (including Chinese and Tajik ores), but this has now shifted to 70 percent with the addition of concentrates from Polyus, and Roskill forecasts that by the mid-2020s mixed gold-antimony ores will account for half of the primary antimony mine supply.

Recycled, secondary antimony is largely sourced from antimonial lead and is produced in a number of countries, mainly in secondary lead smelters. The antimony recovered from this product is mainly recycled back into metallurgical applications, as it typically carries impurities that make the economics to produce trioxide or other chemicals unfavorable. However, because of the declining demand for antimony in lead-acid batteries and the growing supply from secondary sources, there will be a fundamental shift in the antimony market, when recycled-antimony units alone will exceed metallurgical demand, closing the supply chain in a self-sufficient recycling loop. Roskill forecasts this level to be reached by 2022, which implies that the surplus secondary antimony supply will begin to build.

Roskill understands that there is already significant investment in China at lead smelters to produce antimony trioxide and, with the declining metallurgical-grade market, this new supply source will start to compete with primary ore supply, at which point the cost competitiveness will become a more pressing point across the industry, as well as the gold price.

The outlook for nonmetallurgical antimony demand seems broadly positive when considering construction and plastics trends, which suggests demand for flame retardants will increase. Antimony demand in glass is far smaller but could potentially have a high growth rate due to use in photovoltaic panel production. In general, Roskill expects the antimony market to be sufficiently supplied over the next decade. However, Polyus remains a swing supplier despite being the largest producer in 2018 and 2019 with output able to vary significantly given gold and antimony market conditions. Output from Polyus can quickly swing the balance of the antimony market (by as much as 15 percent of the total market), the downside of which is a key development in early 2021 that has caused supply tightness of feed for ingot producers in China and driven prices to its highest levels since end-2012. ■

BALL CLAY

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

Ball clays are fine-grained, highly plastic sedimentary clays that consist primarily of kaolinite, mica and quartz. Valued for providing strength and malleability to ceramics prior to firing, ball clays produce a cream- to white-colored pottery once fired.

Production

According to U.S. Geological Survey publications, over the past three decades, U.S. ball clay production (the quantity sold or used by domestic producers) increased from a low of 784 kt in 1991 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, which resulted in decreased sales of ball clay. The continued decrease in ball clay sales continued through the Great Recession, which lasted from late 2007 through mid-2009. Since then, ball clay production steadily increased through 2017, before decreasing during the past three years. In 2020, owing to the COVID-19 pandemic, U.S. domestic production of ball clay was estimated to have decreased by 7 percent to 990 kt from 1,060 kt in 2019. Estimated sales in 2020 were 26 percent higher than in 1991 (low point in past three decades) and 24 percent lower than 2003 (high point in past three decades).

Six companies (Covia Holdings Corp., Gleason Clay Co., H.C. Spinks Clay Co., Imerys S.A., Old Hickory Clay Co. and US Mine Corp.) mined ball clay in five states during 2020. Tennessee accounted for 72 percent of total estimated 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 (55 percent of sales) and sanitaryware (18 percent of sales) continued to be the leading domestic markets for ball clay in 2020. Ball clay also was sold for the manufacturing of bricks, electrical porcelain, fine china, pottery, refractory products, roofing granules and other types of ceramics. In recent years, ball clay producers have also reported sales for fiberglass and filler, extender, and binder applications; however, those were likely to have been kaolin-mined or purchased by the ball clay producers.

Prices

In 2020, the average unit value of ball clay was estimated to have decreased by 5 percent to $53/t, compared with $56/t in 2019. Prices at most of the individual U.S. ball clay operations in 2020 were estimated to range from $30/t to $100/t. The average unit value for exported ball clay increased slightly to $192/t in 2020 compared with $191/t in 2019, and the average unit value for imported ball clay increased to $285/t in 2020 compared with $213/t in 2019. 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, ball clay exports decreased to 67.8 kt valued at $13 million in 2020 compared with 85.3 kt valued at $16.3 million in 2019. Exports of ball clay in 2020 were primarily shipped to Mexico (74 percent), Guatemala (5 percent) and China and Japan (4 percent each). Ball clay imports decreased to 104 t valued at $29,600 in 2020 compared with 679 t valued at $145,000 in 2019. In 2020, imports originated from the United Kingdom (96 percent) and France (4 percent).

Outlook

Historical sales of ball clay have correlated with construction activity. Although the world remains in a global pandemic (COVID-19), the U.S. construction industry has rebounded from the decrease in activity experienced during the initial months of the pandemic in early 2020. The U.S. Census Bureau reported that single-family housing starts in January 2021 were 17.5 percent higher than those in January 2020, and the International Monetary Fund projected that the U.S. economy would grow by 5.1 percent in 2021 and by 2.5 percent in 2022. These trends suggest that the market for ball clay will remain strong and sales of ball clay will increase in the coming years. ■

BARITE

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

Production and consumption

Because of high specific gravity, 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 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. Global oil consumption was adversely affected by travel restrictions owing to the COVID-19 pandemic and reduced demand for transport fuels. In 2020, the annual average count of international rigs decreased by 44 percent to 1,352. Declines were greatest in the United States, where the annual average count decreased by 54 percent to 436. Rig counts in the Asia Pacific and Middle East declined the least, by 15 percent and 19 percent, respectively (Baker Hughes Inc., 2021).

The United States has historically been the world's leading barite consumer but was likely surpassed by China in 2020. Domestically, an estimated 1.3 Mt of barite (from domestic production and imports) was sold by crushers and grinders operating in eight states, a decrease of 45 percent compared with 2019 (Fig. 1), which was the lowest sales volume since 1994. Grinding plants in the Gulf Coast and Eastern United States processed imported crude barite. The largest decrease in rig activity was in the Permian Basin, where drilling activity has been concentrated in recent years. Drilling operations there are primarily supplied by barite ground in Texas, where sales were estimated to have decreased by more than 50 percent. Only one mine was active in Nevada in 2020, which resulted in the lowest domestic mine production since the 1930s. Production was withheld to avoid disclosing company proprietary data.

Domestic apparent consumption averaged approximately 30 percent of world production over the past 10 years. Consequently, significant changes in domestic barite consumption typically affect the world production total and production levels in most leading exporting countries. World production of barite in 2020, excluding the United States, was estimated to have decreased by 11 percent, to 7.5 Mt. China, India and Morocco accounted for approximately 70 percent of world production (McRae, 2021).

Domestic and international trade

In 2020, U.S. barite imports were 1.49 Mt, a 40 percent decrease compared with 2019. China, India, Mexico and Morocco accounted for 95 percent of domestic imports (U.S. Census Bureau, 2021). Similarly, total global exports decreased by 40 percent, with decreased exports from nearly all countries. China's reported exports decreased by 52 percent to 540 kt, India's exports decreased by 23 percent to 1.5 Mt, and Morocco's exports decreased by 62 percent to 410 kt (IHS Markit, 2021).

Figure 1

Historical trends in sales of ground barite, mine production and annual average rig count in the United States from 1975 through 2020. Mine production in 2020 was withheld to avoid disclosing company proprietary data. Source: Baker Hughes Inc. and U.S. Geological Survey.

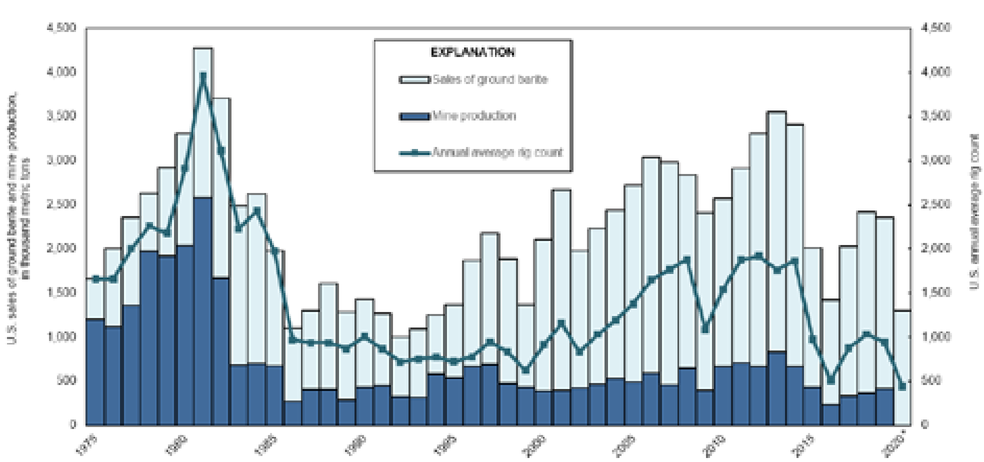

Figure 1. Historical trends in sales of ground barite, mine production of barite, and annual average rig count in the United States from 1975 through 2020. *Mine production in 2020 was withheld to avoid disclosing company proprietary data. Sources: Baker Hughes Inc. and U.S. Geological Survey.

Prices

Fastmarkets IM publishes prices of unground lump barite meeting American Petroleum Institute specifications with specific gravity of 4.2 from leading exporting countries. In December 2020 the free-on-board (f.o.b.) price from China was $95 to $100/t compared with $89 to $93/t in December 2019. The f.o.b. price from Chennai, India was $89 to $92/t, and the f.o.b. price from Morocco was $85 to $92/t, which was essentially unchanged compared with 2019 (Fastmarkets IM, 2020; 2021).

Outlook

Monthly average rig counts in North America reached their lowest levels in the summer months but began to climb throughout the latter half of the year. However, the levels remained well below those at year-end 2019. In other regions of the world, rig counts were still declining at year-end 2020. Barite consumption would not be expected to increase significantly unless rig counts increase, which seems unlikely as long as widespread COVID-19-related travel restrictions continue. For the longer term, some analysts project that oil consumption is unlikely to return to pre-pandemic levels until 2023 (World Bank Group, 2020, pp. 2, 19).

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BENTONITE

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

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

Production

According to U.S. Geological Survey publications, in 2020, domestic bentonite production (the quantity sold or used by producers) was estimated to have decreased by 4 percent to 4.3 Mt compared with 4.49 Mt in 2019. During the past 20 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 2020, 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 comprised an estimated 97 percent of all domestically produced bentonite. An estimated 94 percent of swelling bentonite was produced in Wyoming; Alabama and Mississippi led in the production of domestic nonswelling bentonite. Swelling bentonite was thought to have been produced by 16 companies, and nonswelling bentonite was produced by six companies.

World production of bentonite was estimated at 16 Mt in 2020, a slight decrease from 16.3 Mt in 2019. The United States was estimated to be the global leader in the production of bentonite, followed, in descending order, by China, India, Greece and Turkey.

Consumption

Pet-waste absorbents (an estimated 49 percent of sales) and drilling mud (23 percent) continued to be the leading domestic markets for bentonite in 2020. Bentonite also was sold for the manufacturing of adhesives, foundry sand, miscellaneous civil engineering applications, pelletizing (iron ore) and waterproofing. Primary uses for exported bentonite were, in decreasing order, foundry sand, pet-waste absorbent and drilling mud.

Prices

In 2020, the estimated average unit value of bentonite was $98/t, unchanged from 2019. The average unit value for exported bentonite increased by 4 percent to $220/t in 2020 compared with $211/t in 2019, and the average unit value for imported bentonite increased by 58 percent to $550/t in 2020 compared with $349/t in 2019. 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 728 kt valued at $160 million in 2020 compared with 906 kt valued at $191 million in 2019. Exports of bentonite in 2020 were primarily shipped to Canada (59 percent), Japan (11 percent), China (6 percent) and Mexico (5 percent). Bentonite imports decreased to 17 kt valued at $9.45 million in 2020 compared with 34 kt valued at $11.8 million in 2019. In 2020, imports originated from Mexico (63 percent), China and Turkey (7 percent each) and the United Kingdom (5 percent).

Outlook

Bentonite is a mature market that is expected to remain stable. The American Pet Products Association projected a 6 percent increase in sales of pet products in 2021, which may result in increased consumption of bentonite for pet-waste absorbents. Natural-gas and petroleum well drilling is expected to continue recovering from the decrease that occurred during 2020. The Baker Hughes U.S. rig count has steadily increased during the first quarter of 2021 but is a lesser amount compared with that of the same period of 2020. The U.S. Energy Information Administration has forecasted a decrease in drilling in 2021 compared with 2020 followed by an increase in drilling in 2022, which might reverse the declining trend during recent years for drilling muds.

References are available from the author. ■

BISMUTH

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

Bismuth is one of the rarest elements on earth. Seldom extracted as a primary product, bismuth is typically recovered as a byproduct of lead refining, but it can also be produced as a byproduct of other minerals. In the United States, bismuth was last produced as a byproduct of lead refining in 1997, and lead refining ceased in 2013. In 2020, world refinery production of bismuth was estimated to be 17 kt, a decrease of 19 percent from 2019. China was the world's leading producer of refined bismuth as a byproduct of lead, fluorspar, tin and tungsten ore processing, accounting for 82 percent of the estimated world total, followed by Laos with 6 percent.

Consumption and end uses

In 2020, the estimated apparent consumption of bismuth in the United States was 1.4 kt, a 15 percent decrease from 2019. About three-fifths 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.

The majority 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 imported 1.66 kt of bismuth metal, alloys and waste and scrap in 2020, a 28 percent decrease from 2019. The imported bismuth was principally sourced from China, 55 percent; followed by the Republic of Korea, 29 percent; Hong Kong, 4 percent; Bolivia, 3 percent and other countries, 9 percent. The United States exported 705 t of bismuth metal, alloys, and waste and scrap in 2020, an 11 percent increase from 2019. The bismuth was principally exported to Vietnam, 56 percent; followed by Canada and Mexico, 8 percent each; China, 5 percent; and other countries, 23 percent.

Prices

According to Fastmarkets AMM Daily, the average free market price for 99.99 percent-pure bismuth began 2020 at $2.63/lb and fluctuated between $2.54/lb and $2.65/lb throughout the first half of the year. During the second half of the year, the average price steadily increased from $2.60/lb to $2.98/lb, where it ended the year. The price experienced an overall increase of 13 percent from January to December 2020. Prices for bismuth metal during the first half of 2020 were largely attributed to weak global demand due in large part to COVID-19. Prices increased in the second half of 2020 as pandemic-related closures in China eased and demand for bismuth in the Chinese manufacturing sector increased.

Industry news

The COVID-19 pandemic affected the global economy and trade during the first of half of 2020; in particular, China during the first quarter and the United States in the second quarter. A Chinese company, Vital Materials Co., was the confirmed buyer of the remaining bismuth stock formerly held by the failed Fanya Metal exchange, totaling more than 19 kt. Vital Materials bought the stock from the Kunming Rongke New Materials Co., also of China, which was named the initial buyer of the bismuth stock from the Kunming Intermediate People's Court.

In April 2020, the Office of the U.S. Trade Representative granted an exclusion to bismuth metal, Harmonized Tariff Schedule code 8106.00.00, from the 25 percent duty imposed on List 3 goods from China in September 2018.

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 in Europe and China, bismuth will likely be part of a growing market of lead replacements.

References are available from the author. ■

BORON

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

Four minerals account for 90 percent of the natural borates used by industry worldwide — the sodium borates, tincal and kernite; the calcium borate, colemanite; and the sodium-calcium borate, ulexite. Deposits of borates are associated with volcanic activity and arid climates, with the largest economically viable deposits 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 naturally 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 decreased slightly in 2020 from 2019; production data are withheld to avoid disclosing company proprietary 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 or 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 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

In 2020, the glass and ceramics industries remained the leading domestic users of boron products, consuming an estimated 80 percent of total borate consumption. Boron also was used as a component in abrasives, cleaning products, fertilizers, insecticides 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

U.S. exports of refined borax were 594 kt in 2020, about the same as in 2019. China, India, the Netherlands, Malaysia and Indonesia imported the largest quantities of refined borates from the United States. The average unit value for refined borate exports was $459/t in 2020, a slight increase from $449/t reported in 2019. Boric acid exports were 257 kt in 2020, approximately unchanged from 2019. Imports of boric acid in 2020 were 39 kt, about 7 percent lower than in 2019. Approximately 70 percent of imported boric acid came from Turkey in 2020. The average unit value for boric acid imports was $609/t in 2020, a 4 percent increase from $587/t reported in 2019. The average unit value for refined borate imports was $339/t in 2020, a slight increase from $331/t reported in 2019.

International

Chile, Turkey and the United States led the world in the production of borates in 2020. 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, in comparison to reserves in Turkey and the United States, which 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 state-owned mining company signed a cooperative agreement with a company from China to build a 1,500 t/a boron carbide plant in Balikesir. Construction of the $70 million plant began in October 2019. The completion of the plant and initial production were expected in 2021. This plant was intended to expand Turkey's national defense manufacturing capabilities and will process boron carbide for military applications.

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 boron-based fertilizers 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 several companies to perform prefeasibility studies at new boron mine prospects in a few countries, including the United States and Serbia. One company is expected to begin construction at a boron deposit in southern California in 2021.

The COVID-19 pandemic remains uncertain, and the economies of the United States and the world as a whole were negatively affected in 2020. Some recovery is in expected in 2021, which could influence the performance of the boron industry.

References are available from the author. ■

BROMINE

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

Two companies in Arkansas accounted for all U.S. production of bromine in 2020. The bromine was recovered from underground brine wells in Arkansas, where bromine is found in the Jurassic Smackover Formation. The brines in Arkansas have bromine concentrations ranging from 4,000 to 4,600 ppm bromine. Domestic production data for elemental bromine were withheld to avoid disclosing company proprietary data. However, the United States was one of the top four producers in the world along with China, Israel and Jordan. World production of bromine in 2020 was estimated to be less than in 2019.

Consumption

The leading global applications of bromine are to produce brominated flame retardants and clear brine drilling fluids. Bromine compounds are also used in a variety of industrial applications, as intermediates, and for water treatment. United States apparent consumption of bromine in 2020 was significantly less than that in 2019.

Foreign trade

In 2020, U.S. imports of bromine and bromine compounds were 35.9 kt, gross weight, 49 percent less than what was imported in 2019 (70.7 kt). The average cost, insurance, and freight unit value of elemental bromine imports in 2020 was $2.71/kg, 28 percent less than the average value of $3.78/kg in 2019. Israel was the leading source of bromine imports into the United States, accounting for 86 percent of the total quantity imported on a gross weight basis. Exports of bromine and bromine compounds were 45.3 kt, gross weight, a 24 percent increase from 36.5 kt gross weight in 2019. The average unit value of exported elemental bromine in 2020 was $3.03/kg compared with $2.58/kg in 2019. Saudi Arabia and United Arab Emirates (both 17 percent) and Mexico (14 percent) were the leading destinations of bromine exports from the United States, accounting for 48 percent of the total quantity exported on a gross weight basis.

Industry news

Global consumption of bromine and bromine compounds decreased in 2020. Owing to the COVID-19 pandemic, the demand for flame retardants and clear brine drilling fluids, leading applications for bromine and bromine compounds, decreased. This decreased demand was attributed to declining consumer spending in the automotive, electronic and construction industries (which use brominated flame retardants in their products), as well declining demand for drilling fluids by the oil- and gas-well-drilling industries, which use clear brine fluids in oil- and gas-well drilling. Because of travel restrictions, there was reduced demand for transport fuels, and thus less global oil consumption. This was reflected in a 54 percent decrease in the average number of active drilling rigs in the United States in 2020 compared with 2019.

References are available from the author. ■

CEMENT

by Alison Gillespie, National Minerals Information Center, U.S. Geological Survey

Hardly an industry was left untouched by the impact of COVID-19 in 2020 — a year that saw the largest decline in a single quarter in the national GDP since 1946 when America was transitioning from a wartime economy into a peacetime one. For the cement industry, it was a mixed bag. Given the full-scale shutdown of the whole economy, the industry still put in a modest showing at 2 percent growth, compared to the 3.5 percent growth originally forecast. The overarching good news was that despite some dire forecasts early in the pandemic, the U.S. Portland cement industry experienced no prolonged or widespread negative impacts.

"What helped is that we entered the pandemic with robust order books. There was momentum in the construction industry. Even though we had shutdowns, these orders were longer-term projects that were going to continue despite the chaos," said Ed Sullivan, executive director of the Portland Cement Association. "And a strong vaccine rollout in the first quarter of 2021 coupled with fiscal stimulus money has helped restore consumer confidence for a modest growth outlook this year."

According to the U.S. Geological Survey (USGS) 2020 Annual Report, U.S. Portland cement production increased slightly in 2020 to an estimated 87 Mt, and masonry cement production decreased slightly to 2.3 Mt, for an overall production increase of 1 Mt compared with 2019. Clinker production, an intermediary product, remained stable. Cement was produced at 96 plants in 34 states, and at two plants in Puerto Rico. The four leading cement-producing states that accounted for nearly 45 percent of U.S. production were Texas, Missouri, California and Florida, according to the report.

While the U.S. cement industry's growth

was measurable, the potential for a more robust performance was hampered by some idle plants during the height of COVID-19, production disruptions from plant upgrades, and competition from inexpensive imports. Still, cement producers benefitted from being an essential industry that could remain operational during most of COVID-19.

Cement prices in 2020 held steady and employment in both mine and mill increased slightly. Price per ton was $124, compared to $123 the previous year, while employment remained at 12,500 where it has hovered for the last five years since 2016, according to the USGS year-end report.

One of the positive factors in 2020 for the cement industry was the health of the construction market, which increased by 4 percent during the first nine months of 2020 compared to the same period for 2019. Single-family home construction was, and will continue to be for the short term, the leading force in this sector.

"An historically low inventory of homes and attractive mortgage rates are driving the construction industry," said Sullivan. "Cement consumption in residential was up more than 10 percent in 2020 over 2019. For the first time since before the Great Recession of 2008, we saw one million housing starts. That was the big volume leader for us."

While federal spending for infrastructure projects didn't change in 2020, state spending did. This is because many states fund public projects with gas tax revenues, which, with the shutdown, fell significantly. However, the most recent federal COVID-19 relief package in February included significant funds: $350 billion for state and local government budgets, which brightens the 2021 outlook.

"The public sector has been a huge drag on overall growth in the cement industry this past year. Now we expect this sector to become a mild positive," said Sullivan. Additionally, President Joe Biden has proposed a $2 trillion infrastructure package, which may make the picture even rosier.

"It remains to be seen in what form this bill will ultimately pass. But even if passed this year, the bidding and contracting process means we won't see any concrete poured until 2023 at the earliest," explains Sullivan.

The pandemic accelerated some ongoing trends that will continue to impact the cement industry such as work-at-home practices and online retailing, said Sullivan. The nonresidential construction sector declined 4 percent in 2020, and the hotel sub-sector plunged 17 percent with personal and business travel severely curtailed. Though very few big-box stores are being built, the bright spot within this sector is the construction of distribution warehouses, which jumped 10 percent in 2020.

In terms of exports, the USGS report shows that 2020 exports of hydraulic cement and clinker held firm at 1 Mt, compared with the total shipments to final customers, including U.S. markets, of 103 Mt. Imports of hydraulic cement and clinker from foreign markets, which are generally cheaper, totaled 16.4 Mt, also similar to previous years. In 2020, shipments of cement were essentially unchanged from 2019 and were valued at $12.7 billion. About 70 to 75 percent of sales were to ready-mixed concrete producers, 10 percent to concrete product manufacturers, 8 to 10 percent to contractors, and 5 to 12 percent to other customer types.

The oil and gas sector suffered significantly during COVID-19 with a 50 percent decline in concrete consumption, but this slump is seen as short term. Oil and gas represent about 2 to 3 percent of total concrete consumption.

"We think oil will stabilize. Although this sector will lag other sectors in the economic recovery, we expect prices and drilling to rebound in 2022 and 2023 as supply catches up with demand," said Sullivan.

Looking forward, cement producers are ramping up their industry-wide commitment to achieving sustainability targets, including development of new product lines, use of renewable energy, and emissions reduction equipment.

"The cement industry has a remarkable record on this front. And with the Democrats in office, we will be accelerating our efforts to be net neutral by 2050. In the PCA, environmental discussions dominate all of our activities. It is the critical factor," said Sullivan.

In that vein, "We have a great story to tell about cement. For example, cement roads have greater durability, greater carbon capture, and get more miles per gallon, than asphalt roads. We are educating the public to take a life-cycle approach to projects," said Sullivan. Most U.S. cement plants have moved from coal to natural gas and/or alternative fuels, more efficient processes and even some new products that take less kiln time to produce such as Portland limestone cement.

Moderately rising energy costs due to the cost of decarbonization could impact the cement industry, according to German-based HeidelbergCement AG's 2020 annual report. It is conceivable that some kilns could be shuttered or idled or scaled back to comply with national emissions standards that would constrain U.S. clinker capacity. HeidelbergCement also anticipates increases in the costs of raw materials for cement manufacture, as well as the secondary cementitious materials, particularly for electricity, diesel and petroleum coke, on a like-for-like basis. Despite the concerning news, Heidelberg is expecting demand to develop positively in many markets in the 2021 financial year.

"The good start to the year confirms our optimistic outlook for 2021," said Dominik von Achten, managing board member of Heidelberg. "There should be tailwind from the massive infrastructure programs in many countries. The private residential construction sector should also continue to grow."

For 2021, Sullivan says the PCA is forecasting 2.2 percent growth for the industry. "The public sector will be weak this year, but across the economy the scars of the COVID-19 recession will start to fade as employment increases. Next year, any declines in single-family housing starts due to rising interest rates will start to be balanced by more public-sector construction, and oil and gas will perk up with a 30 percent increase. In 2023, we will see continued economic recovery and the Biden infrastructure bill come to fruition. Then the public construction sector will dominate as state funds click in.

"The chief challenge to the Portland cement industry, and the economic recovery as a whole, will arise if we see a synchronized global recovery," said Sullivan.

"COVID-19 resets the clock for everyone. We will see a huge pent-up demand that will place new pressures on logistical systems. The cost of moving freight around the globe will likely pose a major challenge and lead to rising costs, at least in the short term. This is a major factor impacting the free flow of raw materials around the globe," said Sullivan, "and one we'll be watching closely." ■

CHROMIUM

by Dr. Nils Backeberg, Roskill Information Services Ltd.

Chromium is sourced from the mineral chromite, its only currently economic occurrence. South Africa hosts more than 75 percent of the world's chromite reserves and resources and accounts for approximately 60 percent of annual global chromium ore production. Kazakhstan, India, Turkey, Finland and Zimbabwe together account for more than 30 percent of global chromite supply, making up the rest of the key ore producers.

The majority of chromium is consumed in ferrochrome, which in turn is largely used in the production of stainless steel. South Africa led global ferrochrome production prior to China taking the lead in 2012. Together with developing its stainless steel industry, China has invested heavily in ferrochrome (and ferronickel) capacity to service its domestic demand. China has done so without the benefit of chromium ore resources and as such has been reliant on imported feed, largely sourced from South Africa. The South African ferrochrome industry has lost its competitive advantage against Chinese ferrochrome plants due to continuously rising electricity tariffs that has seen several plants idled, despite having access to abundant and low-cost ores.

The Chinese ferrochrome producers have shown a willingness to focus their technical capability to process the fine-grained low-grade ores from South Africa, such as the Upper Group 2 (UG2) ores of the Bushveld Igneous Complex. UG2 ores are a mined for platinum group metals (PGM) and contain low grades of chromite, but because the ores are milled to very fine size fractions to liberate the PGMs, the chromite is significantly finer than in mines primarily targeting chromite and impacts ferrochrome furnace operations. This UG2 chromite was historically sent into tailings dumps, but with the rise in Chinese ferrochrome output, more than 80 percent of UG2 tailings currently produced is being reworked for the recovery of fine-grained chromite. UG2 chromite is therefore a byproduct of PGM mining and does not carry any of the mining cost associated with the extraction of the ore. As a result, UG2 chromite is the lowest cost chromite available on the market, a benefit that has been largely exported to China.

Chromium ore and ferrochrome prices are typically quite closely linked. This is because both are impacted by similar macroeconomic factors, and because the majority of chromite is consumed in ferrochrome production and accounts for a significant cost of ferrochrome production. Likewise, ferrochrome prices tend to closely follow stainless steel prices, on top of which the alloy surcharge system formalizes the link between ferrochrome benchmark prices and stainless prices; stainless steel accounts for more than three-quarters of ferrochrome consumption and, accordingly, for more than two-thirds of total chromite consumption.

After recovering in 2010 from the 2008-2009 global financial crisis, prices for all three products followed a steady decline from the beginning of 2011, bottoming out in Q1 2016. This was primarily attributable to falling production costs, exacerbated during much of the period by oversupply in the market, which was underpinned by increased supply of lower-cost, byproduct UG2 chromite from South Africa. Ore prices recovered considerably through 2016 and consequently spiked threefold year on year in early 2017, as demand from China increased strongly and production costs rebounded. Prices then declined rapidly through the remainder of 2017. Several modest price swings followed over the second half (H2) of 2017 and 2018 as stainless steel markets encouraged growing supply. Nevertheless, chromite prices remained low in H2 2018 as oversupply dogged the market. The surplus chromite (from South Africa) remained in place in 2019 and saw prices return to the low levels last seen in 2015-2016.

Prices remained subdued over the second half of 2019 and into 2020. The outbreak of the COVID-19 pandemic did not cause major swings in chromium prices, except for a steady recovery following South Africa's first lockdown over April 2020 with prices increasing into July 2020. Initially, COVID-19 had a much larger impact on demand as stainless steel production in most regions saw double-digit year-on-year declines. The contrast to this was, unsurprisingly, China, where government stimuli supported a rapid recovery that helped the country post record production levels in 2020, a trend that supported more than 50 percent of the chromium industry.

Toward the end of 2020, prices began to recover more rapidly as demand returned in earnest from stainless steel mills, exacerbated by the need for restocking, following stainless steel and ferrochrome plants having drawn stocks during the course of the pandemic. A further support to the price rise in H2 2020 and into 2021 was the increase in production costs. Depreciating exchange rates, falling oil prices and declining freight rates in early 2020 allowed many high-cost producers to survive the oversupplied market that was in place toward the end of 2019, but a switch in these underlying trends has driven prices higher.

Supporting the current optimism in the market is China's 14th Five-Year Plan (2021-2024), which has set clear and firm requirements for bringing greenhouse-gas emissions to a peak before 2030 and become carbon neutral by 2060. Regional initiatives are geared toward high-energy-consuming industries, including ferroalloys, and aim to (1) to control capacity expansion, (2) raise industry standards of energy consumption, (3) accelerate the phasing out of old, excessive production capacity and (4) implement energy-saving technologies. With global initiatives shifting their attention to the steel industry's carbon footprint, the adoption of companies to produce carbon-neutral "green steel" is expected to be one of the key narratives over the 2020s that will underpin the outlook of the steel industry and its associated alloys. ■

CONSTRUCTION AGGREGATES

by Mark J. Zkunczyk, Consulting Geologist

In 2020, the U.S. Geological Survey (USGS) estimated production of construction aggregates was 2.43 Gt, a slight decrease from 2019 production. During the year of COVID-19, the industry fared better than expected.

Construction aggregates are considered materials such as crushed stone, sand, gravel, iron and steel slag, recycled concrete and asphalt generally sorted into various sizes and sold from the mine site. After processing to required specifications, construction aggregates are used in ready-mix concrete and bituminous concrete (asphalt) mixtures, road base, agricultural chemical and metallurgical applications, and other minor uses. The ready-mix concrete and asphalt paving industries are the major consumers of construction aggregates.

Crushed stone

According to the USGS, the estimated production of crushed stone aggregate was 1.46 Gt in 2020 valued at more than $17.8 billion. The USGS also estimated that this volume was from 1,410 companies operating 3,440 quarries and 180 sales and distribution yards throughout the United States. The leading states in crushed stone production in 2020 were Texas, Missouri, Florida, Pennsylvania, Ohio, Georgia, Virginia, Illinois, North Carolina and Kentucky which in total accounted for over half the total crushed stone output.

The USGS reports the following rock types (lithologies) are used as crushed stone aggregates: limestone, dolomite, marble, calcareous marl, shell, granite, traprock, sandstone, quartzite, slate and volcanic cinder. Some of these rock types may not meet the specifications needed for some applications.

Specifications

Specifications define the tests or critical observations that must be made on the crushed stone and the limiting values that must be achieved before an aggregate is considered for a particular use.

The specifications controlling the qualities of crushed stone aggregates are variable depending upon the use, their availability and the agency specifying the material. Some of the tests that may be required are the reactions of the crushed stone to alternating cycles of freezing and thawing or wetting and drying. These tests can be performed with or without magnesium and sodium sulfate salts. Other tests are chemical reactivity, resistance to abrasion and impact, particle shape, gradation, petrographic analysis, deleterious material (shale, friable and weathered material and organics), water absorption, specific gravity, color and skid resistance. State and federal specifying agencies may require other tests and test methods.

The most generally used national guidelines for test and test methods are outlined by ASTM and The American Association of State Highway and Transportation Officials (AASHTO).

Markets and transportation

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 aggregates in the United States. Rail and barge or ship together account for about 15 percent. As an industry rule of thumb, trucks can generally travel 56 to 64 km (35 to 40 miles) before transportation costs increase significantly. These costs depend on many factors such as road conditions, traffic, tolls, bridges, back hauls and weight laws, contract trucking companies bid prices or truck ownership by the aggregate companies. For example, relatively straight roads with limited traffic signals can allow trucks to carry material much farther than 64 km (40 miles) at low rates. Rates in these cases are charged at a ton/mile basis that vary across the country. Conversely, in areas near New York City, Atlanta, Dallas/Fort Worth, Los Angeles and other major cities, trucks are slowed by traffic congestion, thus freight rates are much higher. In these cases, many of the truck owners charge an hourly rate. Many large aggregate producers use contract trucking companies to deliver their products but may have one or two roadable trucks for local deliveries. Whether a ton-mile basis or hourly rate, many factors contribute to the final cost.

Rail rates are less than trucking rates, but rail has limited areas of service. The producer using rail generally owns or leases a siding on the production end and a distribution yard on the delivery end. In addition, the producer either owns or leases the 100- to 125-t hopper cars needed for transport. A unit train generally contains 50 cars minimum. Extra costs include storage, loading and unloading. Additional handling incurs more costs for the aggregate. Those producers who have rail access generally have the ballast stone market, as railroads sometimes send their own hopper cars to be loaded. Crushed stone aggregate is railed from producers in areas deficient in quality aggregate. For example, crushed stone is railed from the piedmont regions of Georgia, North Carolina and South Carolina to the coastal plain regions deficient in skid-resistant and quality aggregates. In the Houston area, quality aggregate is railed in from the Oklahoma region and shipped in by ocean-going vessel from Mexico.

Barges and ships are used on the east and west coast, Mississippi, Missouri, Ohio and Columbia Rivers, intercoastal waterways and the Great Lakes. Shipments by water are less costly than rail but the same extra cost is added at the dock or wharf such as demurrage or the time it takes to unload or load the material.

Prices

Construction aggregates are sold free on board (f.o.b.) quarry or sand and gravel pit. The f.o.b. prices are listed at the scale house and given out by salespeople. The f.o.b. prices do not reflect the price to the contractor, bid work or those companies that buy in large volumes. In those cases, prices are reduced. In addition, when a producer is vertically integrated, its price from its quarry for crushed stone or sand and gravel to their asphalt hot-mix plant or concrete may be lower or higher than the f.o.b price. Where aggregate is needed or in short supply, f.o.b. prices are generally higher than areas where aggregate is abundant. F.o.b. prices range from the highs of nearly $30/t for quality crushed stone in some regions like the southeast to as low as $6/t for low-quality material, abundant material and competition.

The marketability of the aggregate depends upon the results of some or all physical tests. However, there are many producers whose aggregates do not meet certain specifications but are sold for low-grade construction products or nonstate specification stone. Many producers in the United States sell more non-specification aggregate by volume than state-approved aggregate. Generally speaking, it is important to be a state-approved source for crushed stone or sand and gravel aggregate. Most municipalities and counties require state-approved stone for their roads and bridges.

Sand and gravel

Sand and gravel as construction aggregate are used for many of the same purposes as crushed stone. There are some differences that are mostly geographic in nature. In the aggregate industry, geography plays an important role between sand and gravel and crushed stone. Where there are large deposits of sand and gravel, such as the large alluvial fans of California or the glacial deposits in the northeast or north-central states, sand and crushed gravel is widely used. Where there are large deposits of rock, crushed stone is generally used, such as the Atlanta, GA area. There are two exceptions: Natural sand is generally preferred over manufactured or stone sand by most ready-mix concrete producers, and crushed stone is preferred over crushed gravel for the same use. In both concrete and asphalt mixtures, crushed stone is more uniform, generally having one rock type, while crushed gravel may contain several lithologies or rock types. Thus, each different lithology may absorb more water or react differently to the cement/cement additives or liquid asphalt, making it more difficult to control a quality product. In some states, natural sand use for concrete is difficult to find, as it requires a certain gradation. Much of the natural sand found is too fine-grained to meet the size (gradation) specifications. In addition, washed concrete-grade sand is being increasingly used by the asphalt-paving industry as it mixes recycled asphalt pavement (RAP) with the washed-concrete sand. This has added to the shortage of concrete sand in some areas of the country. Before blending RAP, asphalt producers generally used a small amount of unwashed sand as a filler in asphalt.

In 2020, the USGS estimates 960 Mt (1.1 billion st) of sand and gravel were produced in the United States. The five leading states were California, Texas, Minnesota, Michigan and Arizona. Most of the sand and gravel production in 2020 went to concrete aggregates such as ready-mix concrete. These leading states have an abundance of mines in the alluvial fans, colluvium, river deposits and glacial deposits. Most of the specifications required by states for crushed stone are similar for sand and gravel aggregates. One noted exception is that natural gravel generally needs to be crushed, exhibiting at least two fractured faces for use in ready-mix concrete or asphalt. Gravel that is not crushed is generally used for landscape products or used on top of flat commercial roofs. This is generally low-volume, high-price material.

Recycling and substitutes

Recycled asphalt pavement and recycled concrete are generally used for base materials, as they do not meet many state specifications for state-approved concrete or asphalt aggregate. The USGS reports that recycling is still a small percentage of aggregate consumption. As for other substitutes such as slag, there are quality issues that prevent major use in the industry especially for steel slag that is highly reactive in concrete casing expansion. Other restrictions of this material include availability and environmental concerns. Asphalt shingles are recycled to some degree at the asphalt plants. RAP is used more commonly as a recycled material especially in road base material and asphalt mixtures. RAP is a disposal issue for many producers, thus blending RAP with washed-concrete-grade sand is becoming more common.

Industry issues

Construction aggregates have many issues facing the industry. Since rock quarries and sand and pits need to be near urban areas to provide their products at a competitive price to the market, the general public is exposed to their operations more than any other mining industry. The industry has come a long way in mitigating many of the environmental concerns of local citizens. Today, all the major companies and most of the other aggregate-producing companies have environmental managers who handle all environmental and compliance issues. Because about 85 percent of aggregate production is transported by 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 widely mitigated in most operations. Still, the fact remains that opposition from not in my back yard (NIMBY) citizens cost the industry undue expenses in permitting or expanding quarries or sand and gravel operations. A few of the many permitting issues in 2020 that were chosen at random follow: Valley Sand and Gravel in Clark County, MT faced zoning change issues. In Skagit County, WA, Concrete Nor'west was met with concerns by residents in permitting a sand and gravel site. Residents near Silverthorne, CO were worried about the impact of dust and noise as well as truck traffic that would result from Peak Materials' effort to seek permits to mine a 75-acre property for sand and gravel; the company was met with adamant resistance from an environmental group.

The U.S. Mine Safety and Health Administration continue their inspections on the industry. Industry producers and trade associations continue to work closely with MSHA to help define many regulations which may or may not be appropriate for individual operations. Safety is very important to the industry as indicated by their hiring of safety professionals full time to help train employees to remain in compliance.

Other issues still plaguing the industry include silica and asbestos exposure from dust in the quarries and sand and gravel mines. Sulfide mineralization in aggregate which is used in concrete can cause staining and eventually failures in the concrete structures.

Acquisitions

Because permitting new operations is difficult, the industry prefers acquisitions of existing operations or permitted sites.

Some of the selected acquisitions in 2020: Peckham Industries of New York acquiring John S. Lane & Son of Westfield MA; Knife River Corp. acquired McMurry Ready-Mix Co. of Casper, WY; Chaney Enterprises in Maryland completed the acquisition of Green Rock Material of Richmond, VA; Rogers Group purchased Reed Contracting Services of Huntsville, AL; Arcosa acquired State Materials; Patrick Industries acquired Front Range Stone; and StonePoint Materials LLC acquired River Aggregates LLC near Houston and Beaumont, TX. ■

DIATOMITE

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

The United States continues to be the world's leading producer and consumer of diatomite. Production of diatomite in the United States during 2020 was estimated to be 770 kt (850,000 st), slightly more than in 2019. Six companies operated 12 mines and nine processing facilities in California, Nevada, Oregon and Washington. U.S. diatomite exports were 65.8 kt (72,500 st). Imports were lower at approximately 13.6 kt (15,000 st). Total world production of diatomite was approximately 2.2 Mt (2.4 million st) in 2020. Following the United States in diatomite production, other significant producers in 2020 were Denmark (370 kt or 410,000 st), Turkey (170 kt or 190,000 st), China (150 kt or 170,000 st), Peru (110 kt or 120,000 st), Mexico (96 kt or 110,000 st) and France (75 kt or 83,000 st). World resources of crude diatomite appear to be adequate for the foreseeable future. However, transportation costs may encourage development of sources of material closer to markets.

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 is a common alternate name, but the term is more appropriate for unconsolidated or less lithified rock of the same origin.

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 2020. The estimated average unit value of diatomite in 2020 was $340/t ($310/st), about the same as in 2019. Diatomite used as an absorbent was priced at approximately $10/t ($9/st), but specialty-grade diatomite, used in art supplies, cosmetics or biomedical applications, was priced as high as $10,000/t ($9,000/st).

Uses

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 2019, approximately 50 percent of diatomite-derived products was utilized in filter aids. The remaining 50 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.

Processing

Diatomite deposits are usually mined as open-pit 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.

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

Although the world remains in a pandemic, which has affected the production of some industrial commodities, the production and consumption of diatomite does not seem to have been negatively affected. Because the resolution of the pandemic remains uncertain, it is possible that the economies of the United States and the world as a whole could continue to be negatively affected, which could influence the performance of the diatomite industry. ■

FIRE CLAY

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

According to U.S. Geological Survey (USGS) publications, 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. Since 2013, fire clay was estimated to account for about 2 percent of total clay produced domestically. Much of the decline may be attributed to greater use of higher-alumina clays, nonclay refractory products, and monolithic refractory products to reduce fuel costs and adapt to changing furnace operation requirements.

In 2020, five companies (Christy Minerals Co.; General Shale Brick Inc.; HarbisonWalker International; The Belden Brick Co. and Triangle Brick Co.) were thought to mine fire clay in four states (Colorado, Missouri, North Carolina and Ohio). Missouri was the leading state in the production of fire clay. Other companies may or may not have produced fire clay because year-to-year output has become variable in recent years as common clay producers randomly entered and exited the fire clay market in response to short-term customer demands. Fire clay production was estimated to have decreased by 5 percent to 570 kt in 2020 compared with 603 kt in 2019. Preliminary production data for 2020 were estimated based on current and previous producer reports as well as employment hours published by the U.S. Mine Safety and Health Administration. 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 2020. Other markets for fire clay were, in descending order of estimated tonnage, common brick, Portland cement, fire brick, refractory grogs and calcines, pottery, and miscellaneous civil engineering and sealing. The USGS 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 $14/t in 2020 as compared with that of 2019, with unit values for individual operations ranging from $13/t to $16/t. The price of fire clay has trended downward since 2007, when the average unit value was $42/t; however, estimated values in 2019 and 2020 were slightly increased compared with the unit value of $12/t in 2018. The average unit value of imported fire clay in 2020 was $662/t, compared with $482/t in 2019 and the average unit value of exported fire clay was $252/t in 2020 compared with $251/t in 2019. Average unit values for exports and imports typically fluctuate from year to year owing to the influence of small, high-value shipments.

Foreign trade

Fire clay exports were estimated to have decreased in 2020 to 190 kt valued at $48.1 million from 194 kt valued at $48.7 million in 2019. The principal destinations for U.S. exports of fire clay in 2020 were the Netherlands (42 percent), Mexico (16 percent), Japan (13 percent), Taiwan (6 percent) and Spain (5 percent). Imports of fire clay significantly decreased in 2020 to 0.35 kt valued at $232,000 compared with 21 kt valued at $9.9 million in 2019. In 2020, the countries from which fire clay was imported were, in decreasing quantity, China (56 percent), Canada (30 percent), Spain (13 percent) and Germany (less than 1 percent). As in recent years, China remained the leading source of imported fire clay in 2020; however, owing to the COVID-19 pandemic the amount imported from China was considerably lower than in recent years.

Outlook

Fire clay production in the past five years has remained relatively stable, fluctuating between a high in 2019 of 603 kt to a low in 2016 of 534 kt. Despite the global pandemic, production of fire clay was estimated to have decreased by only 5 percent in 2020. Fire clay production is expected to resume a slight upward trend over the next several years, supported by expected production increases in the applications that use refractory brick, such as the aluminum, cement, glass, lime and steel industries as well as increased heavy-clay products owing to anticipated increased residential construction. Despite the anticipated increases of fire clay consumption, the widespread use of fire clay that took place during the mid-1900s is unlikely to resume. Because the fire clay industry is a mature sector of the U.S. economy, large changes in production and consumption are not expected to occur on a routine basis. ■

FLUORSPAR

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

Fluorspar is the commercial name that refers to crude or beneficiated material that is mined and (or) milled for 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 97 percent or less 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 used metallurgical-grade fluorspar, although acid-grade may also be used. Other applications of fluorspar include use in the manufacture of cement, ceramics, enamel, glass and welding-rod coatings.

Production

Minimal fluorspar was produced in the United States in 2020. Hastie Mining & Trucking Co. sold fluorspar from stockpiles produced as a byproduct of its limestone quarrying operation in Cave-in-Rock, IL, and continued development on its fluorspar mine in Kentucky. After acquiring the Lost Sheep Mine in Utah, Ares Strategic Mining Inc. (Canada) continued a drilling program to further define the mineral resource, which would facilitate development of a mine plan. The company also initiated plant design and acquisition of processing equipment.

According to U.S. Geological Survey publications, an estimated 29 kt of FSA, equivalent to about 47 kt of fluorspar grading 100 percent, was recovered from five phosphoric acid plants processing phosphate rock, which was primarily used in water fluoridation. World production of fluorspar was estimated to have increased slightly to 7.6 Mt, which was attributed primarily to the ramp up of production at new mines in Canada and South Africa.

Consumption

Domestically, production of HF at plants in Louisiana and Texas was by far the leading use for fluorspar. Total domestic HF capacity was 220 kt/a, second only to China. The United States was also a significant producer of downstream fluorochemicals, including fluorocarbon gases used as aerosols, propellants, and refrigerant gases, and of fluoropolymers. Apparent consumption of acid-grade fluorspar in 2020 was 412 kt, a 20 percent increase compared with 344 kt (revised) in 2019.

In December 2020, the United States passed the Consolidated Appropriations Act, 2021 which included an amended version of the American Innovation and Manufacturing (AIM) Act. The AIM Act authorized a phasedown in the production and use of hydrofluorocarbons with a goal of an 85 percent reduction by 2036. Exceptions were included for chemicals used as feedstock in the manufacture of other chemicals, and certain uses for which there are currently no acceptable substitutes including those used as defense sprays; fire-suppression chemicals such as those used in aircraft, armored vehicles, and ships; medical propellants; and semiconductor manufacturing. State and local governments were preempted from regulating congressionally mandated protected uses for a minimum of five years.

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 58.7 kt, a 9 percent increase compared with 53.8 kt in 2019.

Domestic and international trade

In 2020, acid-grade imports were 414 kt compared with 346 kt (revised) in 2019, an increase of 20 percent. The leading acid-grade import sources in 2020 were Mexico (54 percent), Vietnam (21 percent), South Africa (11 percent) and Canada (11 percent). Imports from South Africa nearly quintupled, imports from Canada nearly quadrupled and imports from Vietnam increased by 27 percent compared with 2019. Metallurgical-grade imports in 2020 were 65.4 kt, a 10 percent increase compared with 2019; nearly 100 percent of metallurgical-grade imports were from Mexico.

In 2018, China, the world's leading producer and consumer of AlF_3, fluorspar, fluorocarbons, and HF, became a net importer of metallurgical-grade fluorspar. In 2020, imports of acid- and metallurgical-grade fluorspar continued to increase, by 31 percent and 7 percent, respectively, and China became a net importer of acid-grade fluorspar as well. Acid-grade imports were 171 kt, with Mexico supplying 90 percent. Metallurgical-grade imports were 608 kt, with Mongolia supplying 84 percent; however, metallurgical-grade imports from Nigeria, Pakistan and South Africa also increased significantly.

Prices

According to Fastmarkets IM, at year-end 2020 the price of acid-grade fluorspar from China was $380 to $430/t, the price from Mexico was $330 to $380/t, and the price from South Africa was $340 to $390/t. Metallurgical-grade fluorspar from Mexico was $280 to $320/t . Compared with prices at year-end 2019, the price of acid-grade fluorspar from China decreased by 5 percent, the prices of acid-grade imports from Mexico and South Africa decreased by 14 percent each, and the price of metallurgical-grade fluorspar from Mexico was unchanged.

Events, trends and issues

An increasing number of new projects continued to focus on developing alternatives to fluorspar in the manufacture of HF. Hydrofluoric acid was produced from FSA at four plants in China and a fifth plant was ramping up production in 2020. In June, Arkema S.A. (France) and Nutrien Ltd. (Canada) announced a partnership to construct a 40-kt/a anhydrous HF plant in Aurora, NC, using FSA feedstock. The new plant, expected to begin production in 2022, would be the first plant of its kind outside of China, although similar projects were reportedly being evaluated in other countries. ■

GEMSTONE

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

The value of natural gemstones produced from U.S. deposits during 2020 was estimated by the U.S. Geological Survey (USGS) to be $8.76 million, a 5 percent decrease from 2019. 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 2020, each of the 50 states produced at least $1,660 worth of gem materials. Thirteen states accounted for 95 percent of the total value, as voluntarily reported to the USGS by survey respondents. These states were, in order of descending value of production, Arizona, Oregon, California, Nevada, Montana, Maine, Arkansas, Colorado, Utah, Idaho, Tennessee, North Carolina and New York. Some states are known for the production of a single gem material, such as Tennessee for freshwater pearls. Other states, including Arizona, California, Idaho, Montana, Nevada and North Carolina are known for producing a variety of gemstones. North Carolina is the only state with identified deposits of all four of the most popular precious gemstones: diamond, emerald, ruby and sapphire.

The USGS estimated the value of U.S. synthetic or manufactured gemstone production was $89.6 million in 2020. Reported output of synthetic gemstones was, in order of decreasing production value, from five firms in California, North Carolina, New York, Maryland and Arizona. 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. U.S. gemstone markets were estimated to account for more than 35 percent of world gemstone consumption in 2020. The U.S. apparent consumption for unset gemstones during 2020 was estimated to be about $15.1 billion. The U.S. apparent consumption for unset gem-quality diamond during 2020 was estimated to be about $13.3 billion. U.S. apparent consumption for unset nondiamond gemstones totaled about $1.80 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 2020, total U.S. gemstone trade with all countries and territories was about $28.0 billion ($16.4 billion in imports plus combined $1.32 billion in domestic exports and $10.3 billion in reexports). In 2020, U.S. domestic exports of diamond were valued at $1.05 billion and re-exports were valued at $9.31 billion. U.S. domestic exports of gemstones other than diamond were valued at $272 million and reexports were valued at $998 million. U.S. imports of diamond were valued at $14.3 billion, and U.S. imports of gemstones other than diamond were valued at $2.03 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.

In a four-year average of U.S. import sources by value, the leading gemstone sources were India, 39 percent; Israel, 32 percent; Belgium, 13 percent; and South Africa, 4 percent. Typically, diamond imports accounted for 90 to 95 percent of the total value of gemstone imports.

Outlook

During 2020, COVID-19 affected the U.S. and global gemstone and jewelry industries. As the restrictions, lockdowns and store closings were imposed, many jewelry stores initially saw reduced sales but later in the year successfully shifted sales to their websites. Monthly U.S. gemstone imports declined from March through August, with the largest year-on-year decrease of 96 percent happening in April. U.S. apparent consumption of gemstones decreased by 32 percent. All major U.S. gemstone trade shows were canceled from March through August.

COVID 19 also affected the global diamond industry in 2020 with temporary diamond mine closings around the world and disruptions of the supply chain. Total world diamond production during 2020 decreased by at least 10 percent from 2019 levels. Global demand for diamonds plummeted during the pandemic, halting sales. Only demand for large, high-quality diamonds remained stable, and their prices increased steadily during the year. The pandemic forced mining companies to cancel or delay sales, and major diamond trade shows were canceled owing to health and travel restrictions. Rough diamond prices declined by between 15 and 27 percent at the few sales that took place, and the rough diamond market was not operating normally during the second quarter. In India, where about 80 percent of the world's diamonds are polished, cutting centers experienced major disruptions as gem workers contracted the virus. Imports of rough diamonds in India decreased from $1.5 billion in February to $1 million in April. Antwerp experienced a 20 percent drop in rough imports and a 46 percent decline in exports of polished diamonds. Worldwide, many temporary mine closures resulting from the pandemic had yet to reopen and were at risk of becoming permanent. Many mining companies sought credit protection or were restructuring their credit. The global diamond jewelry market had an estimated value of $80 billion in 2019 and was expected to decline by 19 percent in 2020.

As domestic and global luxury spending recovers from the effects of the pandemic, sales of gemstones and jewelry are expected to increase also. 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 that emerge to serve the diamond and gemstone industries, partially replacing brick-and-mortar store sales.

Global diamond production is expected to decrease from pre-pandemic levels during the next five years as new projects and expansions fail to offset lost output from mine closures. By 2025, several very large mines will reach the end of their mine life, while only a few new projects are currently being developed.

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 Scogings, KlipStone Pty Ltd.

Graphite is an allotrope of carbon, characterized by a hexagonal structure that facilitates easy cleavage and which makes it one of the softest substances known. Graphite is gray to black, opaque, very soft, has a low density and a metallic luster. It is flexible and exhibits both metallic and nonmetallic properties, making it suitable for diverse industrial applications. Physical properties include specific gravity of 2.2 and Mohs hardness of 1-2.

Natural graphite occurs in several forms, described as amorphous, flake and vein. Graphite may also be manufactured synthetically from carbon-bearing raw materials such as petroleum coke and tar pitch.

Production of natural graphite

Flake graphite deposits typically have tabular or lens-like geometry and are hosted in metamorphic rocks such as gneiss and schist and generally mined opencast (Fig. 1), though some high-grade flake graphite deposits are mined underground in Germany and Norway. Most flake graphite deposits being mined opencast contain about 5 to 15 percent graphite, whereas underground mines have grades of around 20 to 30 percent graphite.

Vein deposits have complex geometry; the veins are generally less than a meter in width (Fig. 2) and are selectively mined underground in Sri Lanka. Amorphous graphite is mined underground and usually extracted using selective room-and-pillar mining methods, similar to coal mining.

Natural graphite products generally contain associated mineral impurities, known as ash. These impurities may include silicate and sulfide minerals such as quartz or pyrite in the case of flake graphite. Amorphous graphite may contain sedimentary rock impurities such as shale, sandstone, quartzite or limestone.

The most common beneficiation method for flake graphite is flotation, and acids or alkalis may be used to leach out impurities. Graphite may also be purified by heat treatment. The graphite ore is crushed and ground in rod mills in closed circuits with screens, before rougher flotation, followed by several regrind and cleaner flotation stages and final drying, screening and packaging.

Global annual natural graphite production is estimated at 1.1 million t (~1.2 million st). Flake graphite is estimated to account for about 800 kt (882,000 st), amorphous graphite about 320 kt (350,000 st) and vein graphite around 4 kt (~4,500 st).

According to U.S. Geological Survey (USGS) data, China was the world's leading producer of natural graphite in 2019 and supplied ~650,000 t (~717,000 st), followed by Mozambique (~120,000 t or ~132,000 st) Brazil (~95,000 t or 105,000 st), India (~34,000 t or ~38,000 st) and Russia (~24,000 t or 27,000 st). The USGS reports Madagascan production of ~47,000 t (~52,000 st); however, the author's opinion is that Madagascan production may have been lower than this.

Downstream production is carried out in the United States by specialist processors such as Asbury Carbons, Superior Graphite and GrafTech International. For example, Asbury processes, upgrades and trades many types of carbons, including natural and synthetic graphite, and sells to a wide range of end markets including lubricants, refractories and foundry industries. Superior Graphite specializes in electro-thermal purification technologies, engineered graphite electrodes, advanced ceramic shapes and powders, precision particle processing and carbon coatings. GrafTech International is focused on synthetic graphite products and markets, particularly electrodes, but the company also manufactures products based on natural graphite for thermal applications in the electronics industry and for sealants. The company buys flake graphite from sources around the world to manufacture into expandable graphite.

Most spherical graphite for lithium-ion battery anodes is manufactured in China and then exported to Japan or Korea for final coating. An Australian company that produces graphite at Balama in Mozambique has established a battery anode material (BAM) plant in Vidalia, LA and announced the first production of purified spherical graphite in late 2019.

Consumption, uses and specifications

The major usages of graphite are in refractories, batteries, expandable graphite, plus brake linings, steelmaking and foundry operations.

The largest end market for natural graphite is in refractories, foundries and crucibles used in high-temperature environments such as steel, glass and cement production. These markets account for around 40 percent of total graphite consumption, predominately consuming flake and vein graphite.

Metallurgy is the second-largest market for natural graphite, which is used in metal production, particularly as a recarburizer in steel, consuming mainly amorphous graphite or fine flake. This accounts for approximately 30 percent of total natural graphite output.

The third-largest market for both flake and amorphous graphite is in parts and components; this range of products includes motor vehicle brake pads, carbon brushes for electric motors and pencils. As a group, it is believed to consume about 10 percent of total output.

Batteries are the fourth-largest graphite market. Although only consuming around 10 percent of worldwide graphite production, it is potentially the fastest-growing market. Chinese producers use minus 100 mesh (94 percent C) small flake for making spherical graphite (for battery anode applications). Anode manufacturers typically blend natural spherical graphite ~50:50 with synthetic graphite.

Solid lubricants based mainly on amorphous graphite consume a further 10 percent of production, having been a classic use for centuries.

Expandable graphite is another market that is anticipated to grow, for applications such as fire retardation to replace halogenated retardants, insulation and heat transmission applications (e.g., graphite foil). These markets require large-flake products generally >80 mesh. Lower product purity is acceptable for the construction industry, compared with graphite foils which require high purity.

Graphite is typically specified at a minimum by particle size and carbon content (see refractory examples in Table 1). There are no set industry specifications, although in countries such as China the government has established national standards (Table 2). Other specifications may include bulk density, crystallinity or expansion volume.

Trade

The major primary producing and exporting countries include China, Brazil, India, North Korea, Mexico, Mozambique and Canada. Imports are generally dominated by the United States, China (from Korea and Mozambique), Germany, Japan and India.

Sri Lanka has exported around 4 kt/a of vein graphite in recent years at prices exceeding $1,600/t according to UN trade data.

U.S. natural graphite imports were approximately 41,000 t (45,000 st) in 2020 compared with 50,000 t (55,000 st) in 2019 and 71,000 (78,000 st) in 2018. Imports during 2020 were described by the USGS as being 71 percent flake, 28 percent amorphous and 1 percent lump and chip graphite.

Table 1

Examples of refractory products and graphite specifications. Source: Christoph Frey, Pro-Graphite (IM Graphite and Graphene Conference 2014).

Product	Flake size	Flake graphite quality (% carbon)
Unshaped refractories	> 150 micron	85-94
Graphite-containing crucibles	> 150 micron	85-96
Magnesia/dolomite carbon bricks	< 150 to > 300 micron	90-95
Alumina magnesia carbon bricks	< 150 micron	92-94

Table 2

China national standards: flake graphite products categorized by carbon content. Source: GB/T 3518-2008 flake graphite standards.

Category	Lower limit (% carbon)	Upper limit (% carbon)
LC (high purity)	≥ 99.9	100
LG (high carbon)	≥ 94.0	< 99.9
LZ (intermediate carbon)	≥ 80.0	< 94.0
LD (low carbon)	≥ 50.0	< 80.0

The USGS noted that sources of imported natural graphite during 2020 into the United States were as follows: China, 33 percent; Mexico, 23 percent; Canada, 17 percent; India, 9 percent; and other, 18 percent. Sri Lanka was the sole source of lump and chip graphite.

Prices

The USGS 2020 Mineral Commodity Summary

Figure 1

High-grade flake graphite mine in Heilongjiang Province, China. Photograph: Andrew Spinks, Ecograf Ltd.

Figure 2

Sri Lankan vein graphite in granitoid host rock. Scale rule = 15 cm (~6 in,). Photograph: Andrew Scogings. Vein graphite sample by courtesy of Margosa Graphite Ltd.

estimated import prices into the United States during 2020 as having increased from 2019 to $1,400/t (~$1,270/st) for flake; $3,400/t (~$3,080/st) for Sri Lankan lump and chip, and $570/t (~$520/st) for amorphous graphite. By comparison, prices during 2019 were $1,350/t ($1,225/st) for flake; $2,390/t ($2,170/st) for Sri Lankan lump and chip, and $496/t ($450/st) for amorphous graphite.

One graphite price not generally quoted is for jumbo flake, a term that describes flakes +35 mesh size or larger. Trade is believed to be relatively limited, and prices may have been around $2,000/t in 2020.

Spherical graphite is another product for which prices are not widely publicized. However, according to China Customs data, prices for uncoated spherical product range around $3,000/t (~$2,720/st) while coated spherical graphite is believed to sell for ~$7,000 to $10,000/t (~$6,300 to $9,100/st).

Geologic settings and mineral resources

Economic natural graphite deposits occur in three main geologic types: flake graphite disseminated in metamorphosed sedimentary rocks, amorphous graphite formed by metamorphism of coal or carbon-rich sediments, and vein or lump graphite filling fractures in granitic country rock.

The USGS estimated 320 Mt of global reserves in 2020. The reserves were predominantly accounted for by Brazil (70 Mt or 77 million st), China (73 Mt or 80 million st), India (8 Mt or 9 million st), Madagascar (26 Mt or 29 million st), Mexico (3.1 Mt or 3.4 million st), Mozambique (25 Mt or 28 million st), Tanzania (17 Mt or 20 million st) and Turkey (90 Mt or 100 million st). The USGS noted that U.S. resources of graphite are relatively limited, but that the inferred resources in the rest of the world exceeded 800 Mt of recoverable graphite.

The past few years have seen intensive exploration for graphite by both privately and publicly listed companies, with most exploration aimed at flake graphite deposits. Australia, Canada, Mozambique and Tanzania were the main hotspots, with the largest deposits discovered in northern Mozambique and southern Tanzania. Other target countries have included Brazil, Finland, Madagascar, Malawi, Sweden and the United States.

Mineral resources for flake graphite projects reported by publicly traded companies totaled more than 5.3 Mt (5.8 billion st) at grades ranging from approximately 2 to 30 percent graphitic carbon for an average grade of ~9 percent graphitic carbon. The contained (in situ) graphite content is estimated to be approximately 464 Mt (511 million st). The largest publicly reported mineral resources are concentrated in East Africa, mainly in northern Mozambique and southern Tanzania. Most of the published mineral resources were reported in terms of international codes, for example NI 43-101 and JORC.

Recycling and environmental

There are no graphite mines in the United States, hence no regulatory or reclamation issues arise. According to the USGS, refractory products led the way in recycling of graphite products, with material being recycled into products such as brake linings and thermal insulation.

Outlook

Global natural graphite production is expected to increase, mainly due to increased demand for electric-vehicle batteries. While most graphite markets are forecast to remain static, growth is expected to come from the battery-anode and expandable-graphite markets. The battery market for natural graphite used in spherical graphite has been forecast by various researchers to grow at a compound annual growth rate of around 15 percent, from a base of 60 kt (66,000 st) in 2016 to 220 kt (240,000 st) by 2025. The conversion rate of natural graphite to spherical graphite is about 40 percent, which means that there will be 60 percent of the feed graphite available for other applications.

Between traditional markets, battery markets and expandable-graphite markets, it may reasonably be expected that additional demand may exceed 300 kt flake graphite per year by 2025.

The Australian company, Mineral Commodities Ltd. acquired the Skaland Graphite mine at Traelen in Norway during late 2019, and in March 2020 announced a maiden mineral resource of 1.78 Mt (1.96 million st) at 22 percent total graphitic carbon (TGC). The company is investigating the possibility of producing anode material in Norway.

The Balama flake graphite mine owned by Australian company Syrah Resources Ltd. in northern Mozambique came onstream during late

2017 and produced 256 kt (282,000 st) in 2018-2019. Production was reduced in the fourth quarter of 2019 and suspended in March 2020 due to restrictions related to COVID-19. Production was scheduled to restart in 2021. This company has established a plant for spherical graphite production in the United States at Vidalia, LA and aims to process Mozambique graphite into anode-grade material as an alternative to Chinese supplies.

Other graphite mines in northern Mozambique are likely to be developed within the next few years, possibly in the Balama and Ancuabe areas, in addition to several projects in southern and central Tanzania and in Madagascar. ■

GROUND CALCIUM CARBONATE

by Lauren Olsen, Minerals Technologies Inc. (MTI)

Ground calcium carbonate (GCC) has a variety of applications in industry. It is used in construction, consumer goods, paper and plastics, food, health and agriculture. The minerology of GCC comes from the calcite mineral, $CaCO_3$ that is sourced from high-quality limestone and marble deposits. The economic value of a deposit depends on the purity, accessibility, proximity to the customer and any local environmental considerations. Additionally, COVID-19 plagued GCC in 2020 with a new external influence that shut down countries and industry worldwide.

GCCs are sourced from sedimentary limestone and marble deposits that are economically important. Limestone is a sedimentary rock that forms in a shallow marine environment composed mostly of biologically deposited calcium carbonate organisms, clays, sands, organics and other impurities. The purest limestone deposits form in high-energy environments where there is constant oceanic flow, which limits the amount of impurities deposited compared to a stagnant basin. This is important to the economic value of a deposit, as the particle size, texture and chemical purity play a role in determining its worth.

Limestone that undergoes metamorphism will eventually form a marble deposit. Metamorphism is the increase of temperature and/or pressure due to burial, convergence of plate boundaries, or even a localized heat source that allow the calcite crystals in the limestone to become denser, often interlocking and growing over time. A high-purity limestone will then become a high-grade marble that will change and enhance the properties of the calcium carbonate minerals that will be mined for GCC applications. According to the 7th Edition IMAR, Limestone and Dolomite, “A practical chemical classification considers that an ultra-high calcium limestone is more than 97.5 percent $CaCO_3$, high-calcium limestone is more than 95 percent $CaCO_3$, and high-purity carbonate rock is more than 95 percent combined $CaCO_3$ and $MgCO_3$.”

GCCs are used in construction applications, such as cement, adhesives, caulks and sealants (ACS), paints, polymers and paper. They also play a role in food, personal care and calcium supplements. GCCs have a variety of qualities that make them economical in the calcium carbonate market. The inherent grain size of GCC can also enhance a product’s brightness, color, strength and smoothness. Processed GCC products can have particle sizes that range from as small as 1 micrometer up to relatively larger chips as applicable to many different specialty applications. GCCs have a basic pH which can be used to neutralize odors and to increase the pH of soils or water.

Production and use

Overall, production and consumption of GCCs has grown approximately 1 percent per year and some market reviews suggested that new applications for GCCs will continue to develop in the coming years. Key suppliers in the industry for GCCs include Omya, Imerys, J.M. Huber, Specialty Minerals Inc. (SMI), Mississippi Lime Co., Carmeuse, Sibelco, Lhoist and other smaller local companies. While there is an abundance of calcium carbonate deposits, high-purity white products extractable without beneficiation or additional processing are rare and are controlled by just a few producers. Additionally, GCCs have increased economic value dependent upon the distance traveled and the means of transportation to end-use customer markets:

- **Construction:** GCCs are used in construction nearly everywhere including portland cement, ACS and paint. In cement GCCs influence the performance of the reaction, setting times, and strength. Ideally very fine grained particle size is used in cement mix applications. The properties of GCCs used in ACS enhance the flow of the material, strength and whiteness. Paint applications use GCCs for densifying and extending the formulation in addition to reducing or enhancing gloss.
- **Paper:** Specialty applications for GCCs include fillers and coatings pigments for paper. Utilizing industrial minerals decreases the cost for paper production and improves the writing surface, opacity and whiteness. They are used in filler loading for pigments in printing paper, writing paper, newsprints, coated mechanical papers and wood-free coated and uncoated papers. As the paper industry has moved from acid to alkaline paper production, industrial mineral fillers like GCCs, are used to cut cost on the expensive paper fibers, and increase brightness and strength. Due to expensive

transportation costs, the utilization of GCCs is often based on proximity to the source. Major growth markets include Asia, where China is continuing to build satellite GCC plants.

- **Consumer goods related to health, food and agriculture:** Other uses of GCCs include agriculture, food and personal-care products. In agriculture GCCs are used to neutralize soils and can be a carrier to transport chemicals to crops. Similarly, GCCs are considered a source of calcium for supplements and to enhance foods. They are used in antacids, to relieve indigestion, heart burn, and upset stomachs. Other competitive fillers include kaolin clays and precipitated calcium carbonate (PCC).

The Specialty Minerals (SMI) segment of Minerals Technologies Inc. (MTI) mines and processes its GCC deposits located in the eastern and western parts of the United States. Despite disruptions by COVID-19, SMI saw growth in GCC food-related applications. SMI sells to the paper, automotive, construction and household-goods markets. The outlook for SMI is to utilize new GCC products in paints, coatings and packaging applications. J.M. Huber produces a high-purity GCC with low silica content which is preferred in ACS application. Omya and Imerys provide a range of GCC products that are innovated to optimize particle-size distribution to improve opacity.

Pricing

Of the total domestic crushed stone produced in 2020, about 70 percent was limestone and dolomite, sources of GCC. USGS estimated from 2019 to 2020 crushed stone decreased in production from 1,490 Mt to 1,460 Mt and in consumption from 1,550 Mt to 1,520 Mt. The average price for a metric ton of crushed stone in 2020 was reported by the USGS as $12.19/t. According to the USGS Commodity Report, "In 2020, 1.46 billion tons of crushed stone valued at more than $17.8 billion was produced by an estimated 1,410 companies operating 3,440 quarries and 180 sales and (or) distribution yards in 50 states. It is estimated that of the 1.5 billion tons of crushed stone consumed in the United States in 2020, 72 percent was used as construction aggregate, mostly for road construction and maintenance; 16 percent for cement manufacturing; 8 percent for lime manufacturing; 2 percent for agricultural uses."

Outlook and trends

In the United States there will continue to be a gradual increase in demand for GCCs corresponding to the need for new and improved product performance in the construction industry and technological advancements in specialty materials.

COVID-19 has shown us that staying home and staying healthy will require minerals. We have seen a transition to single-use items to limit exposure, eating meals at home, and staying healthy. As the world goes back to normal, there will be a need for GCCs in construction, the automotive industry and agriculture. Overall demand will continue to gradually increase, and countries across the globe will re-open and continue to develop new applications and technologies for GCCs. ■

GYPSUM

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

The United States is the world's leading producer and consumer of mined crude gypsum. Production of crude gypsum in the United States during 2020 was estimated to be 22 Mt (24 million st), a 4 percent decrease compared with 2019 production. The average price of mined crude gypsum was $8.60/t ($7.80/st). Synthetic gypsum sales in 2020, most of which were generated as a flue-gas desulfurization product from coal-fired electric power plants, were estimated to be 13 Mt (14 million st) and priced at approximately $5.00/t ($4.50/st). Forty-seven companies mined gypsum in the United States in 16 states. Crude gypsum exports from the United States totaled 32 kt (35,000 st). Imports were 6 Mt (6.6 million st).

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 2020 was estimated to be 150 Mt (170 million st), slightly more than in 2019. The United States was the largest producer of natural gypsum in 2019 with an estimated 22 Mt (24 million st), followed by China and Iran with an estimated 16 Mt (18 million st), Turkey with an estimated 10 Mt (11 million st), and Thailand with an estimated 9.3 Mt (10 million st). Crude gypsum was thought to have been produced in 80 countries in 2020.

Consumption

An estimated 2.4 billion m^2 (26 billion sq ft) of gypsum-derived wallboard products were produced in 2020 domestically. Synthetic gypsum accounted for 38 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; 80 countries are thought to produce gypsum.

Outlook

Approximately 700 kt (770,000 st) of gypsum scrap that was generated by wallboard manufacturing, wallboard installation, and building demolition was recycled. That quantity included an estimated 600 kt (660,000 st) of preconsumer wallboard waste recycled by wallboard manufacturers coupled with an estimated 100 kt (110,000 st) 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 electrical 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.

Although the world remains in a pandemic, which has affected the production of some industrial commodities, the production and consumption of gypsum does not seem to have been negatively affected. Because the resolution of the pandemic remains uncertain, it is possible that the economies of the United States and the world as a whole could continue to be negatively impacted, which could influence the performance of the gypsum industry. ■

HYDRAULIC FRACTURING SAND

by Mark Zdunczyk, Consulting Geologist

In 2020, according to the U.S. Geological Survey (USGS) about 58 percent of the U.S. industrial silica sand tonnage was used as hydraulic-fracturing sand, well-packing and cementing sand, comprising 41.18 Mt. The frac-sand mining industry estimates about 60 Mt (personal communication) were sold or produced in 2020. This discrepancy is not unusual as the annual mineral surveys sent to producers are not mandatory and therefore may not be completed accurately or filled out at all. In addition, during the year of COVID-19, many producers were struggling with other company business such as low production, prices and shutdowns. Using either statistic, the decrease was between 20 Mt and 39 Mt from 2019.

Hydraulic fracturing sand, commonly called frac sand, is a silica sand (high quartz content) used in the oil and natural-gas industry to improve the flow of oil and gas to the well head. Hydraulic fracturing or fracking has been used for more than 50 years. In the last decade fracking has increased due to oil and gas being produced from new sources called gas-shale. This new source was generally found in shale and some sandstone beds which were previously bypassed until about 20 years ago. This development required more horizontal drilling that resulted in more fracking to improve permeability of these tight rock formations with naturally occurring fractures. These fractures were closed by tectonic stress, cementation and salt deposits. The fracking process includes injecting water under high pressure to open the fractures. The fractures are kept open by injecting particles such as sand, ceramic balls, glass beads and, early on, walnut shells of various sizes to prop open fractures, thus the name proppants.

The most common proppant used is silica sand because it is abundant and relatively inexpensive. During the golden years of fracking, most of the sand was produced in certain areas of the country that always met recommended specifications by the American Petroleum Institute (API) and International Standards Organization (ISO). These specifications include roundness and sphericity (Krumbein-Sloss Chart), crush resistance (ability to withstand high pressure), acid solubility (free of carbonates), sieve analysis (size gradations), turbidity (silt content) as well as other tests.

These specifications were well met by the sandstones in Wisconsin, Minnesota, Illinois, Indiana, Missouri and Iowa. The fracking industry calls this sand Northern White because of the relatively white color. Similarly, the Hickory Sandstone near Brady, TX was called Brady Brown because of the brownish tint. The fracking industry generally used these two types of frac sands. The Northern White geologic formations are the St. Peter, Jordan, Mt. Simon, Galesville, Wonewoc and to some extent the Mclish and Oil Creek in Oklahoma.

Hydraulic fracturing operations are under constant change. Completion engineers and fracking operators are expected to be aware of costs, priorities and expectations of well completion. They are requested to enhance performance and do more with less especially in recent years. This is the key to success in the changing fracking environment. Since sand is the major component in well completion, sand performance and specifications were scrutinized along with freight costs from the northern states. Engineers were finding that perfect roundness and sphericity and high crush resistance were not needed to frac a well. They were finding success with sands which were not as uniform or strong as northern white and Brady brown. Furthermore, some engineers now feel that the sand bridges the fractures rather than fills the fractures to keep them open. This discovery and the potential for lower costs led to more testing of local or regional sands closer to the active basins, thus leading toward their use in the last few years.

Northern White and Brady Brown sands were replaced by the dune deposits in and around Midland, TX where the Permian Basin had most activity. Similarly, unconsolidated deposits not far from the Eagle Ford Basin, roughly south of San Antonio and Austin and north of Houston were being mined for fracking purposes. These deposits generally consisted of high quartz (silica) but grain uniformity and strength were not comparable to Northern White sand. The regional and in-basin sands became popular because it worked and freight costs were low. When the in-basin sands became active operations, many of the Northern White sand plants closed or production significantly decreased. However, some of the same operators began mining near the Permian and Eagle Ford Basins.

In 2020, the COVID-19 pandemic certainly had an effect on the frac-sand industry. In April to June of 2020 the price of West Texas Intermediate (WTI) crude oil was very volatile from as low as the teens to nearly $40 per barrel by June. Prior to the pandemic, the frac-sand industry outlook was dim because drilling and well completion activities became flat in the second half of 2017. There were positive and negative swings of rig activity in 2018 and a significant decline of rig activity in June 2019 culminating in a steady decline in the first quarter of 2020. *World Oil* reported that U.S. drilling totals for 2020 were the lowest in more than 80 years. In addition, most of the wells drilled were not completed or drilled uncompleted wells (DUCs). Therefore, frac-sand volumes decreased significantly.

Operators idled their sand plants near the Permian and Eagle Ford Basins and prices dropped drastically. Frac sand prices in 2020 ranged from $15 to $30/st f.o.b. plant. The lowest prices were for Northern White sand, but some regional sands were priced low as well. Frac-sand mining operations bankruptcies and closures climbed in 2020. Vista Proppants and Logistics LLC filed Chapter 11, Emerge Energy (Superior Sand) was purchased out of bankruptcy by an investment group through a Chapter 7 process. Others were liquidating assets of some of their plants while others idled operations and still others were trying to venture into other industrial-sand products to keep their businesses afloat. Some Northern White sand operations will remain open on a limited basis to provide sand to the Bakken and Niobrara Basins.

Many of the same issues which face the industrial-minerals mining industry are faced by the frac-sand mining operations such as environmental permitting, noise, dust, endangered or threatened species, and truck traffic, to name a few. One of the biggest issues is respirable crystalline silica or silica dust which becomes airborne during mining operations. Mining and processing personnel are constantly exposed. The industry mitigates such exposure by wet suppression, employee monitoring programs and in some cases protective clothing.

The outlook for frac sand seems relatively good as crude oil prices increase during 2021. Increasing crude prices generally means more drilling in the Permian, Eagle Ford, Bakken and other basins. In addition, many DUCs will need to be fracked, increasing frac sand demand. *World Oil* magazine reported that it polled 100 oil producers that said $52-a-barrel crude is needed for a new well to be profitable. As of this writing (5-27-21), WTI was $66.86 a barrel. ■

INDUSTRIAL DIAMOND

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

During 2020 world production of natural and synthetic industrial diamond was estimated by the U.S. Geological Survey (USGS) to be about 14.6 billion carats, 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. At least 15 countries have the technology to produce synthetic diamond, and synthetic industrial diamond was produced in 11 countries during 2020. About 99 percent of the combined natural and synthetic global output was produced in China, Ireland, Russia, South Africa and the United States. During 2020, China was the world's leading producer of synthetic industrial diamond followed by the United States and Russia. In 2020, the two U.S. synthetic producers, one in Pennsylvania and another with facilities in Florida and Ohio, had an output estimated by the USGS to be 112 million carats, valued at about $43.6 million. This production was entirely synthetic diamond bort, dust and powder, and grit. Also, in 2020, 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 USGS estimated a total of 35.1 million carats of used industrial diamond, valued at about $5.66 million, was recycled in the United States during 2020. This was an estimated 35 million carats of recycled diamond bort, dust and powder, and grit with a value of about $5.5 million combined with an estimated 98,000 carats of recycled diamond stone with a value of $150,000. Lower prices of newly produced industrial diamond appear to be reducing the number and scale of diamond stone recycling operations. 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, CVD diamond technology has seen strong growth. The global market value of industrial diamond and diamond films and coatings was estimated to have been more than $1 billion in 2020. Early applications for CVD diamond focused largely around thin- and thick-film PCD for cutting tools and dressing applications owing to the mechanical properties of diamond. Newer applications that use CVD diamond's mechanical properties include wear parts, such as watch gears and chemical mechanical polishing pad conditioners. CVD diamond is being used in microelectronic components, such as high-speed processors, medical devices, wide-bandgap radio frequency and power conversion devices, and optoelectronic devices (light-emitting diodes, laser diodes) that generate exceptionally high heat densities, which require innovative approaches to thermal management. 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. 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. This has led many industries to revisit development activities and actively pursue the use of CVD diamond for a growing number of applications. At least one U.S. company was developing projects in 2020 using single-crystal CVD diamond materials in high-voltage power switches, lasers, quantum communications and computing, and water treatment and purification.

Consumption

The United States remained one of the world's leading consumers of industrial diamond in 2020. Estimated U.S. apparent consumption of natural and synthetic industrial diamond bort, dust and powder, grit, and stones was 246 million carats, valued at $38 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 2020, about 99 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 2020, the average unit value for diamond bort, dust and powder, and grit material was $0.39 per carat. During 2020, U.S. imports of all types of industrial diamond had an average unit value of $0.20 per carat. These imports were a combination of natural and synthetic diamond stone that had an average unit value of $8.52 per carat and natural and synthetic diamond synthetic diamond bort, dust and powder, and grit that had an average unit value of $0.18 per carat.

Foreign trade

During 2020, the United States led the world in industrial diamond trade. Trade data in this report are from the U.S. Census Bureau and were adjusted by the USGS. U.S. imports of industrial-quality diamond stones (natural and synthetic) were about 499,000 carats valued at about $4.25 million. U.S. imports of industrial-quality diamond dust, grit and powder (natural and synthetic) were about 190 million carats valued at about $34.5 million. During 2020, the U.S. exports of industrial diamond stones (natural and synthetic) were about 20,500 carats valued at $41,600. U.S. exports of industrial diamond dust, grit and powder (natural and synthetic) were about 90.7 million carats valued at $49.7 million.

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.

Global natural industrial diamond production decreased slightly during 2020. This decrease was due to mine closures and lower output as mines approach the ends of their mine life. 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.

Although the world remains in a pandemic that has affected the production of some industrial commodities, the production and consumption of industrial diamond does not seem to have been negatively affected. Because the resolution of the pandemic remains uncertain, it is possible that the economies of the United States and the world as a whole could continue to be negatively impacted, which could influence the performance of the industrial diamond industry. ■

INDUSTRIAL GARNET

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

Although garnet has been a popular gemstone since the Bronze Age, its angular fractures, relatively high hardness and specific gravity, chemical inertness and nontoxicity make nongemstone-grade garnet ideal for many industrial applications. In addition, it 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, and lower-quality garnet is used as a filtration medium because 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 2020, U.S. production of crude garnet concentrate for industrial use (industrial garnet) was estimated by the U.S. Geological Survey (USGS) to be 110 kt valued at about $23 million, a 6 percent increase in quantity compared with 2019 crude production. This increase was owing to higher production at a mine in Montana, although all other U.S. garnet mines produced less compared with 2019. In 2020, industrial garnet was mined by four firms in Idaho, Montana and New York. 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 150 kt valued at $65 million, a slight increase in quantity compared with 2019 refined production.

Total world industrial garnet production was estimated to be about 1.1 Mt, slightly less than that in 2019. Australia (360 kt) and China (310 kt) were the leading producers in 2020. World production of industrial garnet decreased in 2020 owing to decreased production in South Africa. The United States produced about 10 percent of the industrial garnet mined worldwide.

Consumption

In 2020, apparent consumption of industrial garnet in the United States was estimated to be 204 kt, accounting for 19 percent of global garnet production. U.S. apparent consumption decreased by 32 percent compared with 2019 owing to a large decrease in imports of crude garnet from South Africa.

The major end uses for industrial garnet in the United States are, in descending order by estimated market share, 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 2020, estimated domestic values of industrial garnet crude concentrate averaged about $210/t. The average unit values of refined garnet sold in the United States during the year averaged $433/t. The average customs unit value of U.S. garnet imports in 2020 was $250/t, an increase of 17 percent compared with the average unit value in 2019.

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 that time, despite increasing domestic production in recent years, the United

States has become increasingly dependent on foreign sources of industrial garnet to meet its needs.

According to data from the U.S. Census Bureau that were adjusted by the USGS, U.S. imports in 2020 were estimated to be 114 kt, a decrease of 45 percent from 2019. Most of the decrease was attributed to a lack of imports of garnet from South Africa, because the Pennsylvania processing facility reached its storage capacity. Exports were estimated to be 20 kt, an increase of 60 percent compared with 2019. In 2020, Australia (32.5 percent), India (23.4 percent), South Africa (23.1 percent), and China (14.3 percent), combined, supplied the majority of U.S. industrial garnet imports, with the remainder coming from several other countries. U.S. exports of industrial garnet were shipped to Canada (54.3 percent), Mexico (19.7 percent), China (5.5 percent), and Trinidad and Tobago (3.2 percent), with the remainder going to several other countries.

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. Worldwide industrial garnet production is expected to slowly increase, with the highest growth in consumption in water-jet-assisted cutting and abrasive blasting.

The world remains in a pandemic that has affected the production of some industrial commodities, and the consumption of industrial garnet may have been negatively affected. Because the resolution of the pandemic remains uncertain, it is possible that the economies of the United States and the world as a whole could continue to be negatively affected, which could influence the performance of the industrial garnet industry. ■

IODINE

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

In 2020, iodine was produced from brines in the United States by three companies operating in Oklahoma. U.S. iodine production in 2020 was withheld to avoid disclosing company proprietary data. As in recent years, Chile was the world's leading producer of iodine, followed by Japan and the United States. World production of iodine in 2020, excluding the United States, was estimated to be about 30 kt compared with 30.1 kt in 2019. Excluding the United States, Chile accounted for about 67 percent and Japan accounted for about 30 percent of world production in 2020.

Consumption

Globally, 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 of iodine 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 2020. U.S. consumption of iodine in 2020 was estimated to be about 4 kt.

Foreign trade

In 2020, U.S. imports of crude iodine were 4.57 kt, a 6 percent increase from the 4.3 kt imported in 2019. The average unit value of crude iodine imports in 2020 was $31.57/kg compared with $26.38/kg in 2019. Chile was the leading source of crude iodine imports into the United States, accounting for 91 percent of the total quantity imported. Exports of crude iodine decreased by 8 percent to 1.13 kt compared with 1.23 kt in 2019. The primary recipients of U.S. exported crude iodine in 2020 were Germany (28 percent), India (27 percent), Canada (15 percent) and the Netherlands (14 percent). The average unit value of exported crude iodine in 2020 was $24.55/kg compared with $23.34/kg in 2019.

Industry news

Owing to the COVID-19 pandemic, global demand for iodine and iodine compounds decreased in 2020. Future growth in iodine consumption will likely be dependent on the recovery of the global economy, in particular, the market demand for medical applications and LCDs as these are the primary consuming markets of iodine and iodine derivatives. ■

KAOLIN

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

According to U.S. Geological Survey publications, in 2020 U.S. kaolin production (the quantity sold or used by producers) was estimated to have decreased by 9 percent to 4.6 Mt compared with 5.06 Mt in 2019. Georgia continued to be the leading producing state with an estimated 92 percent of U.S. kaolin output, followed by South Carolina with 7 percent. Other producing states included Alabama, California, Florida and Nevada. About 52 percent of all kaolin sold was water washed, followed by calcined (17 percent), airfloat (16 percent), delaminated (12 percent) and unprocessed (3 percent). Production data were estimated based on current and previous producer reports as well as employment hours published by the U.S. Mine Safety and Health Administration.

World production of kaolin was an estimated 44 Mt in 2020, virtually unchanged from 2019. Germany was estimated to lead in the production of refined kaolin followed, in descending order, by China, the United States, Uzbekistan, India and Czechia.

Consumption

In recent years, the estimated leading domestic markets for kaolin remained unchanged and were, in descending order of tonnage, paper coating (31 percent); refractories (14 percent); miscellaneous ceramics (14 percent); paint (8 percent); and catalysts, rubber and miscellaneous fillers, extenders and binders (each with 6 percent). Smaller but significant domestic markets were adhesives, chemical manufacturing, floor and wall tile, heavy-clay products (brick and portland cement), plastics and sanitaryware. Paper coating and filling remain the leading export markets for kaolin.

Prices

In 2020, the average unit value of kaolin was estimated to have decreased slightly to \$160/t, compared with \$162/t in 2019. The average unit value of kaolin varied based on individual kaolin types from an estimated \$35/t for unprocessed clay to \$197/t for water washed clay. Georgia kaolin was estimated to have an average unit value of \$169/t. The average unit value of imported kaolin was \$131/t, a 5 percent increase compared with \$125/t in 2019, and the average unit value of exported kaolin was \$250/t, a 3 percent increase from \$242/t in 2019.

Foreign trade

According to the U.S. Census Bureau, kaolin exports decreased to 1.98 Mt valued at \$495 million in 2020 compared with 2.28 Mt valued at \$552 million in 2019. Exports of kaolin in 2020 were primarily shipped to China (18 percent), Mexico (18 percent), Japan (11 percent), Canada (7 percent) and Finland (6 percent). Kaolin imports decreased to 221 kt valued at \$28.9 million in 2020 compared with 321 kt valued at \$40 million in 2019. Most kaolin imported into the United States originated in Brazil (93 percent), followed by United Kingdom (4 percent) and Germany (1 percent).

Outlook

Based on usage trends, domestic production of kaolin is expected to remain unchanged or decrease slightly. The use of kaolin in the paper market has continued to decline as information exchange continues to shift away from paper to electronically delivered methods. Producers will continue investigating cost-effective and innovative applications for kaolin to offset the declining paper market and meet the needs of their customers. ■

KYANITE, ANDALUSITE AND SILLIMANITE

by Kenneth C. Curry, National Minerals Information Center, U.S. Geological Survey

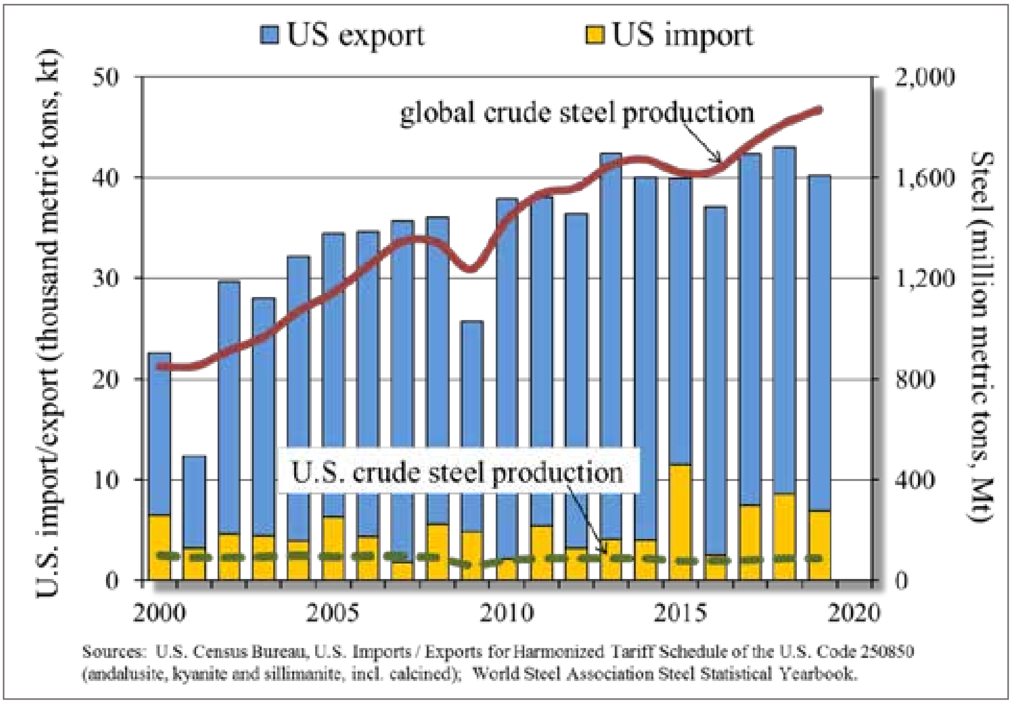
Kyanite, andalusite and sillimanite are naturally occurring polymorphic minerals, collectively known as the sillimanite minerals group, with the chemical composition $Al_2Si_2O_5$. These occur as accessory minerals in metamorphic rocks derived from aluminous protoliths, typically making up a small fraction of the mineral composition of pelitic gneisses and schists. Economic deposits occur in several forms, as semi-massive segregations with quartz in metamorphosed aluminous sediments, as stratiform replacement deposits often associated with hydrothermally altered metavolcanic strata, as disseminated minerals in contact metamorphic aureoles, in mineralized quartz veins and pegmatites and in heavy mineral placer deposits. In the United States, economic and sub-economic concentrations of sillimanite minerals occur in the Appalachian regions of Alabama, Georgia, North Carolina, South Carolina and Virginia. Other known geologic occurrences are in Alaska, California, Florida, Idaho, Nevada and New Mexico. Outside of the United States, known economic deposits are located in Australia, Brazil, Cameroon, Canada, China, Finland, France, India, Iran, Kenya, Madagascar, Nepal, Norway, Peru, Russia, South Africa, Spain, Ukraine and Zimbabwe.

Physical properties and industrial uses

The sillimanite minerals have a relatively high alumina content, 62.9 percent Al_2O_3, which together with their unique crystal structures and chemical stabilities at high temperatures make them suitable for a range of industrial refractory applications. In the high-temperature metallurgical, glass manufacture and ceramics industries, sillimanite minerals provide volumetric stability, resistance to thermal shock, low thermal conductivity, electrical insulation and resistance to chemical corrosion. Thermal treatment (calcination) of the sillimanite minerals results in the production of the synthetic mineral mullite, $Al_6Si_2O_{13}$, a closely related aluminum silicate that occurs only rarely in nature with no known commercial deposits. The conversion to mullite with silica admixtures occurs at decomposition temperatures ranging from about 1,250 °C for kyanite, 1,450 °C for andalusite, and 1,650 °C for sillimanite. Below these temperatures of decomposition, the minerals have relatively low coefficients of thermal expansion. Thermal conversion to mullite results in irreversible volumetric expansion that is dependent on the polymorphic form and initial particle size. In the case of calcined kyanite, very fine particles (passing 325-mesh, 0.044 mm) will increase volumetrically by about 1-2 percent in the resulting mullite, and 8-9 percent for coarser particle fractions (35-mesh, 0.5 mm). Calcined andalusite and sillimanite expand in volume by about 5-7 percent and 4 percent, respectively. Synthetic mullite is highly valued as a refractory material due to the high alumina content of over 70 percent Al_2O_3, high thermal resistance (melting temperature at 1,840 °C), and crystalline morphology characterized by inter-locking forms with high aspect ratio that enhances the mechanical strength of ceramic products.

Figure 1

Sillimanite minerals foreign trade and steel production.



Sources: U.S. Census Bureau, U.S. Imports / Exports for Harmonized Tariff Schedule of the U.S. Code 250850 (andalusite, kyanite and sillimanite, incl. calcined); World Steel Association Steel Statistical Yearbook.

Iron and steel manufacturing industries consume as much as 70 percent of the annual global supply of sillimanite minerals produced by mining operations. The minerals are used in refractory firebrick, insulating brick, furnace and ladle lining materials, castables, mortar and other high-performance heat- and corrosion-resistant products. Industrial ceramics and glass manufacture consume most of the remaining 30 percent of the annual global supply. In these industries, sillimanite minerals are used in monolithics, kiln furniture, investment casting, porcelain and sanitary ware. Other products include refractory additives and fillers, electrical insulators, ceramic tiles, brake shoes, and spark plugs.

Global mineral sources

The global supply of sillimanite minerals comes mainly from longstanding mining operations located in France, India, Peru, South Africa and the United States. Other sources of these minerals are known in China, Madagascar, Nepal and Russia, although very little information is readily available regarding annual production tonnages, mine capacities, and the grades of mineral products. Over the past decade (2010-2019), the total reported annual production quantities from the established mining areas have averaged about 390 kt. In 2020, global production was likely lower due to the impacts of industry lockdowns to mitigate the spread of COVID-19. The U.S. Geological Survey (USGS) reported preliminary estimates for 2020 that included 180 kt of andalusite from South Africa, 85 kt of kyanite and calcined kyanite from the United States, 69 kt of combined sillimanite and kyanite from India, and 37 kt of andalusite from Peru (Hatfield, 2021).

In the United States, Kyanite Mining Corp. (KMC) is the world's largest producer of industrial-grade kyanite and calcined kyanite marketed under the trademark names Virginia Kyanite and Virginia Mullite, respectively. The company has been in continuous operation since 1945, producing kyanite products from surface mines and processing facilities in central Virginia. KMC reported production of about 74 kt of combined kyanite and calcined kyanite during 2020, down from 101 kt (revised) reported in 2019. Ores extracted at the Willis Mountain and East Ridge quarries, near Dillwyn, consist of kyanite-quartzite rocks associated with a sequence of interlayered metamorphosed felsic and mafic volcanic strata of Ordovician age. Ore-grade material contains 10 to 40 percent kyanite, averaging about 25 percent. The quarries, located about 1.25 miles apart east to west, are situated on opposing limbs of the Whispering Creek Anticline, where the kyanite-quartzite host rocks stand out as resistant topographic ridges. The annual production capacity at the Virginia operations is about 130 kt for commercial-grade kyanite concentrates. The company markets a range of milled kyanite and calcined kyanite (>55 percent Al_2O_3, <0.85 percent Fe_2O_3) products that are shipped mainly by truck to domestic customers and port facilities for delivery to international customers.

Resco Products Inc. (Piedmont Minerals Division) mines massive pyrophyllite ($AlSi_2O_5(OH)$) containing 15 to 20 percent disseminated andalusite from surface operations located in Hillsborough, NC. The company has been in continuous operation since

1958. The mineralized zones formed in structurally controlled, hydrothermally altered andesitic to dacitic metavolcanic rocks that are part of the Proterozoic-age Carolina terrane. The company produces high-purity alumina and silica mixes used in a wide range of castable refractory formulations, high-alumina brick and specialty mineral products serving the foundry and ceramic industries.

Imerys Group, headquartered in Paris, France is the world's leading producer of industrial andalusite-based products for the refractory industries. In 2020, the High Temperature Materials and Solutions business segment reported andalusite production from mines located in France and South Africa. The Kerphalite Mine located just southwest of Glomel, France has been in operation since the 1960s and recovers andalusite from deeply weathered Ordovician-age schists proximal to granitic rocks of the Armorican Massif. Imerys markets andalusite products under the trademarked name Kerphalite KF for use as specialty foundry sand in moulding processes, ceramics, and other refractory applications. In South Africa, Imerys' operations include the Annesley Mine in Mpumalanga Province, and the Rhino Mine in Limpopo Province. These deposits occur in highly weathered pelitic rocks of the Pretoria Group within the contact metamorphic aureole of the Bushveld Igneous Complex. Imerys markets a range of size-classified products under the trademarked names Durandal, Randalusite and Purusite.

Near the community of Thabazimbi in Limpopo Province, South Africa, andalusite ore is mined at the Maroeloesfontein Mine. Andalusite Resources (Pty) Ltd. initiated mining operations in 2001, producing milled and run-of-mine products from this deposit located about 13 km southwest of Imerys's Rhino Mine. In past reports, the annual production capacity was stated to be in excess of 70 kt, with reserves amounting to about 100 years of mining at that annual rate. Following a period of intermittent operations in 2019-2020 due to financial distress, the company developed a business rescue plan in accordance with procedures of the S.A. Companies and Intellectual Property Commission. Mine operations are expected to resume in 2021, potentially under a new owner, as the company emerges from business rescue.

In northern Peru, Andalucita S.A. recovers andalusite from alluvial sediments in surface mining operations near the port of Paita. The company markets products ranging from fine (0-1 mm) premium grade andalusite (58.5 percent Al_2O_3, <0.75 percent Fe_2O_3) to coarse (3-6 mm) premium grade (58 percent Al_2O_3, <1 percent Fe_2O_3) in 25-kg bags up to bulk quantities. The company reports annual production capacity at about 60 kt, with mineral reserves that will extend for decades.

India is the world's leading producing country of industrial sillimanite for the high alumina refractory industries. Most of the production comes from the state of Andhra Pradesh, where Trimex Sands Pty. Ltd. has capacity to recover about 50 kt/a of sillimanite. The mineral is part of the heavy mineral composition of beach sand deposits located on the coastline east of Srikakulam that also includes ilmenite, rutile, zircon and garnet. Official production statistics for 2020 are not presently available, but for 2019, the Indian Bureau of Mines reported 69 kt of sillimanite produced in the country. This was about 15 percent less than the prior year. Estimated geologic resources of sillimanite are more than 70 Gt, with the majority of this classified as granular high-grade sillimanite in heavy mineral enriched beach sand deposits. The U.S. Bureau of Mines also estimated about 105 Mt of kyanite resources in the country, of which less than 2 percent is classified as medium to high grade.

In China, Xinjiang Xinrong Yilong Andalusite Company Ltd. extracts andalusite ore from surface mining operations in the Tianshan Mountains area near Korla, Xinjiang Province. The company indicates andalusite reserves of about 213 Mt in the deposit. Annual production capacity is stated to be 40 kt, and the available product grades are presently 56 and 57 percent Al_2O_3 in a range of particle sizes. The company was founded in 2003 and briefly operated as a subsidiary of Imerys until 2018.

Foreign trade and prices

Sales prices for imported and exported minerals vary depending upon many factors including quantity, grade and purity, particle (mesh) size, packaging, monetary exchange rates, source and destination. The U.S. Census Bureau reported exports of about 37 kt of domestic sillimanite minerals in 2020, mainly kyanite concentrates, with an average value of about $369/t, about a 3 percent increase from the previous year. The United States also exported about 17 kt of mullite, including calcined kyanite, with an average value of about $432/t. Imports of sillimanite minerals to the United States during 2020 were less than 1 kt, which was down substantially from the previous five years in which the average was about 7 kt imported per year. Regarding sillimanite, India reported exports of sillimanite mineral concentrates (56-60 percent Al_2O_3) in 2018-19 with an average value of about $151/t.

Trends and outlook

Global crude steel production remains a reliable indicator of the demand for refractories and the sillimanite minerals used in their manufacture. Annual exports of sillimanite minerals from the United States since 2000 show a close correlation with annual steel output (Fig. 1), which was down nearly 1 percent in 2020 compared to 2019. The World Steel Association reported global steel production was 1,864 Mt in 2020, compared to 1,880 Mt in 2019. Production in Asia increased 1.5 percent compared to 2019, with China's share of the global output at 1,053 Mt, or about 57 percent. Countries within the EU reported 138.8 Mt, about 12 percent less production than in 2019. Steel production in North America was also down almost 16 percent from 2019. The United States reported 72.7 Mt of crude steel, a decrease of about 17 percent compared to 2019.

The impacts of COVID-19 on the sillimanite minerals producing industries in 2020 were significant but will hopefully be short-lived. Forecasts of the global demand for steel are very positive, with growth expected to be about 5.8 percent in 2021 and 2.7 percent in 2022. This assumes that the worst stages of the pandemic are over and there will be a gradual return to normal industrial operations, construction activities and investor and consumer confidence. The production of sillimanite mineral products remains a critical link in the industrial refractories supply chain.

References are available upon request. ■

LIME

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

In 2020, 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 83 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 2020, an estimated 16 Mt of quicklime and hydrate was produced (excluding independent commercial hydrators), which was estimated to have decreased by 5 percent from 2019. 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 74 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 2020, the five leading U.S. lime companies produced quicklime or hydrate in 22 states and accounted for about 72 percent of total U.S. lime production. Principal producing states were, in alphabetical order, Alabama, Kentucky, Missouri, Ohio and Texas. The United States was the world's second-ranked lime producer in the world after China.

Apparent consumption at 16 Mt was estimated to have decreased by 5 percent from 2019. 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 mining.

Foreign trade

Imports of lime decreased by 10 percent to 308 kt in 2020 from 342 kt in 2019. Canada (90 percent) and Mexico (6 percent) were the leading sources of U.S. lime imports. U.S. lime exports decreased by 23 percent to 266 kt in 2020 from 347 kt in 2019. Lime exports were primarily shipped to Canada (98 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 $128/t and hydrate sold or used was $154/t in 2020, which were about the same in 2019.

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 2020, 20 percent of domestic utility-scale electricity generation was from coal.

In March 2020, some U.S. lime plants were temporarily closed as a result of the COVID-19 pandemic. The lime industry was later identified as an essential industry because it is used in a variety of products including steel and other metal products, which were recognized by the U.S. Department of Homeland Security as part of the critical manufacturing sector. The critical manufacturing sector was not directly affected by the COVID-19 pandemic restrictions issued in March 2020, but some industries may have seen decreased demand as a result of the COVID-19 pandemic.

References are available upon request. ■

MAGNESIUM COMPOUNDS

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

In 2020, the estimated domestic production of magnesium compounds was 318 kt magnesium oxide equivalent, 7 percent less than in 2019. Seawater and natural brines accounted for about 70 percent of U.S. magnesium compound production in 2020. The value of U.S. production of all types of magnesium compounds was estimated to be $360 million. In 2020, world mine production of magnesite, excluding U.S. production, was estimated to be 26 Mt magnesium oxide equivalent, 4 percent less than in 2019. China was the world's leading producer of magnesite, accounting for 69 percent of the estimated world total, followed by Brazil and Russia with 6 percent each.

Magnesium oxide and other compounds were recovered from seawater by one company in California and another company in Delaware, from well brines by one company in Michigan, and from lake brines by two companies in Utah. Magnesite was mined by one company in Nevada. One company in Washington processed olivine that was mined previously for use as foundry sand.

Consumption and end uses

In 2020, the estimated apparent consumption of magnesium compounds in the United States was 690 kt, 11 percent less than in 2019. About 67 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 33 percent was used for refractories in the form of dead-burned magnesia, fused magnesia, and olivine.

Dead-burned magnesia and fused magnesia

Dead-burned magnesia was produced by Martin Marietta Specialties LLC from well brine and dolomitic lime at a plant in Manistee, MI. Refractory products were the main use of dead-burned magnesia and fused magnesia; however, fused magnesia has not been produced in the United States since 2013. The steel industry was the leading consumer of dead-burned and fused magnesia, and lesser amounts were consumed by the cement, glass and nonferrous metals industries. Dead-burned magnesia and fused magnesia have the same harmonized tariff system code so distinguishing trade trends for both materials by analyzing trade data is impracticable. Imports of dead-burned and fused magnesia in 2020 were 147 kt, 33 percent less than 2019. The leading source was China, accounting for 62 percent of imports, followed by Brazil, accounting for 27 percent. The annual average import unit value for dead-burned and fused magnesia was $580/t in 2020, 25 percent less than in 2019. Exports of dead-burned and fused magnesia in 2020 were 7,638 t, 83 percent less than in 2019. The leading destination was Taiwan, receiving 18 percent of exports; followed by Canada, 15 percent; the United Arab Emirates, 13 percent; China, 12 percent; and France, 11 percent. The annual average export unit value (free alongside ship [f.a.s.]) for dead-burned and fused magnesia in 2020 was $1,221/t, 46 percent more than in 2019.

Although more expensive than dead-burned magnesia, many consumers have switched to using fused magnesia because it has a more prolonged use period and needs to be replaced less often compared with dead-burned magnesia, reducing time for maintenance. This trend is expected to continue, which may result in reduced imports of dead-burned magnesia in favor of fused magnesia over the long term.

Caustic-calcined magnesia

Caustic-calcined magnesia was produced by Premier Magnesia LLC from magnesite mined at Gabbs, NV, and Martin Marietta Magnesia Specialties LLC produced caustic-calcined magnesia from well brine and dolomitic lime in Manistee, MI. Agricultural uses such as in feed supplements and for fertilizer, and environmental applications, mainly for wastewater treatment, were the leading end markets for caustic-calcined magnesia. Other uses included specialty cements, magnesium-based chemicals, and as fillers in plastics and rubber. Imports of caustic-calcined magnesia in 2020 were 170 kt, essentially unchanged from 2019. The leading source was China, accounting for 66 percent of imports, followed by Canada, 19 percent. The annual average import unit value for caustic-calcined magnesia in 2020 was $291/t, 17 percent less than 2019. Exports of caustic-calcined magnesia in 2020 were 26,038 t, nearly six times more than in 2019. The leading destination was Mauritius, receiving 79 percent of exports; followed by Germany, 5 percent, and France, 4 percent. The annual average export unit value (f.a.s.) for caustic-calcined magnesia in 2020 was $986/t, 18 percent more than in 2019. Consumption of caustic-calcined magnesia was expected to continue to increase as its use in agricultural markets increases.

Magnesium hydroxide

Magnesium hydroxide was produced by several companies including Martin Marietta Magnesia Specialties LLC, SPI Pharma Inc. and the Dallas Group of America Inc. Water treatment was the leading use of magnesium hydroxide. Other uses included magnesium-based chemicals, flame retardants, flue-gas treatment, paper production and pharmaceuticals. Imports of magnesium hydroxide in 2020 were 10,600 t, a slight increase from 2019. The leading source was Mexico, accounting for 54 percent of imports, followed by the Netherlands, 15 percent, and Israel, 13 percent. The annual average import unit value for magnesium hydroxide in 2020 was $1,728/t, 5 percent more than in 2019. Exports of magnesium hydroxide in 2020 were 16,238 t, 3 percent less than in 2019. Canada was the leading destination, receiving 59 percent of exports, followed by Sweden, receiving 23 percent. The annual average export unit value (f.a.s.) for magnesium hydroxide in 2020 was $970/t, essentially unchanged from 2019. Consumption of magnesium hydroxide was expected to continue to increase, mainly as its use increases in flame retardants, where it substitutes for bromine compounds.

Magnesium chloride

Major domestic producers of magnesium chloride include Compass Minerals International Inc. and Intrepid Potash Inc. Magnesium chloride was primarily used for deicing, dust control, drilling fluids and environmental applications. Imports of magnesium chloride in 2020 were 72,122 t, a 10 percent decrease from 2019. The leading source was Israel, accounting for 54 percent of imports; followed by Netherlands, 17 percent; and the Czech Republic, 11 percent. The annual average import unit value for magnesium chloride in 2020 was $375/t, 5 percent less than in 2019. Exports of magnesium chloride in 2020 were 7,783 t, 4 percent less than in 2019. The leading destination was Canada, receiving 80 percent of exports, followed by Italy, 7 percent. The annual average export unit value (f.a.s.) for magnesium chloride in 2020 was $692/t, 4 percent less than in 2019. Consumption of magnesium chloride for deicing is expected to continue being seasonal. For the remaining uses, consumption of magnesium chloride is expected to be stable.

Industry news and issues

China remains the leading producer of magnesia and magnesite. Policy changes, coupled with the impacts of the global COVID-19 pandemic, have resulted in inconsistent supplies and restricted availability of all grades of magnesia in the world market. Pandemic-related closures of mining and manufacturing activities and reduced demand from downstream industries in early 2020 caused decreased steel production, a major consumer of refractory-grade magnesia.

PRCO America Inc., a refractory products supplier announced plans to open a production facility in Graves County, KY, a $5.5 million investment. The plant will produce custom resin-bonded magnesia graphite refractory brick. It is reported that the raw materials will be sourced primarily from China. PRCO America Inc. is a subsidiary of Puyang Refractories Group Co. Ltd., China.

This year's notable acquisitions include the purchase of Australian magnesia producer Queensland Magnesia by Germany's Refractechnik Group and a 60 percent majority acquisition of the Hazednar Group, a Turkish refractory manufacturer, by French multinational industrial mineral producer and processor, Imerys S.A.

Outlook

Globally, magnesium compounds are used for agricultural, chemical, environmental, pharmaceutical and refractory applications. Demand for magnesium compounds for these uses is expected to continue as major world economies recover from the impact of the COVID-19 pandemic. Emerging and growing nations may drive the consumption of dead-burned and fused magnesia as the demand for steel, cement, nonferrous metals and glass continues to grow in those countries. Products sourced from recycled magnesia may increase due to raw-material restraints, improving recycling technologies, and stricter regulatory environments.

References are available upon request. ■

MICA

by Adam Merrill, 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 2020, U.S. mine production of scrap and flake mica was estimated to have been 35 kt, which was down from 40.1 kt in 2019 (USGS Mineral Commodity Summaries, 2021). Production of ground mica also was estimated to have been lower at 57 kt compared with

61.3 kt in 2019. 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. A small amount of sheet mica was produced as a byproduct of feldspar mining in North Carolina. In 2020, world production of scrap and flake mica was estimated to have decreased to 350 kt from 405 kt in 2019. China (95 kt), Finland (65 kt), the United States (35 kt) and Madagascar (30 kt) were the leading producers. World production of sheet mica was unavailable in 2019, but India (1 kt) was thought to be the leading producer.

Consumption

Domestic consumption of all forms of scrap and flake mica was 50.3 kt, down from 61.3 kt in 2019. Imports, exports and production were all lower in 2020, owing to the effects of the COVID-19 pandemic on industrial sectors that use large quantities of mica. The largest decreases occurred in the use of mica in oil and gas well drilling muds and additives to plastic automobile components, because fuel consumption and automobile sales fell as a result of restrictions put in place to mitigate the effects of the COVID-19 pandemic.

Consumption of sheet mica was estimated to have decreased slightly to 2.32 kt in 2020 from 2.35 kt in 2019.

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 natural-gas and oil 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, lipstick, lip gloss, 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 2020, the average unit value of scrap and flake mica produced in the United States, which included high-quality sericite, was estimated to be $118/t. The average unit value of dry-ground mica was estimated to be $300/t, and the average value of wet-ground mica was estimated to be $430/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 2020 was $1.66/kg.

Foreign trade

In 2020, U.S. imports and exports of scrap and flake mica were 19.4 kt and 4.1 kt, respectively. Imports and exports were significantly affected by reduced demand caused by the effects of COVID-19. Imports of scrap and flake mica decreased by 27 percent and exports decreased by 25 percent, compared with 2019. In 2020, Canada (37 percent), China (37 percent), and India (11 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 Brazil, Canada, Germany and Mexico.

In 2020, U.S. imports and exports of sheet mica were 2.85 t and 527 t, respectively. Imports of sheet mica decreased by 9 percent and exports decreased by 34 percent, compared with 2019. In 2020, China (74 percent), Brazil (9 percent), and Belgium (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 Canada, Germany and Mexico.

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 at about 1 percent per year 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 mica are expected to come increasingly from imports, primarily from Brazil, Canada, China and India.

As the effects of the COVID-19 pandemic diminish, increased manufacturing of automobiles and production of gasoline and other fuels could lead to a rebound in mica consumption. ■

NITROGEN

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

Ammonia was produced domestically by 16 companies at 35 plants in 16 states during 2020. About 70 percent of total U.S. ammonia production capacity was based in Iowa, Louisiana, Oklahoma and Texas because of those states' large reserves of natural gas, the dominant domestic feedstock for ammonia production. Four companies — CF Industries Holdings Inc.; Nutrien Ltd.; Koch Nitrogen Co.; and Dyno Nobel ASA, in descending order by quantity —accounted for about 70 percent of the total U.S. ammonia production capacity.

Production and consumption

U.S. production was estimated to be 14 Mt of nitrogen (N) content in 2020, a 4 percent increase from 2019. In 2020, U.S. producers operated at about 85 percent of their rated capacity (excluding plants that were idle for the entire year). Apparent consumption was estimated to have increased by 3 percent to 16 Mt of N content in 2020 from 15.2 Mt of N content in 2019. 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 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 plastics, synthetic fibers and resins, explosives and numerous other chemical compounds.

Foreign trade

Imports of ammonia (N content) decreased slightly to 1.99 Mt in 2020 from 2.02 Mt in 2019. Trinidad and Tobago (56 percent) and Canada (44 percent) were the leading sources of U.S. ammonia imports. U.S. ammonia exports increased by 9 percent to 369 kt of N content in 2020 from 338 kt of N content in 2019. Ammonia exports were primarily shipped to Mexico (36 percent) and Chile (23 percent).

Prices

U.S. Gulf Coast ammonia prices in 2020 averaged \$213/st, 8 percent lower than the average in 2019. The Gulf Coast ammonia price was \$220/st at the beginning of 2020, decreased to a low of \$186/st in mid-June, and by yearend was \$231/st.

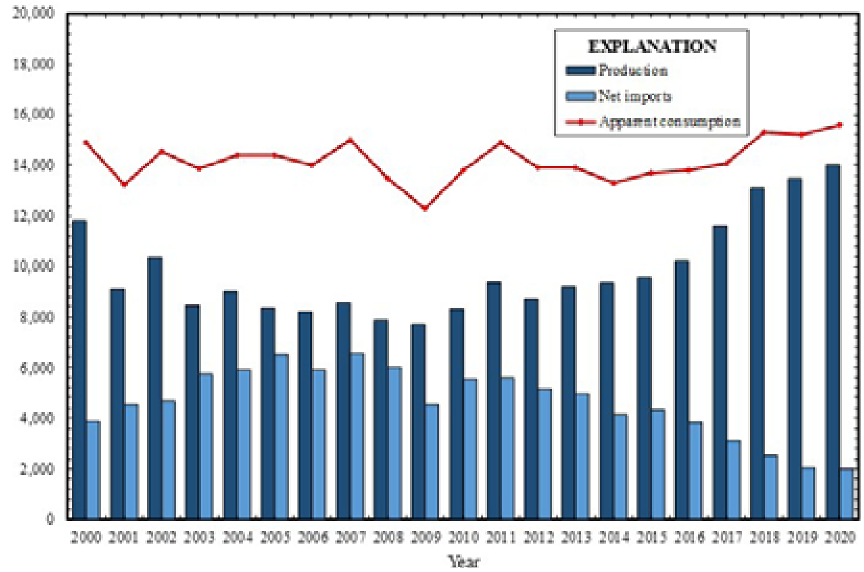
Natural gas is often used as the feedstock to produce ammonia fertilizers, and the cost of natural gas can account for 70 to 90 percent of the production costs. The Henry Hub spot natural-gas price ranged between \$1.34 and \$3.08/million Btu for most of the year, with an average of \$2.03/million Btu. The U.S. Department of Energy, Energy Information Administration projected that Henry Hub natural-gas spot prices would average \$2.95/million Btu in 2021.

Outlook

A long period of stable and low natural-gas prices

Figure 1

U.S. supply and apparent consumption of ammonia, 2000-2020.



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 throughout the past five years; however, no additional ammonia plants are expected to be commissioned before 2022. In addition to North America, capacity additions are expected in Africa and south Asia; however, ongoing plant closures will decrease capacity in East Asia and Latin America. Demand for ammonia is expected to increase in all regions with the largest increases expected in Africa, central Asia and Eastern Europe.

According to 10-year projections (2020-2030) 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 were expected to remain at about 100 Mha. Corn, soybeans and wheat were expected to account for about 90 percent of acreage utilization for the eight major field crops. Corn production accounts for about one-half of U.S. fertilizer use and planting fewer crops affects the demand for nitrogen fertilizers. Overall corn acreage in the United States was 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.

In 2020, the fertilizer industry was considered part of the critical chemical sector by the U.S. Department of Homeland Security. The COVID-19 pandemic "stay at home" orders issued in March 2020 did not apply to the fertilizer industry, and U.S. ammonia plants maintained full operations. In 2021, U.S. ammonia plants are expected to maintain full operations.

References are available upon request. ■

PEAT

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 2020, peat was known to be harvested in 12 conterminous states, with Florida, Michigan and Minnesota being the leading producing states. Although peat has been produced in Alaska, the current status of operations in Alaska is not known because the Alaska Department of Natural Resources, Division of Geological & Geophysical Surveys discontinued its survey of peat producers in Alaska. Reed-sedge comprised approximately 93 percent of the reported peat production in the United States, followed by sphagnum peat, with 3 percent.

Production and foreign trade

In 2020, domestic production of peat, excluding Alaska, was estimated to be 430 kt, compared with 456 kt in 2019 (Fig. 1). In 2020, imports increased by 20 percent to 1,390 kt compared with 1,160 kt in 2019 (Fig. 1), and exports remained unchanged from 46 kt in 2019. U.S. apparent consumption for 2020 increased by 22 percent compared with 2019. World production was estimated to be about 29 Mt in 2020, a decrease of about 9 percent compared with 2019 production.

At least 95 percent of all peat used in the United States was imported from Canada, which has extensive deposits of high-quality sphagnum peat. Deposits of sphagnum peat 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

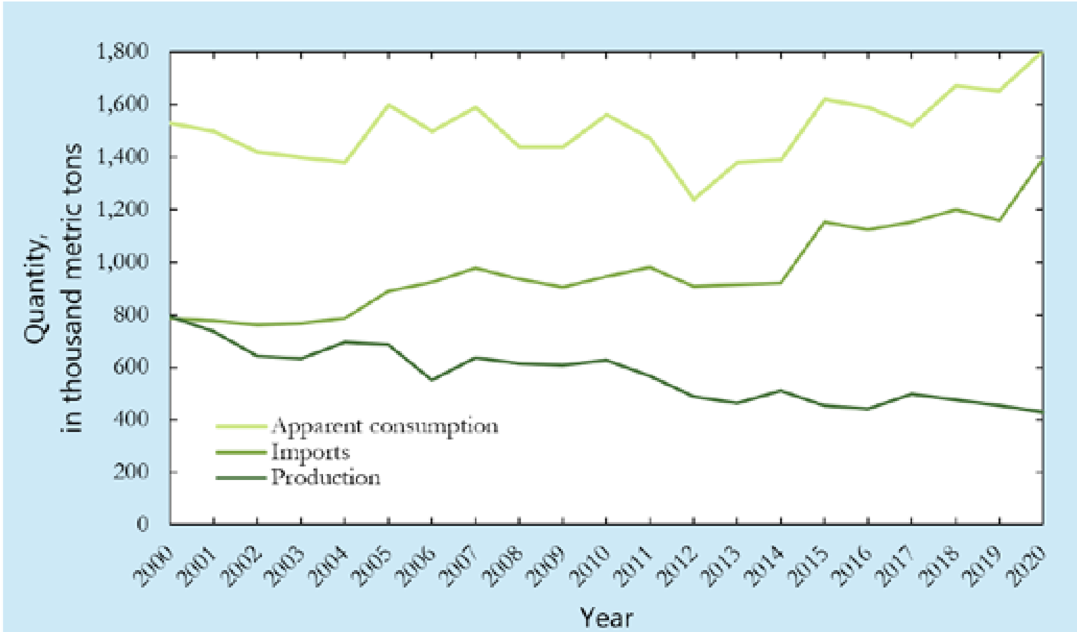
Demand for peat generally follows that of horticultural applications. Potting soil mixes and general soil improvement were the leading domestic end-use categories, accounting for about 90 percent of domestic peat sales. Sphagnum peat is preferred for custom soil mixes and for sale to retail consumers 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

Finland, Germany, Belarus, Sweden and Ireland were the world's top-five leading peat producers, in descending order of production, based on estimated 2020 world production. Climate-change concerns have prompted several countries to plan to decrease or eliminate the use of peat, owing to peatland's ability to act as a carbon sink. Ireland announced in 2019 that it planned to stop all peat harvesting by 2028 and continued such efforts to reduce production throughout 2020. Finland also 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. 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.

Figure 1

U.S. production, imports and apparent consumption of peat, 2000–2020 (Source: A.S. Brioche, Peat: U.S. Geological Survey Mineral Commodity Summaries 2021).



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, U.S. producers 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.

Peatlands have been identified as carbon sinks, storing more carbon per hectare than any other ecosystem. Preservation and restoration of peatlands may become a high priority in the efforts to reduce greenhouse gas emissions, further restricting its availability for commercial use in future years (International Union for Conservation of Nature, 2017). Peat production is expected to decrease across Europe during the coming years as peatland restoration efforts and use of alternative fuel sources increase.

Despite the disruptions from the COVID-19 pandemic, the peat industry was positively impacted by the pandemic as more people started to home garden. The duration and the outcome of the COVID-19 pandemic remains uncertain and the economies of the United States and the world as a whole were negatively affected in 2020. Some recovery is expected in 2021, which could influence the performance of the peat industry.

References are available upon request. ■

PERLITE

by Bowen Li, Michigan Technological University

Perlite is an amorphous volcanic rock that mainly consists of silica with a high content of water molecules. The typical chemical composition of perlite is (wt percent): SiO_2 70-75 percent, Al_2O_3 12-15 percent, Na_2O 3-5 percent, K_2O 3-5 percent, and H_2O 3-5 percent. Once it is quickly heated to high temperatures of about 900 °C (1,700 °F), the crude perlite rock expands like popcorn due to the trapped water being vaporized, which converts perlite into a lightweight and porous product (named expanded perlite).

Crude perlite in the United States

According to the U.S. Geological Survey (USGS), the estimated domestic production of crude perlite in the United States in 2020 was 520 kt, which was a 6-kt or 1.1 percent decrease compared with 2019, and a 3.8 percent increase over 2015 (Fig. 1). The imports of perlite were 190 kt, a 7-kt or 3.8 percent increase compared with 2019, and a 23.4 percent increase from 2015. The majority of the imported crude perlite was from Greece. The exports of perlite slightly increased to 22 kt from 19 kt in 2019. The estimated domestic consumption of crude perlite in 2020 was 610 kt, a 5.2 percent increase from 2019. This represents one of the highest levels of consumption since 2009. Over the past 10 years, the production of crude perlite in the United States showed a gradual and continuous growth, and apparent consumption slightly increased, while the imports and exports kept relatively

Figure 1

U.S. production, trade and apparent consumption of crude perlite.

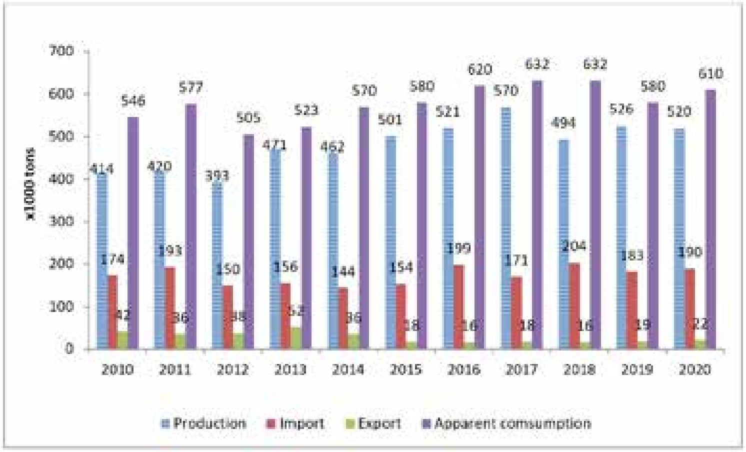


Figure 2

Unit price change of crude perlite in the United States over the past 10 years. Source: USGS Mineral Commodity Summaries; price in 2020 is estimated.

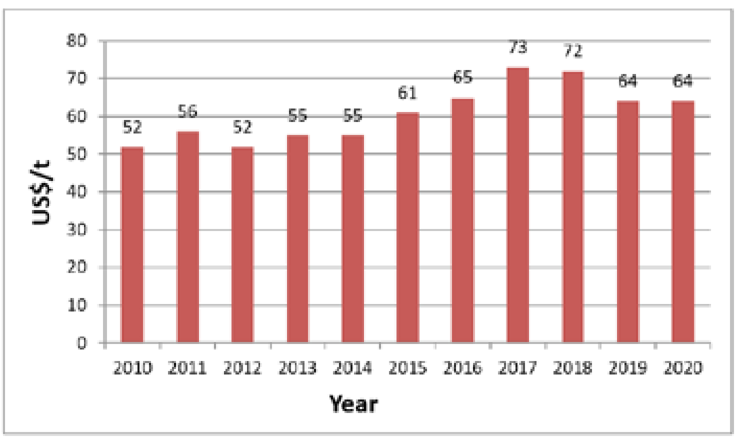


Table 1

Estimated world perlite production in 2019 and 2020 (thousand tons).

	2019	2020	Percent
China	3,270	3,270	61.12
Greece	719	700	13.08
Turkey	650	640	11.96
United States	526	520	9.72
Iran	72	70	1.31
Hungary	71	70	1.31
Slovakia	40	40	0.75
Mexico	20	20	0.37
Other countries	20	20	0.37
World total	5,388	5,350	100.00

stable, as Fig.1 shows.

The major perlite deposits discovered in the United States are mainly distributed in Arizona, Idaho, Nevada, New Mexico and Oregon. In 2020, crude perlite ores were produced from eight mines operated by six companies in five western states. As in 2020, New Mexico and Oregon continued to be the major producing states. The average price for crude perlite ore was estimated to be $64/t in 2020, showing a gradually rising tendency over the last decade. This was a 23.1 percent increase from 2010 (Fig. 2). The annual sales value of domestic crude perlite product in 2020 was estimated at $28 million.

Expanded perlite in the United States

There were 57 plants in 28 states that produced expanded perlite in the United States in 2020, one additional plant over 2019.

Many commercial applications of perlite have been developed in past decades. The major applications of perlite are in its expanded form. The application markets in the United States were still in building construction (such as insulation, lightweight plasters, aggregates and ceiling tiles) as it is lightweight and fire retardant, which accounted for 53 percent of the total consumption. Other applications include fillers (16 percent), horticulture (16 percent), filter aids (12 percent), and 3 percent for miscellaneous uses, such as soil amendment, foundry, bioremediation, and explosive additive. Comparing to 2019, the construction industry consumed less expanded perlite, but filter applications increased. Research of expanded perlite in new applications such as anticaking agent, cosmetics, crop protection, photo-catalyst, fungicide, energy arresting materials, perlite-epoxy composite, perlite geopolymer, high-strength proppant ingredient, absorbent and toothpaste fillers has been recently reported.

Overall, though the COVID-19 pandemic has critically wounded the global economy in 2020, the U.S. perlite industry maintained similar production capacity and consumption level in that year comparing to 2019.

Perlite in other countries

The worldwide reserves of perlite are estimated at more than 2 Gt. China owns more than half of the known reserves of crude perlite in the world. According to China Non-Metallic Mineral Industry Association, there were more than 46 deposits of perlite that have been explored in China by 80 mining companies, with an estimated 1.2 Gt of perlite reserves. Other major countries with perlite reserves include Greece (120 Mt), Iran (73 Mt), Turkey (57 Mt), United States (50 Mt), and Hungary (49 Mt). India again reported (2019) 2.41 Mt of perlite reserve, as only one perlite deposit was found in the country. Many other countries including Japan, Russia, Germany, UK, France, Spain, Australia, New Zealand, Indonesia, Malaysia, Brazil, Mexico, Nigeria, Zimbabwe, Thailand and South Africa have reported perlite deposits, but no specific data are available. More perlite deposits will be explored and reported in the near future.

China was the largest producer and consumer of both crude and expanded perlite in the world. Greece and Turkey were the second and third largest producers of crude perlite and expanded perlite in the world. The United States was the fourth largest producer but may be the second largest consumer worldwide. As of 2017, China produced 3.27 Mt of crude perlite, and 100 million m^3 of expanded perlite, of which 90 percent was used as building materials, mainly insulation, and the remaining 10 percent was used for other industries. There have been no new production or consumption data published from China since 2017.

As Table 1 shows, other major countries producing crude and expanded perlite in 2020 include Greece (700 kt), Turkey (640 kt), Iran (70 kt), and Hungary (70 kt). There are no production data from the traditional producers of perlite such as Japan, Italy, Russia, Georgia, Slovakia, Australia, New Zealand, Philippines, Indonesia, South Africa, and Zimbabwe. Since no official data are available from most of the countries, the overall global data are estimated.

Construction and agriculture were among the major application areas of perlite in the world. In the next few years, strong demand in the construction sector will be a major factor driving the market growth of expanded perlite, especially in green roofs and thermal insulation units (such as concrete additives, cement mixture, masonry, boulders and bricks). Water filtration and horticulture will significantly enhance the global market of expanded perlite. According to MarketWatch Inc., the global market size of expanded perlite was valued at $365.9 million in 2020 and will grow with a CAGR of 12.09 percent from 2020 to 2027.

For specific applications, diatomite, pumice, expanded clay and shale, vermiculite can be used to substitute for expanded perlite. ■

PHOSPHATE

by T.M. "Mike" Gurr, P.G., and David M. Gurr, Gurr Professional Services Inc.

2020 crop year. U.S. marketable phosphate rock production for the 2020 crop year (July 1, 2019 to June 30, 2020) showed an increase to 24 Mt from the 2019 crop year production of 23.4 Mt, as reported to the U.S. Department of the Interior by the mining companies operating in the United States during crop year 2020. Domestic consumption decreased in the 2020 crop year to 25.9 Mt, as compared to the 26.5 Mt consumed in crop year 2019. U.S. imports of phosphate rock decreased to 2.2 Mt for the 2020 crop year from the 2.53 Mt for crop year 2019. Imports of phosphate rock were from Peru and Morocco. There was a decrease of 0.5 Mt in producers' stocks from 10.6 Mt in crop year 2019 to 10.1 Mt in crop year 2020 (Table 1).

2020 calendar year. For calendar year 2020, Florida and North Carolina phosphate rock production accounted for 75 percent of the total U.S. production, with the balance being produced in the western states of Idaho and Utah. The Florida and North Carolina percentage of U.S. production is declining. U.S. production of 23.5 Mt in calendar year 2020 was produced by five companies at 10 mines in four states and accounted for approximately 10.54 percent of the world production of 223 Mt for calendar year 2020 (Table 2).

In calendar year 2020, U.S. phosphate production increased slightly by 0.2 Mt; in addition, companies decreased stocks of phosphate rock by 0.44 Mt. The domestic production for calendar year 2020 of 23.5 Mt represents 75 percent of the domestic production capacity of 31.1 Mt.

China has revised the 2019 and 2020 phosphate rock production to only report production from large mines which totals 95 Mt and 90 Mt respectively, as compared to 2019, which previously reported annual production at 140 Mt. Morocco production has increased from 35.5 Mt in 2019 to 37 Mt in calendar year 2020, which is approximately 17 percent of the world's production

Table 1
Phosphate rock production and consumption.

Crop year (July 1-June 30)						
	Production (marketable, beneficiated)				Consumption	
Crop year	Phosphate rock tons²	% BPL	Value (f.o.b. mine)¹	Ending stocks tons²	Tons²	Value¹
2010	26.7	62.5	$64.53	7.57	30.1	$64.78
2011	26.5	63.4	$93.72	5.37	30.6	$92.31
2012	28.8	63.1	$98.36	5.60	31.3	$100.51
2013	31.9	62.6	$99.58	7.14	30.9	$95.51
2014	28.0	62.0	$80.97	7.94	30.4	$80.97
2015	26.1	61.3	$70.09	6.87	28.4	$72.94
2016	26.2	61.3	$81.71	9.34	27.7	$83.78
2017	27.1	61.1	$75.45ᵉ	7.45	27.2	$77.55
2018	25.8	60.8	$74.61	10.30	28.3	$74.30
2019	23.4	61.1	$69.00ᵉ	10.60	26.5	$68.90
2020	24.0	61.1	$70.80	10.10	25.9	$70.00

¹ Price (U.S. dollars per metric ton), ² million metric tons, ᵉ estimated. Source: Stephen M. Jasinski USGS Minerals Industry Surveys, draft crop year 2020.

Table 2

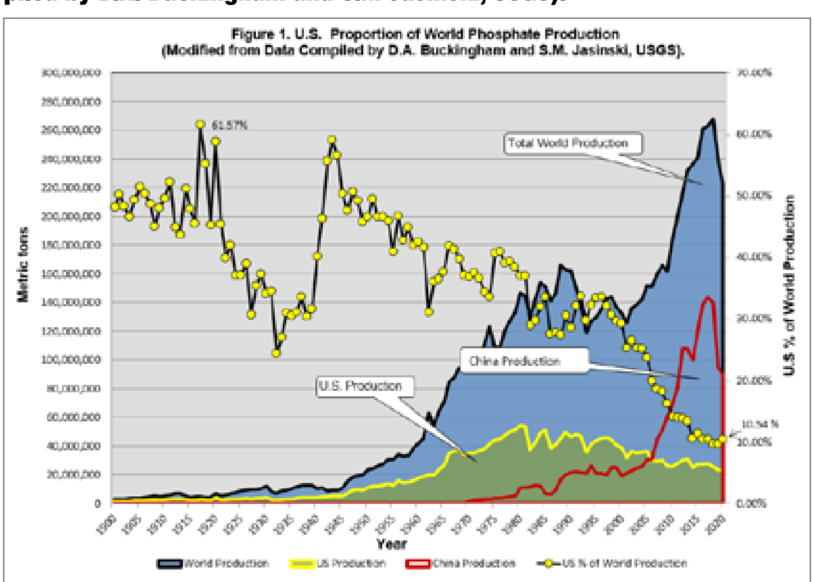
Phosphate production, U.S. position.

Calendar year	World production[1]					
	Tons[1, 2]				U.S. percent	Morocco[3] percent
	World	China	Morocco[3]	United States		
2010	181.0	68.0	25.8	25.8	14.25	14.25
2011	198.0	81.0	28.0	28.1	14.19	14.14
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	25.8	10.36	12.33
2019	227.0	95.0	35.5	23.3	9.70	15.00
2020	223.0	90.0	37.0	23.5	10.54	16.59

[1] Estimate for 2020, [2] million metric tons, [3] includes Western Sahara. Source: Stephen M. Jasinski, USGS Mineral Commodity Summaries, January 2020 pp 123-124, Phosphate Rock and Marketable Phosphate Rock in January 2021.

Figure 1

U.S. proportion of world phosphate production (modified from data compiled by D.A. Buckingham and S.M Jasinski, USGS).



(Table 2). 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 2020; 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 monoammonium phosphate (MAP), diammonium phosphate (DAP) and triple super phosphate (TSP), in preference to phosphate rock. Approximately one-half of the MAP, DAP and TSP produced in calendar year 2020 were exported.

Importation of phosphate rock in calendar 2020 is estimated by the U.S. Geological Survey (USGS) at 2.52 Mt as compared to 2019 imports of 2.15 Mt. Imports were from Morocco (15 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 equivalents

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

Calendar year. The 2020 calendar year average price at the mine was reported at $74.55/Mt , which is 6.5 percent higher than the calendar year 2019 average price of $70/Mt (Table 3). The value of the imported phosphate in calendar year 2020 of $74.60/Mt also increased from $73.55/Mt in the prior calendar year (Table 3).

Morocco. Morocco phosphate rock prices increased from $72.50/Mt in January 2020 to a high in December 2020 of $83.33/Mt.

Fertilizers. DAP spot prices, Tunisian granular, free on board (f.o.b.), increased from $264.9/Mt in January 2020 to $388.50/Mt in December 2020. TSP increased from $239.00/Mt in January 2020 to $320/Mt.

Industry news

There are currently only two phosphate rock producers mining in Florida, one in the Central District (Mosaic) and one in the North District (Nutrien Ltd). There is only one producer in North Carolina, Nutrien Ltd.

In the western states of Idaho and Utah, there are currently three producers, Bayer (which acquired Monsanto), Itafos, a Brazilian operation (which acquired Nutrien), and J. R. Simplot. All producers are developing/permitting replacement mines for mines nearing exhaustion of reserves. The new mines will generally be located near existing facilities.

Late in 2019, prices began to improve and have continued to increase in 2020.

Despite the low prices in the past few years, the world capacity to produce phosphate rock is expected to continue to increase as a result of many other phosphate mine expansion projects. Although slowed by prices in 2018 and 2019, active exploration and feasibility studies of the potential for development of phosphate deposits worldwide are on-going.

Most of the growth in phosphate production since 2000 has principally been in China (Fig. 1 and Table 2). However, in the last two years, the reported production in China includes only the large mines which is 50 Mt/a lower than earlier reported. China has transitioned from the largest importer of phosphate to the largest exporter of phosphate. At the present time, 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 2020 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.

Table 3

Phosphate rock prices[1].

Phosphate use	Calendar year				
	2016	2017	2018	2019	2020
Domestic production (f.o.b. mine)	$76.90	$73.67	$70.77	$70.00	$74.55
Percent change from prior year	6.20%	-4.20%	-3.94%	-1.09%	6.50%
Exports (FOB port)	N/A	N/A	N/A	N/A	N/A
Imports (CFI)	$101.00	$84.00	$77.97	$73.55	$74.60

[1] Price (U.S. dollars per metric ton). Source: USGS Mineral Industry Surveys, Stephen M. Jasinski, Mineral Industry Surveys Marketable Phosphate Rock in December 2020, Table 2, January 2021, Table 3, and 2020 Annual Phosphate Rock pp. 122 and 123.

Environmental, regulatory and reclamation issues

Mosaic has continued to mine the newly permitted 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. In addition, in 2020 Mosaic obtained the state and local permits to mine approximately a 4,000-acre extension to the South Fort Meade Mine in Hardee County referred to as the South Fort Meade-Eastern Reserves. At the present time, 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 Bureau of Land Management (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

The worldwide demand for phosphate fertilizers is expected to increase gradually in proportion to the increase in the world population. U.S. consumption and production of fertilizer increased slightly in 2020 as a result of a slight increase in phosphoric acid and combined DAP and MAP production. The leading plans for growth are reported to be in Africa and the Middle East. The USGS reports that the industry global capacity of phosphate rock mines is predicted to increase to 261 Mt in 2024 from the 233 Mt in 2020. This includes marketable phosphate rock production in China of between 80 Mt and 85 Mt as compared to the official Chinese production reported as 90 Mt to 95 Mt.

Continued depletion of high-yield deposits of phosphate ore in Florida and the environmental restrictions being placed on U.S. facilities will result in stable or declining production capacity from some of the existing and proposed U.S. facilities, which will limit U.S. production. Western phosphate production is increasing. U.S. production is expected to gradually decline as a percentage of total world production as U.S. reserves are depleted and as other countries continue to increase production as a result of the increased global competition in the fertilizer industry. As a result, domestic phosphoric acid production is also expected to slowly decline as a percentage of world production capacity.

Most of the near-term increases in world production are expected to occur in Africa and the Middle East, where expansion and startup projects are ongoing in Algeria, Egypt, Morocco, Saudi Arabia, Senegal, Guinea Bissau and Togo.

References are available upon request. ■

POTASH

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

In 2020, U.S. potash consumption was estimated to have increased slightly to 5,400 kt of K_2O compared with 5,300 kt of K_2O in 2019 (USGS Mineral Commodity Summaries, 2021). U.S. production was estimated to be 470 kt of K_2O, which was 8 percent lower than in 2019. World production was estimated to be 43 Mt of K_2O, which was 4 percent higher than in 2019. Canada (14.0 Mt), Russia (7.6 Mt), Belarus (7.3 Mt), and China (5.0 Mt) were the leading producers, accounting for 79 percent of total production.

COVID-19 did not have a significant effect on the world potash industry, because fertilizers and agriculture were considered essential businesses by most countries. Financial assistance was provided to farmers and agribusinesses in the United States and other countries. Potash consumption in some industrial uses declined, such as oil-well drilling additives, which was lower owing to reduced demand for gasoline and jet fuel.

Production

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•$2MgSO_4$) 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.

In 2020, about 35 percent of U.S. production was in the form of MOP, all of which 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.

Consumption

According to a 2020 report from the International Fertilizer Association, world consumption of all forms of potash in 2020 was 41 Mt of K_2O, the same as in 2019. Asia and South America were the leading consuming regions. World consumption of potash was projected to increase slightly in 2021, with Asia and South America as the leading regions for growth.

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

U.S. imports of potash increased slightly to an estimated 5 Mt of K_2O in 2020, compared with 4.94 Mt of K_2O in 2019. The United States imports around 90 percent of the potash consumed annually. Canada (78 percent), Russia (11 precent) and Belarus (7 precent) were the leading suppliers. The United States is not a significant exporter of potash. SOP and SOPM accounted for 83 percent of U.S. potash exports. In 2020, exports increased slightly to 147 kt of K_2O from 145 kt of K_2O in 2019.

Prices

The Vancouver, British Columbia, Canada spot price for granular potash began the year averaging \$249/t and ended the year at \$225/t. The U.S. price for SOP began 2021 in the range of \$550/st to \$615/st and ended the year in the range of \$550/st to \$585/st. The U.S. price for SOPM, fob Carlsbad, NM, began the year in the range of \$245/st to \$290/st and fluctuated slightly during the year and ended in the same price range as that in January.

Industry developments

Canada is the leading potash-producing country in the world, with 38 percent of global capacity. All production in Canada was from Saskatchewan in 2020. 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 2020 production in Canada was estimated to have increased to 14 Mt K_2O from 12.3 Mt K_2O in 2019.

In Belarus, JSC Belaruskali commenced production of beneficiated potash at its new Petrikov Mine, which started mining operations in late 2019. The company produced about 100 kt of MOP in 2020 and planned to reach full capacity of 1.5 Mt/a by 2023.

In February 2021, Emmerson plc (Isle of Man) received the mining license from the government of Morocco for its Khemisset potash project in northern Morocco. The company planned to begin construction of the mine and associated facilities by the end of 2021, with production starting in late 2023. Emmerson planned to produce an average of 735 kt/a for 19 years in the first phase of the mine.

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 potash capacity is projected to increase to 69 Mt/a in 2024 from 64 Mt/a in 2020. Most of the increase would be MOP from new mines and expansion projects in Belarus, Canada and Russia. Other projects that are ongoing included new MOP mines in Brazil, Congo (Brazzaville), Ethiopia, and Spain; new SOP mines in Australia, China and Eritrea; and a new polyhalite mine in the United Kingdom. The startups of some of the other projects are likely to be delayed to beyond 2025 because of unfavorable economic conditions. ■

PUMICE

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

Mine production of pumice in the United States during 2020 was estimated to be 480 kt (530,000 st), which was 15 percent less than in 2019. The unit value of pumice was estimated to be $28/t ($25/st) in 2020, unchanged from 2019. Since 2016, the average unit value of pumice has ranged from $28/t to $39/t ($25/st to $35/st). Production occurred at 10 operations in California, Idaho, Kansas, New Mexico and Oregon. U.S. pumice exports totaled about 7.9 kt (8,700 st). Imports were higher at 90 kt (99,000 st).

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 21 Mt (23 million st) in 2020. 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 2020 were, in descending order of production, Turkey (7.8 Mt or 8.6 million st); Ethiopia (2.4 Mt or 2.6 million st); and Cameroon, Greece and Uganda (1.0 Mt or 1.1 million st each).

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 (19 miles) 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 (0.20 in.) 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.

Processing and uses

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. Although the generation and disposal of reject fines in mining and milling result in local dust issues at some operations, the environmental impact is restricted to a relatively small geographic area.

Lightweight pumice building blocks, the primary use for pumice, may be sawn into a variety of shapes and sizes. In 2020, 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 (e.g., 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.

The pandemic (COVID-19) affected the production of some industrial commodities, including pumice. Because the resolution of the pandemic has not been completed, it is possible that the economies of the United States and the world as a whole could continue to be negatively affected, which could influence the performance of the pumice industry. ■

RARE EARTHS

by Himesh Patel, McClelland Laboratories Inc.

Rare earth elements (REE, also called rare earth oxides, REO) 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 2020, rare earths were mined in the United States at the Mountain Pass Mine, CA. Bastnaesite was the primary product from the mine which is a Precambrian carbonatite deposit. The trade balance between the United States and the rest of the world in rare earth oxides, compounds and metals stood at $110 million (net imports) in 2020 which is a considerable decrease from $160 million in 2019.

Rare earth elements are used in electric components (electric vehicles, wind turbines, hard disc drives, microphones, etc.), glass, metallurgy and alloys, magnetic materials, and ceramics. Figure 1 shows the estimated distribution of rare earth applications in the United States by different sectors.

Figure 1

Applications of rare earth elements by sector, 2020.

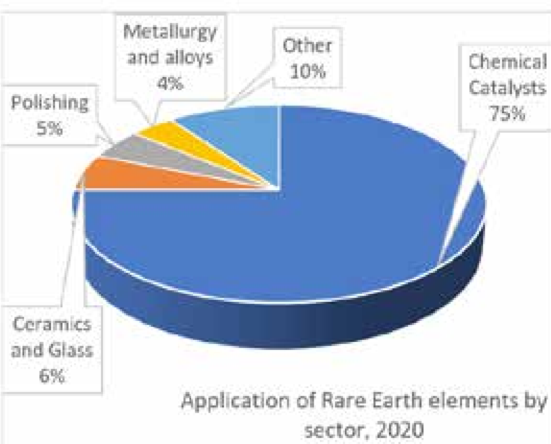


Table 1

Global mine production (rare earths, metric tons).

Country/year	2019	2020
Australia	20,000	17,000
Brazil	710	1,000
Burundi	200	500
China	132,000	140,000
India	2,900	3,000
Madagascar	4,000	8,000
Malaysia	0	0
Myanmar	25,000	30,000
Russia	2,700	2,700
Thailand	1,900	2,000
United States	28,000	38,000
Vietnam	1,300	1,000
Other countries	66	100

Production

Even though the COVID-19 pandemic adversely affected almost every economy, global production of rare earth oxides continued an upward trend. China remains the main producer of rare earth oxides. The country had produced 140 kt of REOs in 2020 which is ~58 percent of world production. Over the past four years, the total contribution of China has decreased from 80 to 58 percent. The primary reason for this decrease was a significant increase in REO production by other countries.

Imports and exports

Over the past three years, U.S. imports of rare earth oxides, metals and other compounds were mainly from China (~ 80 percent). A few other countries like Estonia (5 percent); Japan and Malaysia (4 percent each) and other countries (7 percent) contribute the remainder. In the past four years, U.S. imports of rare earth compounds and metals have decreased from 11 kt to 6.7 kt. In the meantime, the U.S. exports its mine production to other countries, mainly China for processing to recover REOs, metals and compounds.

Prices

During 2020, most rare earth oxide prices remained fairly stable. As shown in Fig. 2, neodymium and dysprosium increased slightly in price while terbium registered a large increase to $628/kg, which is the highest since 2011. Prices of cerium at $2/kg, europium at $31/kg and lanthanum at $2/kg had decreased.

Reserves, resources and recycling

Rare earths 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. In North America, reserves are estimated to be at 1.5 Mt in the United States and about 0.83 Mt in Canada. Rare earth resources are generally categorized as: alkaline (carbonatites), igneous systems, ion-adsorption clay deposits and monazite-xenotime-bearing placer deposits. Light rare earths are mostly recovered from carbonatites and placer deposits. Ion-adsorption clays are the major source of heavy rare earth elements. Limited quantities of rare earths are recovered from batteries, permanent magnets and fluorescent lamps. 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, and those substitutes generally are considered less effective when used.

Environmental, regulatory and reclamation issues

Tailings generation from rare earth mining and processing is considerable because of low concentration of rare earth oxides and the potential presence of radioactive elements in the tailings. The concentrations of heavy metals near mining sites can increase, and other serious environmental consequences can occur if not properly managed. Low concentrations of radioactive elements in tailings present a potential hazard and should be properly handled.

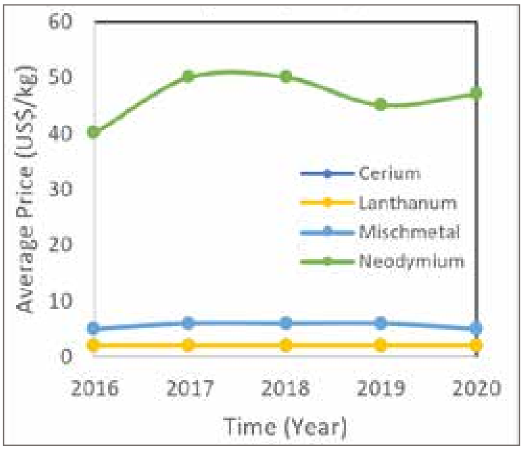
Trends and outlook

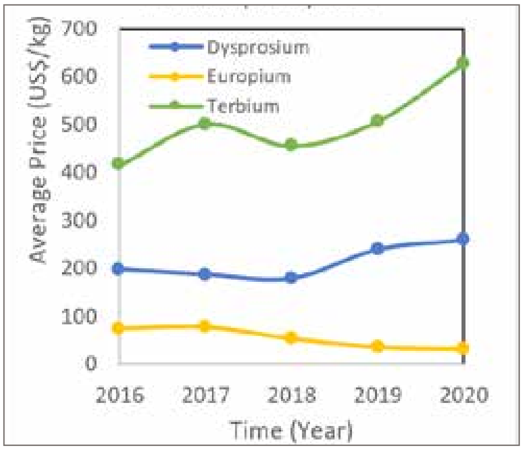
Global mine production of rare earth oxides in 2020 was estimated to have increased to 240 kt, up by 9 percent from the previous year. The mine-production quota for 2020 in China was 140 kt with 120,850 t allocated to light rare earths and 19,150 t allocated to ion-adsorption clays. The global demand for electric vehicles, consumer electronics, energy-efficient lighting and catalysts is expected to rise rapidly over the next decade. Rare earth magnet demand is expected to increase, as is the demand for rechargeable batteries. New developments in medical technology are expected to increase the use of surgical lasers, magnetic resonance imaging, and positron emission tomography scintillation detectors. Rare earth elements are heavily used in all these products, so the demand for them should remain high.

References are available upon request. ■

Figure 2

(a) Cerium, lanthanum, mischmetal and neodymium prices, 2020, (b) dysprosium, europium and terbium prices, 2020.





SALT

by H. John Head, Head & Associates LLC

Salt remains the most cost-effective material for maintaining full mobility on roads and highways and to prevent accidents during the winter snow season. It is also the most useful component for regenerating the ion exchange resins used for water conditioning. It is critical in the production of animal feed products and the most ubiquitous ingredient used in the food industry. Salt is also a significant feedstock for the chemical industry.

Since 2005, China has been the world's largest salt producer, with 2020 production estimated at 60 Mt by the U.S. Geological Survey (USGS), while the total U.S. salt production (including brine directly captured for the chemical industry) was estimated at 39 Mt (Table 1). Combined, both countries accounted for about 37 percent of total world production, while the six other countries producing 9 Mt or more produced a total of 83 Mt or 31 percent.

The production and sales of salt in the United States differ significantly from year to year as a result of fluctuations in the weather, since the primary market for non-brine salt is for highway deicing. Other salt markets are relatively steady and consistent.

Total apparent U.S. salt sales (production plus imports less exports) amounted to an estimated 53 Mt in 2020, a 10 percent decrease over the estimated 2019 volume, due to the milder winter weather and reduced highway salt requirements. Water conditioning and food-grade salt sales remain stable.

Highway deicing accounted for about 43 percent of total salt consumed. The chemical industry accounted for about 38 percent of total salt sales, with salt in brine accounting for 90 percent of the salt used for chemical feedstock. Chlorine and caustic soda manufacturers were the main consumers within the chemical industry. The estimated percentage of salt sold or used was, by type, rock salt, 43 percent; salt in brine, 40 percent; vacuum pan salt, 10 percent and solar salt, 7 percent.

The total value of U.S. salt sales was estimated at \$2.4 billion. Average prices for rock salt have increased from \$35.67/t in 2010 to between \$57 and \$60/t over the last five years.

Table 1
Global salt production.

Country	Production (million tons)	
	2019	2020
United States	42	39
Australia	13	12
Belarus	3.3	3
Brazil	7.4	7.2
Canada	11	10
Chile	10	10
China	59	60
Djibouti	3.8	3.5
France	5.6	5.5
Germany	14.3	14
India	29	28
Iran	3	3
Italy	4.2	4
Mexico	9	9
Netherlands	5.9	5
Pakistan	3.7	3
Poland	4.5	4
Russia	6.7	6
Spain	4.2	4
Turkey	6.5	6.4
United Kingdom	4.1	4
Other countries	33	30
World total (rounded)	**283.2**	**270.6**

The United States imported an estimated 16 Mt of salt in 2020, while exports were an estimated 1.2 Mt.

Events, trends and issues

The COVID-19 pandemic affected production and consumption of salt throughout the world in 2020. The most significant impact was felt in the chloroalkali industry because international trade declined, but the entire salt sector was negatively affected to varying degrees. The chloralkali industry was also disrupted by severe weather events, mainly hurricanes, in the primary production areas of Louisiana and Texas.

The 2019-2020 winter was slightly milder than average after several years of average or below average winter temperatures and more winter weather events than usual. Rock salt production and imports in 2020 decreased compared with 2019 because demand from many local and state transportation departments decreased. Most local and state governments in regions that experienced a less intense winter season reportedly had remaining stockpiles and therefore less need to replenish supplies of rock salt for the winter of 2020-2021.

Issues, events and trends

Many municipalities continue to use salt brine as one tool for de-icing. This can be seen as parallel wet lines on the road, generally before the snowy or icy conditions start. The Salt Institute has reported that the use of salt brine allows for states and localities to keep roads clear while using less salt, resulting in significant financial savings as well as protecting the environment. Since the late 1990s brine anti-icing strategy has become one of the most popular winter road maintenance strategies across North America.

The production and usage data used in this report relied almost entirely on research done by the Minerals Commodity specialists at the U.S. Geological Survey, who are to be commended for their rigorous analysis of minerals statistics.

References are available upon request. ■

SAND USED IN CONCRETE

by John Googins, Aggregate & Mining Consultants LLC

Natural sand is produced by natural processes including rock ground under a heavy burden of glacial ice over millions of years of time. This sand is most often found in and around rivers and streams. Many of the best sources of sand and rock are used to build homes, buildings and highways. Sand on ocean beaches is contaminated with salt from the sea and sand from the desert is the wrong size to be used for concrete or asphalt. Transportation plays a significant role in the delivered price of sand to the consumer —truck haul cost is typically $.25/ton/mile, whereas unit train costs are approximately $.10/ton/mile.

Sand extraction and usage is at more than 50 Gt/a. Sand-and-gravel associations and concrete associations from all over the world forecast shortages of sand for concrete now and in the future. The United States, Canada, Australia, England, Europe, China and many other countries are hauling sand long distances to meet their concrete needs. Concrete mix designs have about 1.6 t of aggregate per cubic yard of concrete. Mix designs vary from 40 to 45 percent sand and many pump mixes use up to 50 percent sand. The average sand use is about 0.75 t (1.5 t x .45) per cubic yard of concrete. It is important to note that even if the sand meets the ASTM specification it needs also to have a fineness modulus (FM) of 2.5 to 3.00.

Byproduct sand, crusher dust, crushed rock fines

The byproduct sand produced when crushing large rock of 6 in. or more using jaw crushers or horizontal shaft-impact crushers as a primary crusher, or cone crushers used to crush rock from 1 to 6 in., can be classified to meet the C-33 sand specification, but the shape will have a large percentage of flat and elongated material. When tested by ASTM C1252, it will have a high voids numbers of 46 or greater, indicating a high percentage of flat and elongated material. In cases in which the crusher fines are mixed with natural fines, the ratio is normally 70 percent natural fines and 30 percent crusher fines and the product can be used as concrete sand with little negative effect. This material can be used as asphalt sand as-is. In a quarry application where there is no natural sand, it would not be suitable as concrete sand because of poor particle shape.

You can, however, run this material through a vertical shaft impact crusher with rotor and rock box to improve the particle shape and then classify to the C-33 specification and use it as manufactured sand.

During classification, approximately 50 percent of the #4 x #8, 75 percent of the #200 x 0.and 50 percent of the #100 x #200 is rejected.

Manufactured concrete sand and manufactured sand

Manufactured sand needs to be capable of replacing natural sand in concrete without any negative side effects. Two of the most common complaints regarding manufactured sand are a high FM and excessive flat and elongated material in the finished product. For most materials that means recrushing part of the #4 by #8 material or wasting it. The first step in the production of manufactured sand is crushing the rock to a size that by only removing the excess material passing the #100 and #200 sieve, will meet the C-33 sand specification on all the other sieves (#4, #8, #16, #30 and #50). Normal manufactured sand will result in sand with less than 80 percent passing the #8 sieve before classification and 70 to 75 percent after classification (less than the 80 to 100 required by the specifications. This also results in a higher than 3.00 FM, one of the less than desirable manufactured sand conditions.

When using a compression-type crusher such as the cone crusher or high-pressure grinding roll crusher (HPGR), the crushing is autogenous, which is rock-on-rock crushing. In autogenous crushing, the crusher receives the new feed plus the recirculating load with 75 to 100 percent less than the crusher closed side setting. This forces the crushing action to be many layers of rock to rock with interparticle crushing. This produces a product with good quality shape.

Sand production crusher wear cost

The chemical analysis and the paddle abrasion test can be used to help predict the wear cost of the crusher used. By finding the chemical content of the calcium carbonate ($CaCo_3$), silicon dioxide (SiO_2), iron oxide (Fe_2O_3), aluminum oxide (Al_2O_3) and magnesium carbonate ($CaCO_3$) the silica equivalent

Table 1

Typical natural sand deposit that needs only to have the amount of minus 200 material removed from the gradation through classification to meet the ASTM C-33 specification.

Sieve sizes (in.)	Sieve sizes (mm)	Sieve sizes (U.S.)	Natural sand	Classified sand	ASTM c-33
.185	4.7	#4	100	100	95-100
.131	3.33	#6	92	92	
.093	2.36	#8	85	83	80-100
.046	1.168	#16	65	61	50-85
.0232	.589	#30	45	39	25-60
.0116	.295	#50	30	23	10-30
.0058	.147	#100	20	9	2-10
.0029	.074	#200	12	3	0-5
		FM		2.20	2.5-3.0
		Wash loss		10-15%	

Table 2

Aggregate usage, U.S. Geological Survey, Pit & Quarry, April 2021 (millions of tonnes).

Material	2016	2017	2018	2019	2020	2021 (estimated)	2022 (estimated)
Aggregate	2,320	2,227	2,360	2,500	2,243	2,460	2,560
Concrete sand (estimated)	812	779	826	875	785	861	896

Table 3

Byproduct sand produced as a result of crushing.

Sieve sizes (in.)	Sieve sizes (mm)	Sieve sizes (U.S.)	Natural sand	Classified sand	ASTM C-33
.185	4.7	#4	100	100	95-100
.131	3.33	#6	85	91	
.093	2.36	#8	70	83	80-100
.046	1.168	#16	50	54	50-85
.0232	.589	#30	39	38	25-60
.0116	.295	#50	28	22	10-30
.0058	.147	#100	19	9	2-10
.0029	.074	#200	12	4	0-5
		FM		3.02	2.5-3.0
		Wash loss		30-35%	

Table 4

Gradations of the crusher.

Sieve sizes (in.)	Sieve sizes (mm)	Sieve sizes (U.S.)	New feed	Recir-culating load	Crush-er dis-charge	Crush-er feed	Man sand	Washed sand	ASTM C-33
			34%	66%			Dry		
1	25.4		100%			100			
.75	19.1		95	100	100	98			
.5	12.7		71	85	90	80			
.375	9.5		39	70	80	59			
.25	6.35		15	32	55	26			
.185	4.7	#4	5	12	42	10	100	100	95-100
.131	3.33	#6		6	36	4	90	93	
.093	2.36	#8			30		85	87	80-100
.046	1.168	#16			22.8		65	62	50-85
.0232	.589	#30			15.3		43	37	25-60
.0016	.295	#50			10.8		31	22	10-30
.0058	.147	#100			6.9		20	9	2-10
.0029	.074	#200			5.1		15	3	0-5
		FM						2.9	2.5-3.0
	Wash	Loss						15%	

Table 5

Material types to crush and their characteristics.

Test result	Very difficult	Difficult	Medium	Easy	Very easy
Los An-geles	Minus 12	12-17	17-22	22-27	27+
Crush-ability	Minus 20	20-30	30-4-	40-50	50+
Com-pressive Strength	40,000 psi+	30,000-40,000 psi	20,000-30,000 psi	10,000-20,000 psi	Minus 10,000
Abrasion index	.9-1.5	.5-.9	.2-.5	.1-.2	Minus .1
	Tap Rock	Granite	Marble	Limestone	Talc
	Gabbro	Basalt	Dolomite	Shale	Gypsum
	Quartzite	Andesite	Limestone	Bauxite	
	Granite (fine-grained)				

number can be established. The silica equivalent number = the percent of ($CaCo_3$) + (SiO_2) + 2 x [(FeO_3) + (Al_2O_3)] + (MgO).

Example of silica equivalent number = (15%) + (40%) + 2 x [(12%) + (15%)] + (3%) = 112.

The higher the number, the more abrasive the feed material. When the paddle-abrasion test is not known, you can estimate the result with abrasion index = .6 x silica equivalent number.

More accurate results of the paddle-abrasion test can be found by running the following test. A vertical shaft with a paddle of known weight is rotated through a metal pan holding 400 g of rock 1/2 in. x 3/4 in. The paddle is run for 15 minutes and four separate tests are run with four separate paddles. By measuring the weight loss of the paddle, a wear chart can be used to establish an abrasion index (AI) number.

- Highly abrasive material has an AI of .75 to 3.00.
- Abrasive material has an AI of .25 to .75.
- Mildly abrasive material has an AI of .05 to .25.

- Nonabrasive material has an AI of .01 to .05.

Best wear analysis can be established by running a pilot test, crushing 10,000 t of rock to sand size and determining the wear life in that application, with crusher type and material type. High wear cost is not the problem if you can incorporate the cost into the selling price of the material. As sand becomes in shorter supply the price will increase, making it more possible to manufacture man sand to replace natural sand. What can be a problem is not knowing the wear cost beforehand.

Other tests that can be used to help predict crusher wear cost are:

- Compressive strength (megapascal x 145 = psi)
- Specific gravity (for aggregate + 2.65)
- Los Angeles abrasion test (Range of 10 to 50)
- Paddle abrasion test (1.5 to .02)
- Metso crushability (CR) 10 to 50 + and abrasiveness (ABR) 0 to 2500

Table 6

Specifications used in many parts of the world, as percentages.

Sieve sizes	Sieve sizes	Sieve sizes (U.S.)	Man Sand Dry	International spec	Man-sand classified	ASTM C-33
.185	4.7	#4	100	100	100	95-100
.131	3.33	#6	92		91	
.093	2.36	#8	85	80-100	83	80-100
.046	1.168	#16	65	50-85	61	50-85
.0232	.589	#30	43	25-60	35	25-60
.0116	.295	#50	31	10-35	22	10-30
.0058	.147	#100	20	10-20	10	2-10
.0029	.074	#200	14	0-10	3	0-5
		FM	2.56	2.5-3.0	2.89	2.5-3.0
		Wash loss				

ASTM C1252 particle-shape test

The ASTM C1252 voids test uses a relationship of measured voids in noncompacted sand and the particle shape. The test consists of putting a dried sand sample into a container of known volume and comparing the calculated weight of the material using the specific gravity of the sand sample to the measured weight in the test. Natural sand with a result of 35 to 45 percent voids is considered acceptable for concrete sand. Sand with results of 45 to 50+ percent is acceptable for asphalt mixes. Natural sand with no crushed sand particles added will give results of 35 to 40 percent and manufactured sand with crushed material produced by a compression crusher in autogenous crushing (the feed material, new feed plus recirculating load, is smaller than the crusher closed side setting) will produce a sand product with 40 to 45 percent voids.

New Zealand and ASTM C939 flow cone tests can also be used to measure the particle shape of sands. The more alluvial the material with rounded particles the faster the material will flow through a funnel with fixed opening.

Another way of decreasing the effect of particle shape on the concrete mix is to only replace 50 percent of the natural sand with manufactured sand.

Byproduct sand can be used as concrete sand if you pass it through a VSI Rotor and rock box as a shaping operation. It is recommended to send a sample of the material to determine if a single pass in open circuit will improve the ASTM C1252 test results enough to consistently provide acceptable results.

International manufactured sand specification

In most countries outside the United States, manufactured sand is used on a regular basis and a specific specification has been adopted that allows for more passing the #50, #100 and #200 sieves in the specification. This change in gradation will also lower the FM by .15 in most cases and reduce the amount of plus #8 that needs to be added to keep the gradation greater than 80 percent passing the #8 sieve.

For most of the concrete work that is performed for federal- and-state regulated projects the manufactured sand must be classified to the C-33 specification. The mix could consist of 50 percent manufactured sand and 50 percent natural sand if particle shape requires it, but the classified manufactured sand can meet all the requirements of the C-33 specification. A separate set of mix designs could be developed that would include the use of the international manufactured-sand specification by reducing the minus 200 mesh to less than 10 percent with air classification.

Conclusion

More frequently, sand is hauled in from long distances away to satisfy demand and the haul cost frequently approaches the FOB price at the quarry or pit. To test a source material to manufacture sand for concrete, first test the existing crusher discharge material and determine the size fractions. Unlike normal crushing where the feed material is greater in size than the crusher setting, the crusher discharge gradation will change with the setting. The sand gradation, #4 x 0 will increase in percentage of the crusher discharge but the sand gradation between #4 and 0 will remain about the same. No two sources will produce the same gradation and sometimes different elevations in the quarry may produce different results. Manufactured sand (# 4 x 0) tends to produce a coarser sand with a high percentage of #4 x #8 material. This is the most difficult size to crush and in most cases the crusher discharge will contain 25 to 35 percent of #4 x #8 fraction when crushed to #4 x 0 product. To produce a finished product that meets the C-33 specification, 80 to 100 percent passing the #8 sieve the excess #4 x #8 sieves to be either rejected or send back for re-crushing into the recirculating load. The goal is to produce a finished product with a target gradation of dry crushed sand that will allow only the removal the excess #100 and #200 material during classification to meet the product specification. The classified sand should meet the concrete sand specification and keep the FM under 3.00. Sand with a FM of plus 3.00 is too coarse and leads to problems with finish ability, segregation of the mortar and the workability of the plastic concrete. The material size and gradation to feed the crusher to produce the manufactured sand must be determined next. It is recommended to crush some material through a pilot plant for two or three months to establish the gradations, production rate and wear cost before investing in larger-size equipment at higher production rates. Alternatively rent a portable plant that can be set up at the plant site and try different crusher types, such as cone crusher, HPGR, VSI rotor and rock box and VSI rotor and anvil, hammer mill or double reversing cage mill with different gradations of material. After crushing the sand to minus #4 the sand must be recrushed to address the excess amount of #4 x #8 that is typically present (normally 30 percent) and the specification only allows 15 to 20 percent. Many concrete producers that have used manufactured sand in the past have had bad experiences because the sand they were furnished had a combination of poor particle shape, coarse gradation, and FM above 3.00 to 3.5. ■

STRONTIUM

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

In 2020, U.S. apparent consumption of strontium (contained in celestite and manufactured strontium compounds) was 5.47 kt (6,030 st), 59 percent less than in 2019. The gross weight of total imports of strontium compounds and minerals in 2020 was 10.2 kt (11,200 st) and was 63 percent less than that of 2019. Mexico was the source of 55 percent of all strontium imports. In 2020, the average U.S. Customs unit value of imported strontium carbonate was $0.96/kg ($0.43/lb), and for strontium nitrate, the average unit value was $1.34/kg ($0.61/lb). Imports of celestite, nearly all of which came from Mexico, decreased by 87 percent. The average value of imported celestite increased to $90/t ($82/st), a 10 percent increase from that in 2019. Celestite imports declined so much because of the significant decline in oil and natural-gas well drilling in the United States caused by the decline in demand for motor fuels that was the result of restrictions put in place to mitigate the COVID-19 pandemic. In recent years, celestite imports have been variable, corresponding to the variations in oil and natural-gas well-drilling activity.

Although strontium is the 15th 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. Deposits of strontianite have been identified in China and Malawi, but production has been reported only from China.

The world's leading producers of celestite were Spain, China, Mexico and Iran in 2020. Of an estimated 210 kt (230,000 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.

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 use of strontium carbonate in ferrite magnets and other ceramics and glass applications was estimated to be about the same as the use of strontium nitrate in pyrotechnics in 2020. These two end uses are thought to account for most strontium compound and metal consumption. Other applications include master alloys for aluminum casting, pigments and fillers in corrosion-resistant paints and electrolytic production of zinc.

China is the world's leading producer of strontium carbonate, followed by Germany and Mexico. China uses domestic and imported celestite to supply its strontium carbonate plants; Germany is 100 percent reliant on imported celestite; and Mexico consumes domestic ore for its strontium carbonate production. Celestite reserves in China are smaller and of lower quality than those in Mexico and Spain. Celestite deposits in Iran are thought to be large but may be of lower quality than those in Mexico and Spain. ■

TALC AND PYROPHYLITE

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 least pure and utilized of all the origin types. Another representation of the four talc origin categories noted above can be as 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. Additional groupings of a talc product are categorized as chloritic-talc, carbonate-talc or tremolitic-talc with a hyphened statement denoting the second most dominant mineral phase (usually 20-50 percent) in addition to the predominant talc component (at 50 percent or greater).

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 with more expanded types as:

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.
5. In clays formed by weathering.

Pyrophyllite has a high dielectric strength, low electrical conductivity, reasonably high thermal stability and chemical inertness that allows for primary usages in refractory and ceramic applications. Critical attributes in refractory applications are iron and quartz contents 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.

Production and consumption

In 2020, the primary producer of pyrophyllite in the United States and 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, NC. 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 with its parent company, RESCO. While the company's actual domestic production figures were not disclosed by USGS, domestic 2020 pyrophyllite production was estimated to have decreased from 2019 and could be attributed to the pandemic through the majority of 2020. Consumption was dominant kiln refractory, ceramics and paint. Employment associated with pyrophyllite has remained stable over the last six years at 30 to 31, 2020 estimated (2020e). In North America, Trinity Resources has mining, production and port facilities located in Newfoundland. Trinity Resources sells and distributes pyrophyllite products under the Altifil, Altiplus and Altiblock trade names with usage in refractory, automotive, plastics, paints, paper coatings and cosmetics.

In 2020, three talc companies operated five talc mines and production facilities located in three states

Figure 1

Twenty-two-year trend data for talc production (kt) and consumption (kt), 1999 to 2020e.

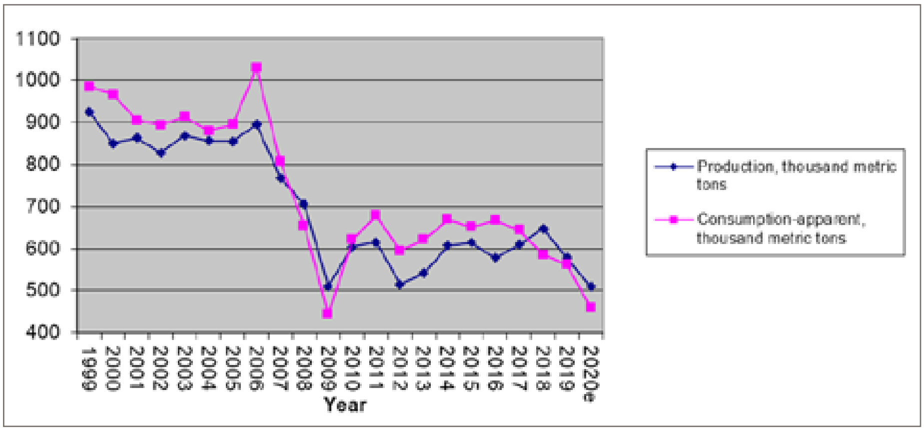


Figure 2

Twenty-two-year trend data for import consumption (kt) and exports (kt), 1999 to 2020e.

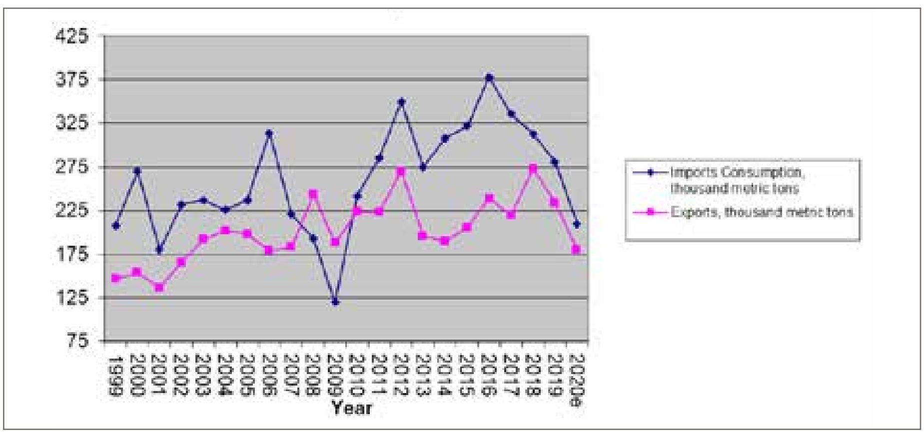
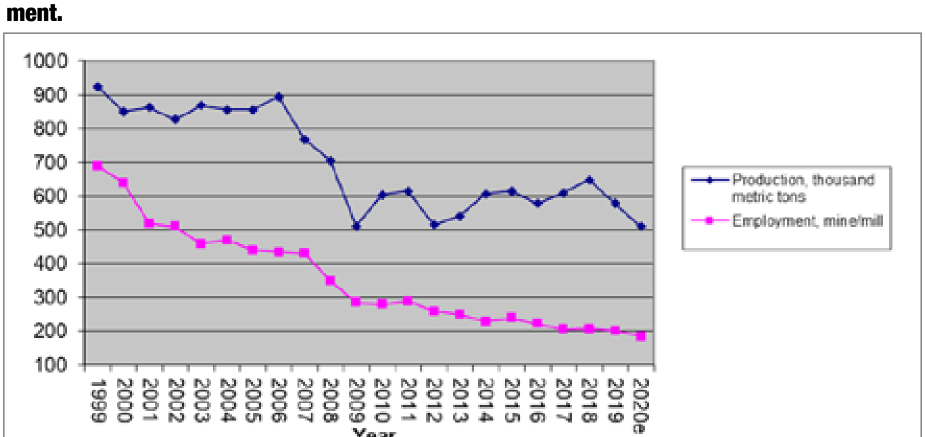


Figure 3

Twenty-two-year trend data for talc production (kt) and employment, 1999 to 2020e. *Prior to 2012, pyrophyllite mine employment was apparently included under talc-mine employment.



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. Imerys Talc remained the top domestic and international talc producer with domestic mines and processing facilities in Montana and Vermont, and processing in Texas, in addition to operations in Canada, Australia, China and Japan. Imerys Talc America has operated under Chapter 11 bankruptcy since February 2019. 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.) has 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. Alberene Soapstone Co. operated in Virginia and Southern Oregon Soapstone Co. LLC operated in Oregon and still had active websites.

Previously reported 2019 estimated production and consumption values have been corrected with 2019 actual data as shown in the 22-year trend (Fig. 1). For 2020e, talc production is estimated at 510 kt, a decrease of about 12 percent from 2019. Total talc sold by the producers, a combination of domestic and exports, was estimated at 430 kt, a substantial decrease of about 17 percent from the 2019 level of 515 kt. The total talc sold was valued at $100 million. Talc has experienced a pandemic-driven economy similar to that of the 2008-2009 recession.

For 2020e, apparent consumption of talc was at 459 kt, a substantial decrease of 18 percent from 2019 levels. The 2020e average price for a processed ton of product remained unchanged from the 2019 average price at $240/st.

The distribution of talc produced and sold domestically was as follows: ceramics including catalytic converter (22 percent), paint (19 percent), paper (17 percent), plastics (11 percent), rubber (4 percent), roofing (3 percent), cosmetics (2 percent) and other (22 percent). The “other” uses include a variety of applications for pharmaceuticals, refractories, agricultural products, animal feed, sealant, sculpturing, food and polishing.

Exports/imports

The 2020e talc exports were 180 kt, a substantial decrease of about 23 percent from 2019 actual at 234 kt. Canada and Mexico accounted for approximately half of the exports. The 2020e talc imports were 210 kt, a substantial decrease of 25 percent from 281 kt in 2019 and a continued decline since 2016. From USGS reporting, imported talc was sourced from Canada, Pakistan and China with imports increasing from Pakistan. Last year USGS had communicated that crude ore from Afghanistan was being milled and exported through Pakistan to other countries but it was not noted in this year's update. 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. The 22-year trend data of imports for consumption and exports taken from the USGS are provided in Fig. 2.

Employment

Talc sector employment continued to decline overall since 2007. An important note to the talc employment overview is that historically, pyrophyllite mine employment was included under talc-mine employment. Pyrophyllite mine employment ranged from 25 up to 31 from 2012-2019 and has been adjusted for in the trend data of production and employment from USGS in Fig. 3.

Uses, new applications, processing technology, 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. Nano-talc 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 anti-blocking/anti-hazing in plastic films, auto body putty, asphalt shingles, joint compounds, pharmaceuticals, ceramics and dimension stone.

In cosmetics, talc competes against corn-starched products and recently pyrophyllite. In ceramic applications of dinnerware, sanitary ware, 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 combining talc with kaolinite and other proprietary additives to formulate fired-cordierite bodies used for catalytic converters for vehicles. The competitive products in this field are SiC or metal-based catalytic converters. 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, UV 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 product will increase for the automotive market. Here, the compacted and submicron talc products enables 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. In ceramics, talc competes with clays and pyrophyllite, in paint, plastics, and rubber with kaolin and mica.

Substitutes for talc in ceramics are bentonite, chlorite, kaolin and pyrophyllite; in paint are chlorite, kaolin and mica; in paper are calcium carbonate and kaolin; in plastics are bentonite, kaolin, mica and wollastonite; and in rubber are kaolin and mica.

Environmental and regulatory

As reported in previous annual reviews, the talc industry had been working on responding to Canada's Health Canada and Environment Canada on the Domestic Substances List Inventory Update Phase 2 through its Chemicals Management Plan as to whether talc should be classified as a health and environmental toxin. In September 2015 and 2016 and most recently in 2018, industry representatives, consultants and Industrial Minerals Association-North America (IMA-NA) staff finalized and presented a concise and informative presentation to Canadian authorities and continue to finalize their work. While Canadian agencies categorized talc in a negative context, IMA-NA and industry provided a prompt additional response for review again by the Canadian agencies in 2019 for a favorable and final categorization.

Under United States Pharmacopeia (USP), a second USP Expert Panel-Talc 2015-2020 had been convened with representation from industry, contract testing laboratories, academia and USP. Work continued from 2017 into 2020 on improving the specificity of the talc USP monograph attribute for

Absence of Asbestos testing. The expert panel had prepared various samples for round-robin testing by X-ray diffraction (XRD) and polarized light microscopy (PLM) and concluded and documented each XRD and PLM methodology. Similar and parallel work on testing of pharmaceutical and cosmetic-grade talc products has been ongoing through the ASTM D22.07 subcommittee (Asbestos). The D22.07 subcommittee has many of the USP talc panel participants involved with the method development.

Talc continues to receive negative press coverage on two fronts through various articles and litigation notices of talcum powder usage and ovarian cancer linkage; and historical talcum powder body usage as purported to contain asbestos with linkage to mesothelioma cases after many years. ■

TIN

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

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 was 41.4 kt in 2020, a slight decrease from 2019. The value of consumed tin in 2020 was estimated to be $729 million, a decrease of 9 percent from 2019. Industry stocks decreased by 13 percent from year-end 2019.

Global tin mine production in 2020 was estimated to be 270 kt tin content, a 9 percent decrease from 2019. China, the global leader, produced an estimated 81 kt (30 percent of world production); Indonesia, an estimated 66 kt (24 percent); Burma, an estimated 33 kt (12 percent) and Peru, an estimated 18 kt (7 percent).

World tin reserves were estimated to be 4.3 Mt, about 16 times the estimated 2020 world primary tin production. Most tin reserves were in Asia and South America.

Consumption

During 2020, tin in the United States was used in tinplate, 24 percent; chemicals, 17 percent; alloys, 11 percent; solder, 9 percent; bronze and brass, 7 percent; tinning, 1 percent; babbitt, less than 1 percent; and other applications, 31 percent. Tin-based chemicals are commonly used in polyvinyl chloride (PVC) production and curing, biocides and catalysts. Tinplate is a layer of tin adhered to steel or wrought-iron substrate for corrosion protection. Tin is used in this case to inhibit rust and is commonly used in food-grade cans. Babbitt is a low-friction alloy that is often used in engines owing to its ability to resist cycling forces. 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. 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.

Foreign trade

U.S. imports for consumption of refined tin totaled 31,6 kt in 2020, a 7 percent decrease from 2019. The leading sources of U.S. imports were Indonesia (29 percent), Peru (28 percent), Bolivia (16 percent), Malaysia (12 percent) and Brazil (10 percent). Refined tin exports in 2020 were 519 t, a 60 percent decrease from 2019. In December 2020, the Chinese government announced that it will keep export tariffs on many nonferrous materials including a 20 percent duty on tin concentrates.

Prices

In 2020, the annual average New York dealer price for Grade A tin was $7.99/lb and the annual average London Metal Exchange Ltd. (LME) cash price was $7.77/lb, each 8 percent less than in 2019. The December 2020 monthly average for New York dealer price for Grade A was $9.15/lb and the LME cash price was $8.95/lb, an increase of 14 percent and 16 percent, respectively, from the monthly average of January 2020. The LME remained the principal commodity exchange for trading tin in 2020, but other exchanges include the Indonesia Commodities and Derivatives Exchange, the Kuala Lumpur Tin Market, the Shanghai Futures Exchange and the Shanghai Metals Market.

Outlook

The COVID-19 pandemic affected the global economy and trade during 2020. Mining and refinery closures in the first half of 2020 coupled with an increased demand for durable products, especially electronics, during the second half of 2020, led to supply restraints and price increases which are expected to last throughout the pandemic. According to industry analysts, refined-tin demand is expected to increase significantly between 2025 and 2030 owing to increased production of lithium-ion batteries, primarily for the automotive sector. Increases in tin consumption is expected for use in brass and bronze, chemicals, float glass, electronic solder and lead-acid batteries. Domestic tin requirements are expected to continue to be met primarily through imports.

References are available upon request. ■

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

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.

Production

According to U.S. Geological Survey publications, in 2020, global production of titanium mineral concentrates was estimated to be 8.2 Mt of contained TiO_2, slightly less than in 2019 (Table 1). Rounded to one significant digit, U.S. production of titanium concentrates was estimated to be 100 kt of contained TiO_2. In the United States, two companies produced mineral concentrates. The Chemours Co. produced titanium mineral concentrates at mining operations near Starke, FL and Offerman, GA. Twin Pines Minerals LLC reprocessed existing mineral sands mine tailings in Stake, FL and Columbia, SC.

TiO_2 pigment production in the United States in 2020 was estimated to be 1 Mt, a decrease from 1.15 Mt in 2019, with domestic consumption estimated to have been 900 kt, a decrease from 965 kt in 2019. U.S. producers of TiO_2 pigment using the chloride process were Chemours, INEOS Pigments USA Inc, Louisiana Pigment Co. L.P., and Tronox Ltd. A buff-color TiO_2 pigment of finely ground synthetic rutile was produced by TOR Minerals International Inc.

Global titanium metal sponge production in 2020, excluding the United States where production data were withheld to avoid disclosing company proprietary data, was estimated to have increased to 210 kt from 200 kt in 2019 (Table 2). In the United States, titanium sponge metal was produced by Titanium Metals Corp. in Nevada and Honeywell Electronic Materials Inc. in Utah. At year-end, plans to idle the 12.6-kt/a sponge plant in Nevada left the 500-t/a Utah plant as the only active domestic producer of titanium sponge. In China, sponge production and capacity increased.

Foreign trade

Based on data from the U.S. Census Bureau, in 2020, the United States was import reliant for titanium mineral concentrates and imported about 830 kt of contained TiO_2 in concentrates. The leading import sources were, in the last five-year period, in decreasing order, South Africa (39 percent), Australia (20 percent), Madagascar (10 percent) and Mozambique (9 percent). The United States was a net exporter of TiO_2 pigments with the majority of these exports, in descending order, going to Mexico (25 percent), Belgium (17 percent)

Figure 1

Average annual prices for ilmenite, rutile and titanium dioxide (TiO_2) pigments from 2010 through 2020. Source: U.S. Census Bureau.

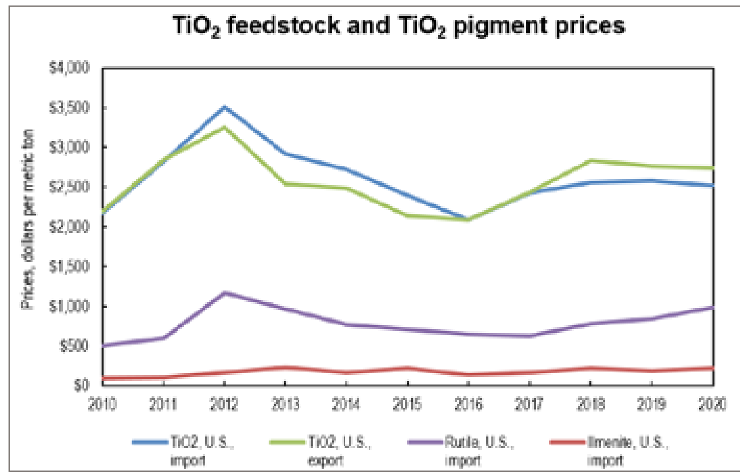


Table 1

Titanium, titanium dioxide and titanium mineral concentrates.

World: ilmenite and rutile production (data in kt of contained TiO_2)		
Country	2019	2020e
Australia	1,040	1,000
Canada	680	680
China	2,300	2,300
India	173	170
Kenya	284	260
Madagascar	289	310
Mozambique	596	610
Norway	400	400
Senegal	319	320
Sierra Leone	166	170
South Africa	1,210	1,100
Ukraine	584	560
United States[1]	100	100
Vietnam	160	160
Other countries	80	80
Total (rounded)	8,400	8,200

Source: U.S. Geological Survey.
e: estimated production
[1]: Rounded to one significant digit to avoid disclosing company proprietary data.

Figure 2

Average annual prices for titanium metal sponge and titanium scrap from 2010 through 2020. Source: U.S. Census Bureau.

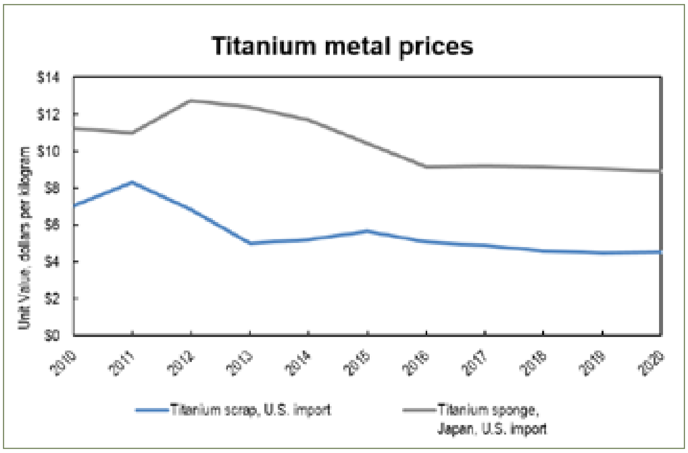


Table 2

Titanium sponge metal production (data in kt).

Country	2019	2020e
China	85	110
India	0.25	0.25
Japan	49	50
Kazakhstan	16	15
Russia	44	33
Saudi Arabia	0.10	0.50
Ukraine	8	6
United States	W	W
Total (rounded)[1]	200	210

Source: U.S. Geological Survey.
e: Estimated production.
W: withheld to avoid disclosing proprietary company data.
[1]Excludes U.S. production.

and Canada (14 percent). The United States was a net importer of titanium sponge metal and imported 19 kt of sponge in 2020. The leading import source was Japan, which accounted for 88 percent of imports.

Prices

Based on U.S. imports for consumption from the U.S. Census Bureau, the average annual prices (unit values) for ilmenite ($215/t) and rutile ($983/t) increased by 16 percent each, compared with 2019. U.S. import prices for TiO_2 pigments decreased slightly, and export prices were essentially unchanged (Fig. 1). The average annual price for titanium sponge metal imported from Japan ($8.90/kg) decreased slightly and the average annual titanium scrap import price ($4.51/kg) increased slightly compared with 2019 (Fig. 2).

Outlook

Global titanium production was forecast to remain essentially unchanged in the short term. The duration and outcome of the COVID-19 pandemic and variants to the original strain remain uncertain, but it is expected that the economies of the United States and the world as a whole will remain affected, with potentially slower growth rates, which could influence the performance of the industry. ■

VANADIUM

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

In 2020, the United States continued to be a major producer of vanadium products from secondary sources. Secondary vanadium production continued primarily in Arkansas and Ohio, where processed vanadium-bearing waste materials (ash, petroleum residues, spent catalysts) were used to produce vanadium products, mainly ferrovanadium and high-purity vanadium pentoxide. It is important to note that secondary vanadium producers continued to rely on imported feedstock for a large portion of their production. There is currently one primary producer of vanadium in the United States, two active secondary producers, and two additional idle secondary producers, one of which is currently upgrading its idled Texas facility. In 2020, 17 t of contained vanadium were produced in the United States from the mining of uriniferous sandstone on the Colorado Plateau, compared to 470 t of contained vanadium produced in the United States in 2019.

Production

Vanadium is extracted from vanadiferous ores, slags and residues and converted into vanadium pentoxide or trioxide. Most vanadium pentoxide is then converted into ferrovanadium. 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 was produced from VTM. In 2020, the vanadium-producing nations (from ore, concentrate and slag) including China (67 percent), Russia (19 percent), South Africa (8 percent), Brazil (6 percent), and the United States (less than 1 percent) produced an estimated total of 105 kt of contained vanadium, slightly more than the 104 kt of contained vanadium produced in 2019. 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. The mill had produced approximately 20.4 kt of vanadium pentoxide (11.4 kt vanadium content) during its 40-year operating history. 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. However, the company produced only 17 t of contained vanadium in 2020, before suspending production at the end of the first quarter. Energy Fuels announced that production could be stopped and started at minimal cost in response to any vanadium market changes. The company estimated that approximately 680 to 1,400 t of recoverable vanadium pentoxide (380 to 780 t of vanadium content) of inventory was in their tailings facility awaiting future recovery, if market conditions improved.

AMG Vanadium LLC is in the process of more than doubling its ferrovanadium production capacity with the construction of a new facility near its existing facility in Cambridge, OH. Gladieux Metals Recycling LLC expected to restart its Texas operations in 2021 and would begin producing both vanadium pentoxide and ammonium metavanadate. Evergreen Metallurgical LLC (under the name Bear Metallurgical Co.) operated a facility converting vanadium pentoxide to ferrovanadium in Pennsylvania that was idled in 2020 owing to lack of feedstock and uneconomical market conditions.

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. Nonmetallurgical applications included catalysts, ceramics, electronics, and vanadium chemicals. Catalysts were the leading nonmetallurgical use for vanadium.

Prices

In 2020, average Chinese vanadium pentoxide prices, as published by CRU Group, were $6.679/lb of contained vanadium. In December 2020, Chinese vanadium pentoxide prices averaged $5.893/lb of contained vanadium, compared with $10.20/lb in December 2019. The annual average U.S. ferrovanadium price decreased to $10.82/lb of contained vanadium in 2020 compared with $22.31/lb in 2019. In January 2020, U.S. ferrovanadium prices averaged $10.94/lb of contained vanadium compared with $43.10/lb in January 2019.

Foreign trade

The United States continued to be a net importer of many vanadium materials in 2020. The United States imported (measured in vanadium content) 1.37 kt of ferrovanadium, 1.67 kt of vanadium pentoxide, 67 t of other oxides and hydroxides of vanadium, and 60 t of vanadium-bearing ash and residues. Total imports for consumption of all vanadium-bearing materials decreased by 61 percent from 2019. In 2020, the United States exported (measured in vanadium content) 165 t of ferrovanadium, 50 t of vanadium pentoxide, 73 t of other oxides and hydroxides of vanadium and 101 t of vanadium-bearing ash and residues. Total exports of all vanadium-bearing materials decreased by 73 percent from 2019. In 2020, the large decreases in the imports of vanadium-bearing ash and residues, vanadium ores and concentrates, ferrovanadium and vanadium pentoxide were the main contributing factors in the large decrease in imports. In 2020, all export categories decreased by more than 40 percent except for the export of vanadium ores and concentrates.

Outlook

Because almost all 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 demand of vanadium in nonferrous alloys is largely dependent on trends in demand for titanium alloys in business, commercial, and military aircraft. As worldwide environmental regulations become more stringent on fuels and other environmental waste, interest in processing spent catalysts and fossil fuel residues is expected to increase.

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 by 2025 or earlier, and VRFB storage is proving to be a potential solution, with many countries having numerous implementations already underway. However, the high cost of the electrolyte used in the VRFBs and the system complexity of the batteries may be difficult for widespread use of VRFBs as the chosen battery technology. Companies are expected to continue to improve VRFB batteries to make them more competitive in the battery market.

The outcome of the COVID-19 pandemic remains uncertain, and the economies of the United States and the world as a whole were negatively affected in 2020. Some recovery is expected in 2021, which could influence the performance of the vanadium industry. ■

VERMICULITE

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

Vermiculite is a magnesium-aluminum-iron silicate and is 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.

Production

According to U.S. Geological Survey publications, in 2020 an estimated 100 kt of vermiculite was produced in the United States by two mining companies: Specialty Vermiculite Corp (a subsidiary of Dicalite Management Group, Inc.) in Enoree, SC, and Virginia Vermiculite LLC in Louisa, VA. Data had been rounded to avoid disclosing company proprietary data. An estimated 70 kt of vermiculite ore was exfoliated in 2020, a 5 percent decrease from 74 kt in 2019. Exfoliation was performed by 12 companies located in 10 states (Arizona, Arkansas, Florida, Illinois, Massachusetts, New Jersey, New Mexico, Ohio, Pennsylvania and South Carolina).

Consumption

Vermiculite concentrate that has not been exfoliated primarily is used 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. Horticulture and soil conditioning were estimated to remain the leading uses of exfoliated vermiculite in 2020. 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), insulation (loose-fill, block, high-temperature and packing insulation and sealants), and fertilizer carriers.

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 40 kt of vermiculite valued at $13 million was imported into the United States during 2020. South Africa and Brazil 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 $2.1 million in 2020, with Canada being the leading destination.

International

Global production of vermiculite was estimated to have decreased by 3 percent to 380 kt in 2020 compared with 390 kt in 2019. South Africa continued to be the leading vermiculite producing country followed, in descending order, by the United States and Brazil. Reliable information for vermiculite production in China, which may have produced significant quantities of vermiculite, was unavailable. Most of the vermiculite in South Africa was mined by Palabora Mining Co. Ltd. in Limpopo Province.

Outlook

Production of finer grades of vermiculite have far exceeded that of coarser grades for several decades. Producers are likely to continue to investigate ways to use the finer grades in higher-value markets. It is also expected that exploration and development of coarser-grade vermiculite deposits (mostly in China and South Africa) will continue because of the higher demand for larger-grade vermiculite. ■

WOLLASTONITE

by Shonta E. Osborne, 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) but may contain trace to minor amounts of aluminum, iron, magnesium, manganese, potassium, sodium and (or) strontium. Economic resources of wollastonite typically form as a result of thermal metamorphism of siliceous limestone during regional deformation or chemical alteration of limestone by siliceous 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

According to the U. S. Geological Survey (USGS), two companies mined wollastonite in the United States in 2020. NYCO Minerals Inc. (a subsidiary of Imerys S.A., France) operated a mine and processing plant near Willsboro in Essex County, NY. The NYCO deposit contains diopside and garnet, which are removed using high-intensity magnetic separators, and up to 60 percent wollastonite. Vanderbilt Minerals LLC (a division 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) and 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 products, metallurgical, plastic and rubber and miscellaneous applications. The USGS does not collect consumption statistics for wollastonite, but consumption was estimated to be about the same as that in 2019. In 2020, trends in domestic manufacturing sectors that use wollastonite were mixed; U.S. single-family housing starts decreased by 2.3 percent and primary iron and steel products increased slightly.

The primary global sales for wollastonite were ceramics, polymers and paint. Plastics and rubber markets (thermoplastic and thermoset resins and elastomer compounds) were estimated to account for more than 25 percent of wollastonite sales in the United States, followed by ceramics (frits, sanitary ware and tile), paint (architectural and industrial paints), metallurgical applications (flux and conditioner), friction products (primarily brake linings) and miscellaneous uses (including adhesives, concrete, glass and sealants). 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 2020, prices for domestically produced wollastonite were estimated to be between \$360/t and \$390/t, modestly higher than in 2019. Price data for wollastonite produced in other countries were unavailable.

Foreign trade

In 2020, wollastonite exports were estimated by USGS to be less than 10 kt and imports were estimated to be about 1 kt. 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

According to the International Monetary Fund's January 2021 World Economic Outlook Update, economic growth in the United States decreased by 3.4 percent in 2020. The World Health Organization declared that COVID-19 was a global pandemic on March 11, 2020. Measures instituted to mitigate the spread of the COVID-19 pandemic, such as closures of nonessential businesses, caused disruptions in the mining industry across the United States and around the world. The duration of the COVID-19 pandemic remains uncertain, but it is expected that the economies of the United States and the world will likely be in a state of recovery for some time, which will influence the performance of the wollastonite industry. ■

ZIRCONIUM

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

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 [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 (YSZ) 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

Industrial Minerals

Table 1

World production of zirconium ores and concentrates, by country (kt, gross weight).

	2019	2020e
United States[1]	100	<100
Australia	470	480
China[e]	140	140
Indonesia	34	60
Kenya	29	25
Mozambique	100	125
Senegal	65	65
South Africa	112	110
Other countries	112	110
Total (rounded)	**1,420**	**1,400**

e: Estimated production.
[1]: Rounded to one significant digit to avoid disclosing proprietary company data. Source: U.S. Geological Survey

Figure 1

U.S. salient statistics for zircon ores and concentrates from 2018 through 2020. Source: U.S. Census Bureau.

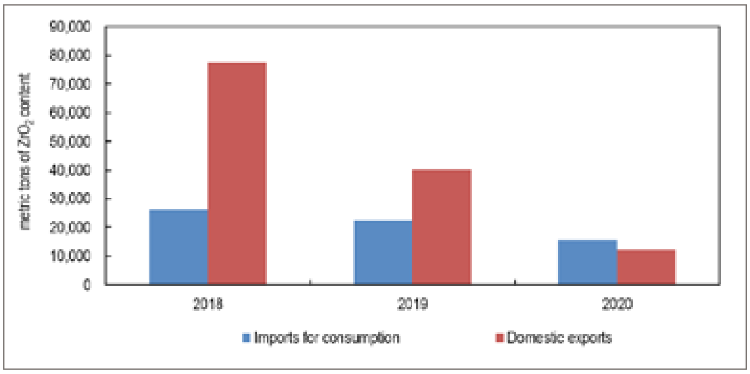
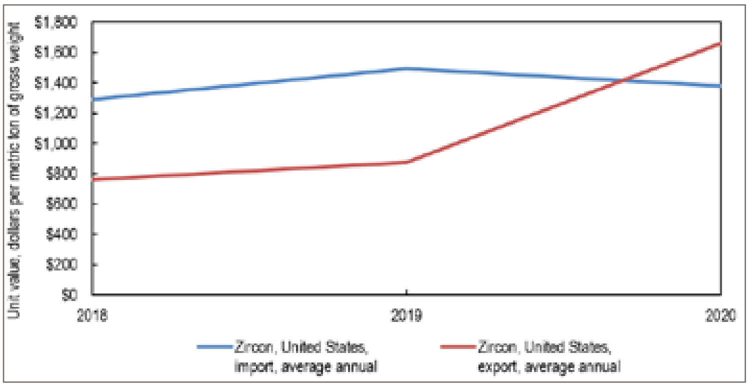


Figure 2

Average annual unit value of zircon ores and concentrates from 2018 through 2020. Import unit value is based on imports from Australia, Senegal and South Africa. Source: U.S. Census Bureau.



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

According to U.S. Geological Survey publications, global production of zircon concentrates was estimated to be 1.4 Mt in 2020, slightly less than in 2019. The leading producing countries, Australia and South Africa, accounted for 57 percent of global production (Table 1). In the United States, production was less than 100 kt (rounded to avoid disclosing company proprietary data). The Chemours Co. produced heavy zircon mineral concentrates at mining operations in Starke, FL, and Nahunta, GA. Twin Pines Minerals LLC processed existing mine tailings to produce zircon in Starke, FL.

Trade

According to the U.S. Census Bureau, the United States was a net importer of zircon concentrates, with exports totaling 12 kt (ZrO_2 contained weight) with a value of $31 million in 2020. Exports were about one-third of the quantity of exports in the prior year, and they were only 16 percent of exports in 2017. In 2020, India (30 percent), Mexico (20 percent) and China (15 percent) were the leading destinations of U.S. exports of zircon concentrates in contrast to 2019, when China received 84 percent of U.S. exports of zircon concentrates. In 2020, the United States imported 16 kt (ZrO_2 contained weight) of zircon concentrates with a value of $36 million (Fig. 1). The leading import sources, in descending order of quantity, were South Africa (39 percent), Australia (36 percent) and Senegal (23 percent). China, the leading global consumer of zircon concentrates, imported 1.09 Mt (gross weight) of zircon concentrates in 2019, a slight decrease from 2019.

Prices

On a gross weight basis, the average U.S. zircon export unit value in 2020 was $1,660/t, almost double that of the previous year. For the first time in three years, average annual U.S. zircon import unit values decreased in 2020. The import value decreased by 7 percent to $1,380/t of gross weight (Fig. 2). For comparison in global markets, China's average annual zircon unit value of imports was $811/t, an 11 percent decrease compared with $910/t in 2019.

Outlook

Global zircon production was forecast to remain essentially unchanged in the short term. The duration and outcome of the COVID-19 pandemic and variants to the original strain remain uncertain, but it is expected that the economies of the United States and the world as a whole will remain affected, with potentially slower economic growth, which could influence the performance of the zirconium industry. ■

The Institute's first 50 years:
1922-1971

by George Luxbacher

AIME 150th Anniversary Year

AIME is the second-oldest engineering professional institute in the United States, and SME is honored to help celebrate the 150th anniversary of the founding of AIME in the pages of *Mining Engineering* in 2021. SME's original roots began with AIME in 1871 and, throughout the year, we will feature several articles in the magazine that provide perspective on AIME's history. In addition, SME will host a culmination of the 150th-year celebration of AIME at the MINEXCHANGE 2022 SME Annual Conference & Expo in Salt Lake City, UT. Enjoy these articles, and let's remember all those who came before us to make the mining, metallurgical and exploration community one of the foundations of our Society.

Envision the Roaring Twenties. AIME, fresh off its 50th anniversary described in the May column, opened its 125th meeting in New York City in 1922 with a mining-camp bar room, including a 7-m (24-ft) bar and denizens of the Old West to match, set up on the fifth floor of the Engineering Societies Building. The local sections (21 at this point) held their first Convention of Local Sections — a meeting that continues at SME in some form today (Phoenix in 2020 as the Sections Best Practices Meeting). As one who has attended numerous local section meetings at the SME Annual Conference, reading the reports from these earlier meetings (including this one) demonstrates that some things never change — then the relationship between the local sections and the Institute, today with the Society. The Petroleum Division was established that same year, although the first petroleum paper was published in Transactions in 1879 (The Bradford Oil District of Pennsylvania). As documented by S. Harries Darrow, one of the AIME founders, in his book *Coal, Iron and Oil or The Practical American Miner* (1866) petroleum was part of the Institute from the beginning. The Petroleum Division's roots dated from a 1913 standing technical committee whose first chair, Anthony Lucas, established the salt deposits/sulfur/oil relationship while working as a mining engineer at salt mines in Louisiana.

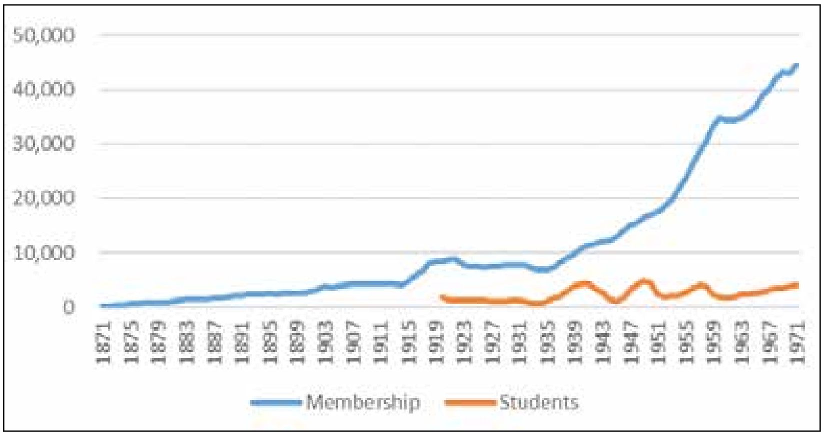
George Luxbacher, member SME, is a past president of SME (2008) and the current president of AIME, email ndu4@cdc.gov.

The 1923 Annual Meeting in New York City included an honored guest, Prince Gelavio Caetani, the Royal Italian Ambassador to the United States and a Columbia University graduate. Each of the annual meetings featured a souvenir and for this meeting a trip to the American Brass Company's plant included a spool of copper wire a mile long (but very thin). At the fall meeting that same year in the Great Northland of Ontario and Quebec was the first mention of a golf excursion, appropriately noted as attracting the surface geologists, at a course on Lake Temiskaming. This was obviously popular, since the next annual meeting included, at the smoker, a lecture on the benefits of golf as rest. Golf became a common meeting activity going forward.

Have you ever wondered where the practice started of leaving copies of *Mining Engineering* and exhibitor information at your hotel room door at SME annual meetings? For the 1924 trip to the Birmingham, AL meeting, the Institute chartered a special train from Washington, DC and provided each member onboard with a copy of the latest issue of *Mining & Metallurgy* (*Mining Engineering*'s predecessor). Mr. and Mrs. F.W. Davis, he of the U.S. Bureau of Mines, took advantage of this scenic trip to celebrate their honeymoon; the WAAIME group took the young couple under its wings for the trip.

The bronze tablet of Rossiter W. Raymond that graces the lobby of the SME offices was unveiled in its original location in the lobby of the Engineering Societies Building at the 1925 Annual Meeting. This tablet was the work of Anthony de Francisci, a noted sculptor who designed the 1921 Peace Dollar. The first Open Hearth Conference was held that same year under the auspices of the Institute of Metals Division. With the increasing specialization within the extractive industries and the Institute's membership, this started the trend to divisional meetings, while both the Institute of Metals and Petroleum Divisions had held separate meetings previously, it became the norm — the fall meeting in Salt Lake City that year was preceded by a Petroleum Division meeting in Casper, WY and followed by an Institute of Metals Division meeting in Syracuse, NY. Utah Gov. George H. Dern, a mining engineer, welcomed the Institute to Salt Lake City.

By 1926, attendance at the Annual Meeting in New York had exceeded 1,300, surpassing the capacity of the Engineering Societies



AIME membership's growth, 1871-1971.

Building, and the meeting overflow had to be accommodated at the adjacent Engineers Club. The universities were represented at tables at the smoker, a tradition that continues to this day with the university receptions at the SME Annual Conference, and entertainment included the band from Columbia. Excursions were done for the first time by De Luxe motor coach, another trend that continues.

With division meetings as well as Annual Institute Meeting and Regional Meetings (as the fall meetings came to be known) the engineers' logic in numbering meetings began to slip; division meetings were never numbered and, beginning in 1927, regional meetings were not numbered, making it difficult to easily identify recurring Institute activities. This started with a joint regional meeting with the American Mining Congress in Salt Lake City in 1927; that same year the Metals Division met in Detroit, MI and Petroleum in Fort Worth, TX.

In 1928, the Founder Societies decided to make a gift of a bell (the liberty bell) and carillon to the University of Louvain for its library tower as a memorial to the engineers who died in the Great War or WWI from 1914-18. That memorial was dedicated on July 4, 1928; several AIME members traveled to Louvain for the dedication. In response to the donation, AIME received a bell, now displayed in the office of the SPE Executive Director. The Iron and Steel Division was also formed that year.

At the annual meeting in 1929, AIME was presented with a bronze bust of Herbert Hoover, the Institute President in 1920 and the then U.S. President-elect, by sculptress Elenora Fisher Leys (the daughter of member, C.A. Fisher, donating the bust,). The bronze bust currently resides at the NYC offices of ASME (although it should be at SME — another mystery of our legacy) and another copy is at the Herbert Hoover Presidential Library and Museum.

Also at the annual meeting that year, the past-president serving as MC, Everette DeGolyer, noted that there were at least four families in which three generations had been in the minerals industry and members of the Institute: the Douglas, Eilers, Johnson and Felton-Peters families. It would be interesting to see if any of the member societies of AIME can identify similar groupings.

The AIME president was expected to attend the local section, regional, division and Annual Meeting as part of his presidential responsibilities. In 1928, that meant almost 39,000 miles of travel. The trend continued and, by 1969, the AIME president logged 80,000 miles and his wife, who happened to be the president of the WAAIMEs that year, accumulated 70,000 miles.

The Seely Mudd Fund was established in 1929 and funded its first handbooks for new members the following year. As a Legion of Honor member of SME (the 50-year hurdle), I still remember receiving my copy of De Re Metallica and Free Gold through the courtesy of the Mudd Fund and many of the books in my reference library were partially funded this way as well.

The Coal Division was established in 1930. Also of note: the Institute sent a telegram of congratulations to the newly elected President of Mexico, Pasqual Ortiz Rubio, an engineer.

The Hoover Gold Medal was established in 1931 and, as the first recipient, presented to Herbert Hoover. AIME continues to have representation today with the other Founder Societies on the Hoover Award Committee, administered by ASME. The 60th anniversary of the Institute was also celebrated that year by 150 members and guests at a regional meeting in Wilkes-Barre, PA. The sole survivor of the Institute's founders, Henry Drinker, addressed the group.

The Mineral Industry Education Division was established as the fifth division of the Institute in 1932, a legacy carried forward with SME's Council of Education today. A portrait of Herbert Hoover by noted artist Philip de Laszlo was unveiled for the Engineering Societies Center (current location unknown). With the country in the midst of the Great Depression, AIME staff agreed to work without one month's wages and the Institute suffered a 40 percent decline in advertising revenue.

The Industrial Minerals Division was formed as the sixth division in 1935. The regional meeting for 1936 was held in Mexico — while still traveling by train (from St. Louis), travel was significantly easier than the trip in 1901 described in my prior column.

For those authors and presenters who dread getting up early at the Annual Meeting to meet their session chair, that tradition started at the Annual Meeting in New York City in 1938. This same meeting started another tradition (that lasted for a few years) of a follow-up trip to Bermuda for those who wanted to escape the Northeast winters with friends.

By 1939, the annual meeting had grown so large that the auditorium at the nearby American Radiator and Standard Sanitary Corp. (today American Standard) offices had to be utilized. The stenographer record of the presentations and comments was dropped, followed by advance registration (1941) to assist in room scheduling, recording committee meetings on 30-minute vinyl records (1942), and finally, in 1944, outgrowing the Engineering Societies Building and moving the meeting to the Waldorf Astoria. At the 1944, 74th Annual Meeting, the president of Lafayette College gave the keynote, a fitting tribute to the one Institute organizer from academia in 1871, Professor Justus Silliman, who taught at Lafayette.

While no Annual Meeting was held in 1945 due to war activities, a headquarters for the Petroleum Division was approved for Dallas, TX. The first steps were taken toward a Western office in Salt Lake City for the mining and metallurgical community and the chairs of the divisions became ex-officio members of the board, with full voting rights.

For the first time in 34 years, the annual meeting was held outside New York City, in Chicago, IL in 1946; this also represented the Institute's first return to that city in 49 years, although regional and division meetings had been held there in the interim.

The Institute's 75th Anniversary was celebrated at the Annual Meeting in 1947 — yes, for those of you doing the math, that was actually the 76th year and 75th Annual Meeting, since annual meeting numbering started in 1872 with number 1. With attendance of 3,149 (26 percent of the nonstudent membership), the technical sessions outgrew the space available at the Waldorf Astoria and had to expand back to the Engineering Societies Building. A few years in the planning, souvenirs were given by Anaconda, International Nickel, Phelps Dodge, Ingersoll Rand, and ALCOA. The Ore Treatment Division was established at this meeting.

In 1948, as a result of input from the divisions (like any proper bureaucracy, through the Kinzel Committee) *Mining & Metallurgy*, supplemented by several other publications with technical papers as content (Open Hearth, started in 1931; Metals Technology, 1934; Petroleum Technology, 1938; Electric Furnace, 1943; Coal Technology, 1946), was replaced by three new magazines: *Mining Engineering*; J*ournal of Metals — Technology, Practice*; and J*ournal of Petroleum Technology*, with *Mining & Metallurgy* discontinued at the end of the year. The Annual Meeting that year was held in the Pennsylvania Hotel, the largest at the time in New York City, to get all the sessions in the same location. Also that year, three new divisions were created: Mineral Beneficiation, Extractive Metallurgy, and Mineral Economics, followed in 1949 by the Mining, Geology and Geophysics Division, making a total of 10 divisions — the "non-divisioned" now had a home and technical committees were discontinued. To further complicate things, the Institute was divided into three semi-autonomous branches, each with assigned divisions:

- Mining Branch: Mining, Geology and Geophysics, Mineral Beneficiation, Industrial Minerals, and Coal divisions.
- Metals Branch: Extractive Metallurgy, Iron and Steel, Institute of Metals divisions.
- Petroleum Branch: Petroleum division.

The Education and Mineral Economics Divisions remained unaffiliated within the Institute. The assignment of Extractive Metallurgy to the Metals Branch was a subject of much debate and remains that way to this day – just ask a metallurgist within SME. In 1951, a Western Field Secretary was appointed for the Mining and Metals branches, located in Salt Lake City.

The Founder Societies were outgrowing the Engineering Societies Building and in 1954 started to consider relocation, ultimately deciding to stay in New York City. At the 1957 Annual Meeting, the three branches of the Institute became societies:

- The Society of Petroleum Engineers (SPE), headquartered in Dallas, TX.
- The Society of Mining Engineers (SME), headquartered in New York City.
- The Metallurgical Society (TMS), headquartered in New York City.

The name of the Institute was changed to the American Institute of Mining, Metallurgical and Petroleum Engineers and the drilling derrick added to the Institute logo, in addition to the traditional crossed hammers. The Institute retained staff in New York City and, starting in 1960, Salt Lake City (Western Field Secretary) and Pittsburgh (part-time) to support the new Societies, referred to as the Constituent Societies.

Also, in 1957 the unaffiliated divisions were made councils: The Education Division becoming the Council of Education, the Mineral Economics Division becoming the Council of Economics, and a new Council, the Council of Section Delegates, was formed. One year later, the Mining, Geology and Geophysics Division within SME changed its name to Mining and Exploration, as it is known today.

In 1958, the American Institute of Chemical Engineers (AIChE) joined the Founder Societies.

When the Branches were formed in 1951, the breakdown of Institute membership was 50 percent mining, 27.1 percent metallurgical and 22.9 percent petroleum. By the end of 1960, those percentages had changed to 35.6, 24.1 and 40.3, reflecting the rapid growth in the petroleum field. As the decentralization of AIME continued, all Institute expenses were allocated based on membership starting in 1960.

Groundbreaking by Herbert Hoover on Oct. 1, 1959 started the construction of the 20-story United Engineering Center, 345 E. 47th St., United Nations Plaza. The building was dedicated on Sept. 5, 1961, completing the move from the Engineering Societies Building at 29 West 39th St. (sold for $1.4 million) that had been constructed through the generosity of Andrew Carnegie. AIME's $500,000 share of the $13.5 million final construction cost was raised through the local sections, the backbone of the Institute. Twenty engineering organizations were initially headquartered at the UEC, with AIME occupying the 13th and 14th floors. Within the SME M&E Division, a Geological Engineering Unit Committee was formed, with the intent of rapidly moving to division status (which never occurred).

SME began a tradition of its stand-alone fall meeting in addition to programming/meetings at the AIME Annual Meeting held in February, selecting Gatlinburg, TN for the first location in September 1962, with an attendance of about 600. SME also started publishing a Transactions Quarterly to get Transactions papers out as quickly as possible. This year also marked the final Joint Solid Fuels Conference — the 25th — held between the Coal Division and the Fuels Division of the American Society of Mechanical Engineers. Although SME now had its own meeting, the majority of attendees at the annual meeting were from SME every year, with limited attendance from SPE.

The Institute joined the National Council of State Boards of Engineering Examiners (NCSBEE) in 1962 on behalf of its Member Societies to provide input on and support for a revised Model Law for Registration of Engineers.

In 1963, the Coal Division of SME instituted a Spring Field Meeting in Morgantown, WV jointly with the Central Appalachian section and the West Virginia Coal Mining Institute. This was followed by visits to Marion, IL in 1964 and Rawlins, WY in 1965.

Through its membership on the Engineering Joint Counsel, AIME participated in the discussions with the National Academy of Science to establish the National Academy of Engineering. The first president of the NAE in 1964 was Dr. A.B. Kinzel, a past president of the Institute and four AIME members were included in the 25 charter members of the organization.

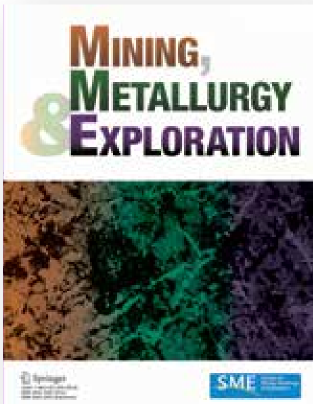
Associated with the 1966 SME 5th Fall Meeting in Tampa, FL, an exposition was added with 79 exhibitors occupying 113 booths and 1,540 attendees. This means by 2021 SME has had 56 years of exhibitors (but, fortunately, only one virtual).

AIME led the way in establishing the interdisciplinary Offshore Technology Conference (OTC), providing financial backing and event management through SPE, with roots in the Institute's Ocean Engineering Committee established in 1966. Sponsored by eight other engineering and scientific societies, the first OTC was held in May 1969, in Houston, TX; roughly 5,000 were in attendance. OTC has contributed significantly to the Institute and Member Society finances ever since that first event.

In 1971, the Institute celebrated its centennial, the result of a five-year planning effort, with a special three-day celebration prior to the annual meeting. The Annual Meeting, in addition to enhanced social events, included special sessions on World Mineral Resources, World Mineral Economics, the Mining and Metallurgical Technology of the Future, and Materials of the Future, all by world-class researchers. Institute membership stood at 48,589, including 3,962 students, with a breakdown between Societies of 35.47 percent SME, 26.9 percent TMS, and 37.7 percent SPE — not bad for an organization founded by 23 individuals 100 years earlier. It took 69 years to reach 10,000 members, 14 more to 20,000, only 4 to 30,000, then nine to exceed 40,000.

As a closing thought, it is worth quoting from SME's report to the AIME Board that year: "The Society of Mining Engineers of AIME went all out to support the celebration throughout the year. Net results of these efforts was an outstanding Centennial Celebration for SME and a whopping ($90,744) financial deficit for SME of AIME. ….The February Annual Review was more than just an annual review issue. It was a once-in-a-century production paying tribute to AIME and the Mining Industry." ■

Extended abstracts from the SME journal
Mining, Metallurgy & Exploration



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Analysis of the impacts of mining sequence and overburden depth on stability at a dipping limestone mine

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Keywords: Mining, Ground control, Rock mechanics, Numerical modeling

To read the full text of this paper (free for SME members), see the beginning of this section for step-by-step instructions.

Special Extended Abstract

Ground falls represent a significant hazard at underground mines in the stone, sand and gravel (SSG) sector in the United States. Researchers from the U.S. National Institute for Occupational Safety and Health (NIOSH) are conducting detailed investigations into the complex loading conditions at underground stone mines operating in challenging conditions. This paper presents the application of numerical modeling to analyze pillar and roof stability at a dipping underground limestone mine.

Background

The Pleasant Gap Mine, located in central Pennsylvania, operates in the Valentine Formation. This formation is a typically light gray, extremely fine-grained limestone and is approximately 21.3 m (70 ft) thick. Situated in a syncline, the top of the Valentine Formation dips at approximately 19° with a strike of approximately N54E in the area of interest. Due to the dipping nature of the formation, the mining height slopes across the heading.

Results and discussion

Comparison between mining sequences. The mining sequence monitored in the area of interest was compared with two alternative mining sequences using FLAC3D models [1]. Alternative sequence 1 represents a mining sequence where the heading is advanced inby the projected crosscut first. The crosscut is subsequently advanced to create the intersection. Alternative sequence 2 represents the typical extraction sequence used elsewhere in the mine. In this sequence, the crosscut is developed prior to the advancement of the heading, creating the intersection.

Using alternative sequence 1, the model results indicate a 15 percent decrease in the maximum vertical roof displacement at intersection A' compared with intersection A. Alternative sequence 2, on the other hand, results in only a 5 percent reduction in the vertical roof displacement at intersection B' compared with intersection B (Fig. 1). Based on these model parameters, alternative sequence 1 results in the least vertical roof displacement.

Comparison between in situ stress fields. In addition to exploring the potential impact of altering the extraction sequence, the mine is projected to encounter overburden depths up to 760 m (2,500 ft). While the effective vertical stress change from increasing overburden depth is well known, the same cannot be said about the horizontal stress that could potentially be encountered. To explore the potential impact of a variable in situ stress field on the conditions that could be encountered in the mine, the base case model was compared to two alternative in situ stress fields.

Alternative stress field 1 represents increasing the vertical stress in the model from 10 MPa (1,450 psi) to 19 MPa (2,750 psi), resulting in a reduction of the ratio of horizontal to vertical stress, or k-ratio, from 3.2 to 1.7 from the base case. Alternative stress field 2 increases the maximum and minimum horizontal stress to 41 MPa (5,950 psi) and 22 MPa (3,190 psi), respectively, while maintaining the same 19 MPa (2,750 psi) vertical stress from alternative stress field 1, increasing the k-ratio to nearly 2.2 (Fig. 2).

This model indicates that roof displacement is expected to increase to a maximum of just over 3.6 cm (1.4 in) for alternative stress field 1. This represents about an 80 percent increase in roof displacement at the intersection compared to the base case. Increasing the horizontal stress to that of alternative stress field 2 results in increased vertical roof displacement from 3.6 cm (1.4 in) in the previous model to over 5 cm (2.0 in). This represents a 40 percent increase in the maximum displacement when compared to leaving the horizontal stress component unchanged.

Comparison of pillar stability. In addition to the roof displacement being used as an indicator of relative stability in the mine, pillar stability as the depth increases was also considered. In FLAC3D, safety factor contours can be determined by plotting the stress-strength ratio (SSR). The resulting SSR contours determined by the validated model (A), alternative stress field 1 (B), and alternative stress field 2 (C) can be seen in Fig. 3.

The average SSR of the pillar for the base case after applying a 37 percent reduction factor is approximately 2.1. For this case, where the overburden depth was increased to 760 m (2,500 ft), the average SSR of the pillar is approximately 1.6. This represents a nearly 25 percent reduction in the SSR when compared to the base case model. Increasing the horizontal stress field appears to have limited impact on the SSR of the pillar itself. Instead, the greatest impact is on the SSR of both the immediate and main roof.

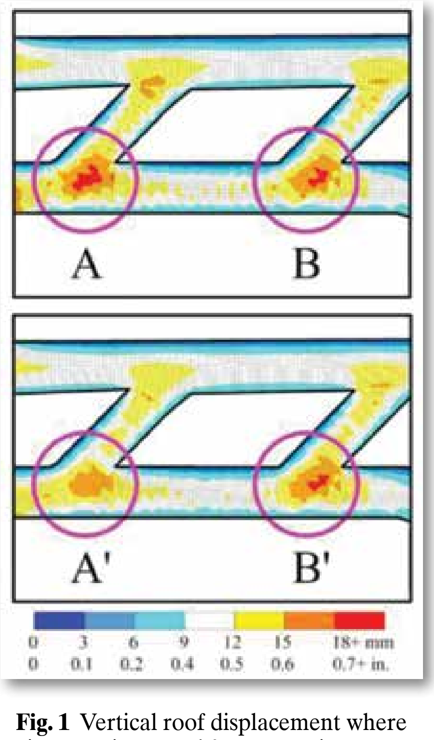

Fig. 1 Vertical roof displacement where intersections used for comparison are labeled A and A' for alternative mining sequence 1, and B and B' for alternative mining sequence 2.

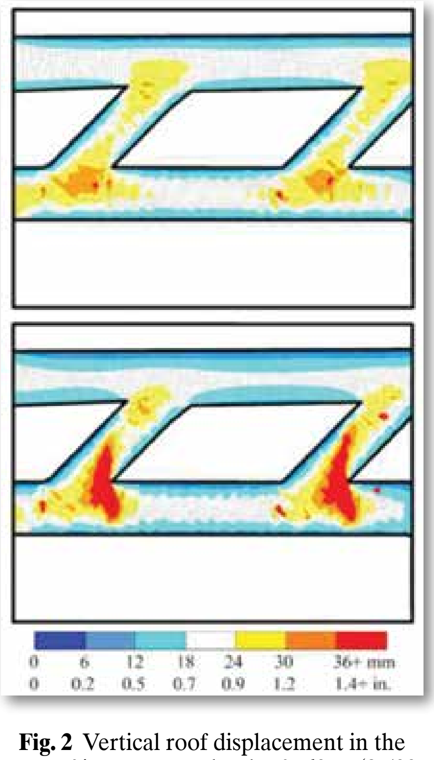

Fig. 2 Vertical roof displacement in the area of interest at a depth of 760 m (2,500 ft) using alternative stress field 1 (top) and alternative stress field 2 (bottom).

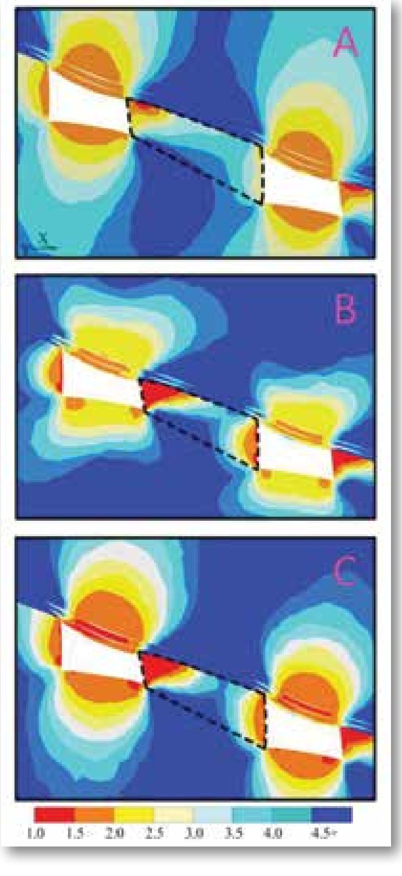

Fig. 3 Stress-strength ratio (SSR) contours within the pillar represented by the dashed line from the validated model (A), alternative stress field 1 (B), and alternative stress field 2 (C).

Conclusions

This paper presented the practical application of a validated FLAC3D model [2]. The validated model was used to compare the conditions currently being encountered in the mine with those that could likely be expected in the future. The practical application of validated numerical models such as this is extremely important for mine management and engineers, particularly when faced with more challenging mine environments. The impact of such applications can result in a reduction of ground-fall accidents and injuries as well as generally safer working conditions. ■

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A review of recent advances in pyrometallurgical process measurement and modeling, and their applications to process improvement

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Keywords: Pyrometallurgical industry, Analytical measurement techniques, Computer-based modelling/simulations, Smelting process and equipment

To read the full text of this paper (free for SME members), see the beginning of this section for step-by-step instructions.

Special Extended Abstract

The pyrometallurgical industry plays a vital role in producing metals for our modern life. With growing demand for metals and declining grade of mineable ore, innovations become critical for many mining companies. This has given rise to the need for a review of recent improvements to the pyrometallurgical industry in terms of analytical measurement techniques, process and equipment improvements, and computer-based modeling/simulations. Because many of these innovations tend to be applied to a wider scope of metals, not restricted to a specific metal, we studied the broad applications of many improvements to a wide range of metals. We found that the challenge of a lack of robust measurement techniques under high-temperature conditions within a furnace hinders optimization of a pyrometallurgical process. Some future opportunities in the pyrometallurgical industry on analytical measurement techniques, computer modeling, and processes and equipment were also outlined and discussed.

Background

Pyrometallurgy has existed in one form or another for several thousand years. It is a massive production industry, encompassing 16.5 Mt of copper by pyrometallurgical production, 1,812 Mt of crude steel and 4.8 Mt of mine production of lead in 2018 in the world [1]. Modern pyrometallurgy looks highly different from ancient methods. Metals that had only been available in small quantities, such as titanium and vanadium, have become more readily available [2], allowing them to be used to improve the properties of steel and other equipment. Nowadays, growing concerns over sustainable development have promoted a circular economy with secondary metal production: that is, production from metal scrap. Secondary metal production accounts for around 20 percent of global metal output for most widely recycled metals, such as steel, aluminum and copper, but less than 1 percent for many other important metals [3].

Summary

To highlight recent efforts to reduce metal losses and raise process efficiency, this paper presents innovations that researchers have investigated over the past several decades. Measurement techniques, process and equipment improvements, and computer modeling are covered. They are summarized in Table 1, along with some of the challenges and opportunities for future research.

Future opportunities

The opportunities in analytical measurement techniques, computer modeling, and processes and equipment outlined here include the use of electromagnetic, ultrasonic and optical-fiber techniques in high-temperature environments. Obtaining real-time measurements for detailed information on the mixing of fluids and phase changes inside a furnace is a major challenge, but this type of information is crucial for process control and validation in simulation software. Due to the current lack of proper measurement tools in the mineral industry, multiphase flows are treated as in a "black-box" [4]. By measuring the conductivity distribution across a measurement area, many researchers have adopted electrical resistance tomography (ERT) to monitor and investigate many processes involving multiphase flows. ERT

Table 1 — Recent improvements of the pyrometallurgical industry by category (see full-text paper for references).

Category	Improvement	Advantages	Disadvantages
Measurement techniques	Electromagnetic sensors	Can accurately detect molten levels in a furnace; Uses resistivity to detect different levels	Distance from the molten bath exponentially decreases effectiveness; Electrical systems in nearby proximity affect effectiveness
	Ultrasonic sensors	Can pass through all solid, liquid and gas phases; Can be used for multiple purposes in a smelting environment: level detection, gas dedusting, grain growth suppression	High temperature makes installation of equipment difficult
	Radar sensors	Can be used for level measurement; Can be used for burden surface measurement	Cannot detect the inner state of the burden descent field beneath the burden surface
	Fiber-optic sensors	Can be used for temperature measurement	Maintenance of sensors is difficult
Primary process improvements	Primary extraction processes and equipment	Can be used for process integration and automation; More efficient with new equipment	Many innovations to a smelting process are not large scale; Based on trial and error; Depends on operator experience
Recycling process improvements	Recycling of waste metal products (electronic and automotive)	Emerging industry; Solution to declining reserves of precious metals; Removes hazardous materials from landfills	High-temperature/high-energy requirement; Process often creates hazardous gases; Grinding and separation of plastics often required prior to smelting
Modeling improvements	Modeling software/ simulations	Predictive modeling optimizes process; Reduces costs/error	Extensive databases required for accurate modeling; Each metal/ore system is different from the other

has the potential to be used for high-temperature flows in pyrometallurgical processes. Recycling valuable metals in waste products, such as spent automotive catalysts and waste electronics, is an exciting area of interest in the industry and a critical necessity. More future research can be envisaged to integrate computational fluid dynamics (CFD) and pyrometallurgical software packages, such as illustrated in Fig. 1. Moreover, the simulation results of CFD models need to be validated by novel measurement techniques.

Environmental impact is another important topic that should be considered in pyrometallurgical research, and research opportunities related to sustainable development of the pyrometallurgical industry will emerge.

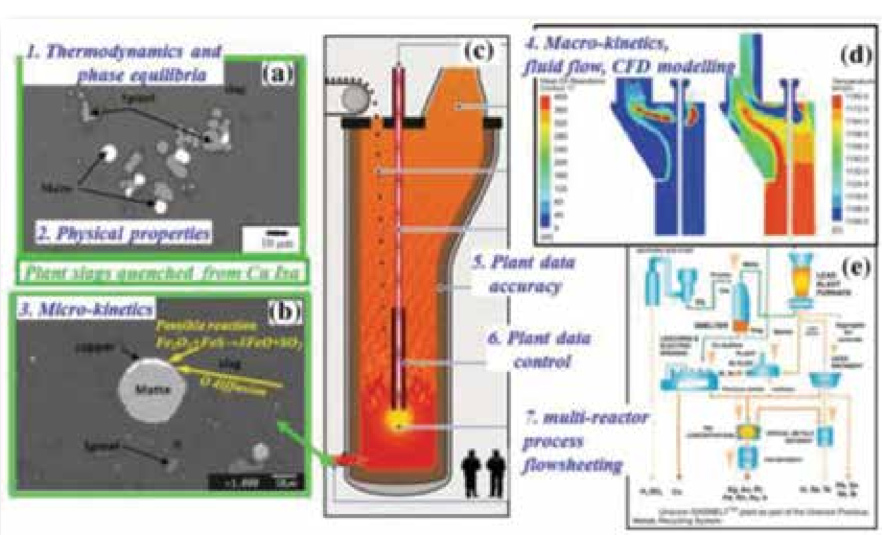

Fig. 1 Schematic illustrations of the critical components for the Virtual Reactor and Pyro-GPS being developed by the Pyrometallurgy Innovation Centre (PYROSEARCH): (a),(b) Slag samples quenched from Cu IsaSmelt, (c) IsaSmelt schematic, (d) CFD predictions for a TSL furnace and (e) plant flowsheet [5].

Conclusions

The pyrometallurgical industry has seen many changes in the past 20 years. A declining concentration of mineable ore and increased guidelines for environmental protection have spurred companies and researchers to invest in new innovations in the areas of measurement techniques, processes and equipment, and modeling software to optimize their businesses. This paper outlines the different pathways for innovations, along with future opportunities. Although not all-inclusive, this literature review of recent innovations provides an overview of some of the ways that the pyrometallurgical industry is adapting and improving to meet the demands of consumers. Despite these recent improvements, many challenges remain for the pyrometallurgical industry. ■

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Occurrence modes of niobium in kaolin clay from Guizhou, China

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Keywords: Niobium occurrence, Titanium dioxide, Morphology, Kaolin clay

To read the full text of this paper (free for SME members), see the beginning of this section for step-by-step instructions.

Special Extended Abstract

Kaolin clay from Late Permian sequences has been considered a potential resource for niobium (Nb) due to high concentrations reported at several hundred micrograms per gram and large areal distribution. A previous case study identified titanium (Ti)-bearing minerals associated with kaolin clay as the main host phases for niobium. Correlation between the Nb and Ti concentrations was poor, however, and the types of Ti-bearing minerals and modes of Nb occurrence were unclear. To investigate this, typical kaolin clay samples from Late Permian sequences in southwest China were characterized, and final products derived from them were investigated using X-ray fluorescence (XRF), inductively coupled plasma-mass spectrometry (ICP-MS), X-ray diffraction (XRD), scanning electron microscope (SEM), transmission electron microscope (TEM) and energy-dispersive X-ray spectroscopy (EDS). The results revealed three types of titanium dioxide (TiO_2) mineral phases in the clay samples: (1) massive TiO_2 minerals, (2) aggregates of nano TiO_2 minerals and (3) granular TiO_2 minerals. The first two did not contain niobium. From the EDS analysis, the granular TiO_2 minerals, including anatase and rutile, were the source of Nb in the kaolin clay samples.

Background

Niobium is an extensively used, strategic metal. Global demand has been increasing for several decades due to its use in the steel and alloy industry. Worldwide, more than 95 percent of niobium ore reserves are estimated to be in Brazil and Canada. This imbalance of resource distribution and the rising industrial demand for niobium have encouraged the exploitation and processing of new niobium resources.

In China, kaolinitic clay rocks from the Xuanwei Formation were reported as new polymetallic resources with high concentrations and large areal distributions for niobium, rare earth elements, zirconium, gallium and other metals. According to the Chinese Geology Mineral Industry Standard, which defines 160 to 200 µg/g as the lower limit of niobium pentoxide (Nb_2O_5) content for exploration, Nb content in the kaolinitic clay rocks is mainly in the range of 200 to 600 µg/g and generally higher than in weathered crust Nb deposits. The aim of the present work is to depict the occurrence modes of Nb and elucidate the relationship between Nb and Ti in kaolinitic clay from the Xuanwei Formation.

Samples and methods

Kaolin clay samples were collected from the bottom of the Xuanwei Formation in Weining county in Guizhou, China. TiO_2 is a common impurity in kaolin clays, and three typical kaolin samples representing low titanium (L-Ti), medium titanium (M-Ti) and high titanium (H-Ti) contents were characterized. The TiO_2 contents in the three samples were determined as 3.67, 8.79 and 11.20 percent, respectively, with corresponding Nb concentrations of 206, 491 and 561 µg/g. As the TiO_2 and Nb contents in the M-Ti sample were close to the averages of the TiO_2 and Nb contents in the kaolin clay of the whole Xuanwei Formation, it was selected to represent the Xuanwei Formation clay for further study on modes of niobium.

In previous work, M-Ti samples had been reported for enrichment of Nb and Ti by using acid and alkali leaching to remove aluminum (Al) and silica (Si). The final products contain more titanium and are easier to investigate and characterize. The main and trace chemical compositions of the kaolin clay samples were determined using XRF and ICP-MS. Powder XRD measurements were performed using a PANalytical Empyrean diffractometer with Cu Kα radiation. Samples of the final products were observed by an FEI Scios SEM and a TEM at accelerating voltage of 200 kV. Analysis methods included high-magnification imaging, high-resolution imaging, EDS, selected-area electron diffraction and Fourier transform structural analysis.

Results and discussion

Kaolinite and anatase matched well in all three samples. Rutile could be recognized in the M-Ti and H-Ti samples, as they had high enough Ti contents. Goethite was judged as one of the iron (Fe)-bearing phases in the H-Ti sample.

The clay samples in this study consisted of kaolinite, anatase, rutile and goethite with trace quantities of common mineral impurities. In general, the kaolin clay samples had simple mineral compositions, indicating that trace accessory minerals might not be the host phases for Nb, as the Nb concentrations in the samples were so high.

The final product derived from the M-Ti sample after acid-alkali leaching was used to investigate the categories of Ti-bearing mineral phases, the occurrence modes of Nb, and

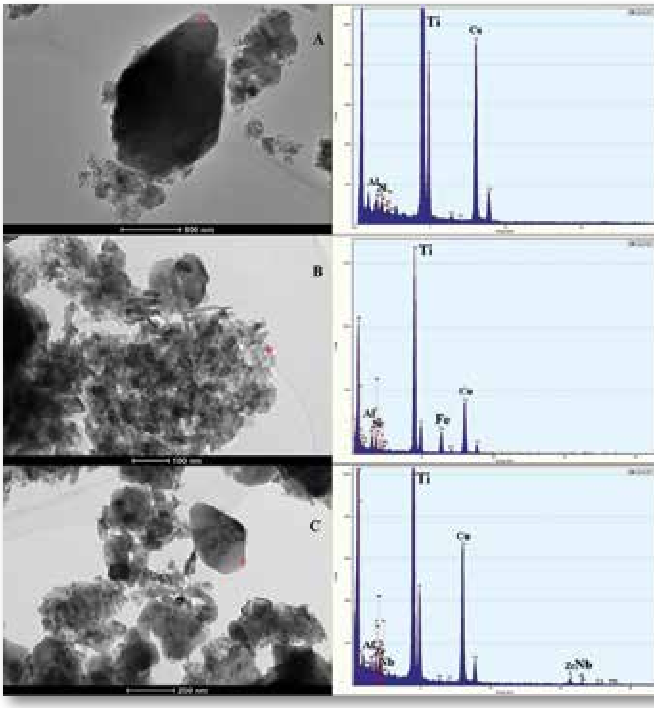

Fig. 1 TEM micrographs and EDS analysis of titaniferous minerals in the final product derived from clay calcined at 850 °C prior to acid-alkali treatment: (a) massive TiO_2 minerals, (b) aggregates of nano TiO_2 minerals and (c) granular TiO_2 minerals.

the relationship between Nb and Ti-bearing mineral phases. The Ti-bearing minerals were actually TiO_2 minerals that could not be identified as anatase or rutile because of their extremely small particle size.

Among the large amount of Ti-bearing minerals in the final product derived from the M-Ti sample, three types of TiO_2 mineral phases were categorized based on their crystal form and size from the TEM analysis (Fig. 1): (1) Massive TiO_2 minerals (Fig. 1a): Relatively large particles, 500-1,000 nm or bigger, with very low iron content and no niobium, as determined by EDS analysis. They accounted for less than 10 percent of the Ti-bearing minerals. (2) Aggregates of nano TiO_2 minerals (Fig. 1b): Small TiO_2 mineral particles with granular or short columnar shape to form xenomorphic textures, which have high iron content and no niobium, as determined by EDS analysis. The nanoscale particles (smaller than 50 nm) occurred closely together. They accounted for about 20 to 30 percent when viewed in the TEM. (3) Granular TiO_2 minerals (Fig. 1c): These were the dominant form of the Ti-bearing minerals, accounting for more than 60 percent under the TEM. They included round, cubic and short columnar shapes and were about 100 to 300 nm in diameter. Niobium and zirconium peaks were seen in the EDS analysis. They are considered to be one of the sources of Nb.

Rutile has been suggested as the major Ti-bearing mineral that retains the high-field-strength elements, such as niobium and tantalum, during magma partial melting, while anatase has been widely considered as the dominant Ti-bearing phase and an essential constituent of sedimentary kaolin deposits. In the present study, the modes of occurrence of Nb had involvement with the morphologies of TiO_2 minerals, and both anatase and rutile were confirmed as sources of niobium in the kaolin clay used in the study.

Conclusion

Clay samples with different titanium contents from the Xuanwei Formation — Late Permian sequences in Guizhou, China — were found to mainly contain Al_2O_3, SiO_2, TiO_2 and Fe_2O_3. Niobium content in the kaolin clays could be as high as 551 µg/g. Three types of TiO_2 mineral phases in te final product derived from the kaolin clay sample were categorized as: (1) massive TiO_2 minerals, which contained no niobium, (2) aggregates of nano TiO_2 minerals and (3) granular TiO_2 minerals. The granular TiO_2 minerals included anatase and rutile, and both were confirmed as sources of Nb in the kaolin clay in the current study. The findings have theoretical implications for the source and origin study of Ti-bearing minerals and can provide guidance for the separation and recovery of Nb from Ti-bearing minerals or kaolin clay. ■

References

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

The Plewes method: A word of caution

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Keywords: Tailings, Liquefaction, Screening method, CPT, Uncertainty

To read the full text of this paper (free for SME members), see the beginning of this section for step-by-step instructions.

Special Extended Abstract

The Plewes method is relatively well known among geotechnical engineers interested in assessing the liquefaction potential of soil deposits. Furthermore, it was one of the four methods considered in the post-failure investigation report of *the Feijao Dam I, also known as the Brumadinho Dam, in Brazil. The inclusion of the method in that report is likely to increase its visibility among geotechnical practitioners tasked with assessing the liquefaction potential of tailings. While the authors of the method duly presented it as a screening method, more recent technical literature contains conflicting views on its reliability. Considering the popularity of the method and that the safety record of tailings dams is a cause of great concern, this study assessed the uncertainty of results from the Plewes method. The study concludes that, even under optimistic assumptions, the results of the method are too uncertain for detailed characterization of tailings deposits.*

Background

The release of liquefied tailings that often follows the failure of tailings dams has enormous destructive consequences and remains an important concern to geotechnical engineers. Difficulties in obtaining high-quality samples in sandy and silty material such as tailings have prompted the development of liquefaction assessment methods that rely on cone penetration testing (CPT), or other in situ tests, and which may be complemented with laboratory testing. One such method was proposed by Plewes et al. [1] as a screening procedure to assess liquefaction susceptibility in a wide variety of soil types ranging from clays to sands, and explicitly including tailings. Specifically, the Plewes method assesses liquefaction susceptibility by using CPT data to estimate the in situ state parameter, ψ, which characterizes the void ratio deviation between the state of a soil and its critical state line. Given the method's popularity and the significant consequences of tailings dam failures, the objective of the current paper is to assess the uncertainties of the Plewes method.

Methodology

The study considered the data that underpin the framework that preceded the development of the Plewes method, data presented in Plewes et al.'s paper [1], and more recent data presented in studies that have explicitly looked at the correlations used in the Plewes method or have investigated the variability of the critical state line in tailings dams. These data were used to quantify the uncertainty of the results of the Plewes method when considering both the intrinsic uncertainty of the method and the uncertainty due to the variability in soil compressibility as indicated by the slope of the critical state line, λ_{10}.

To account for the variability of λ_{10} along the depth of the CPT sounding, the Plewes method suggests a correlation between λ_{10} and the sleeve friction, F, of the CPT: $\lambda_{10} = F/10$. Figure 1 shows the correlation as well as experimental data from multiple sources. While the data generally agree with the correlation, the scatter implies important uncertainties. For instance, for $0.4 \leq F \leq 1.3$, which includes several tailings case histories, the plot suggests that λ_{10} falls between 0.03 and 0.18. To put this range of 0.15 into context, consider that the λ_{10} values of nonplastic soils in general, including tailings, typically vary from almost 0 to 0.3, so the data in Fig. 1 confine the λ_{10} estimate to a range that covers half of all typical values in nonplastic soils. This is akin to estimating the age of a person to an accuracy of ±20 years (assuming a life expectancy of 80 years). Accordingly, this study assumes that implementation of the Plewes method relies on laboratory measurements of λ_{10}. This approach eliminates the uncertainty that arises from the λ_{10}-F correlation shown in Fig. 1, and has been adopted in previous studies.

Results

Even when making an optimistic assessment of the intrinsic uncertainty of the Plewes method, and assuming that λ_{10} values are available from laboratory testing, as opposed to using the λ_{10}-F correlation (Fig. 1), the uncertainty of the estimated state parameter ψ is too high for detailed engineering characterization of tailings deposits. The relatively low values of λ_{10} that are typical of tailings contribute to the high uncertainty. Furthermore, establishing the full range of λ_{10} values present in a nonplastic tailings deposit remains a challenge for a number of reasons. For instance, it is not clear which sample should be tested to get the highest λ_{10} value and which one to get the lowest λ_{10}. It is worth highlighting

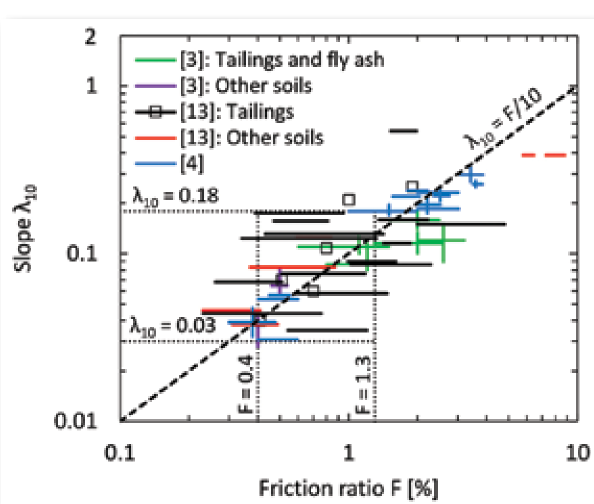

Fig. 1 λ_{10} versus F correlation proposed by the Plewes method (dashed diagonal line) and experimental data (see full-text paper for data sources).

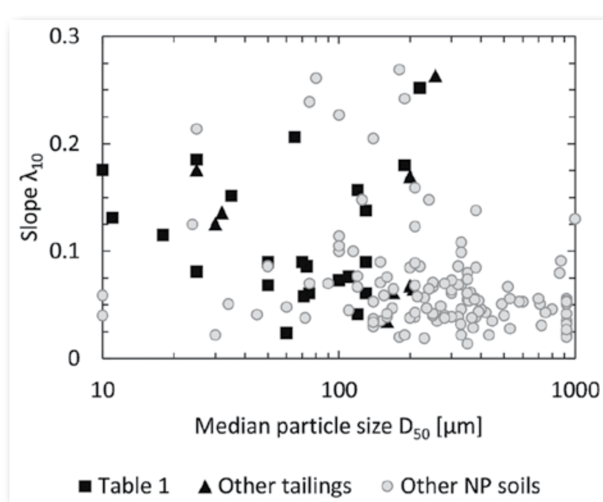

Fig. 2 Lack of correlation between CSL slope λ_{10} and median particle size D_{50} in nonplastic soils (see full-text paper for data sources).

that testing a representative coarse sample and a representative fine sample does not disclose the range of λ_{10} values present in the deposit because the experimental data of nonplastic soils do not support a correlation between λ_{10} and particle size (Fig. 2). Furthermore, recent studies show that reproducibility issues in critical state line testing also impose limits on how confident we can be about λ_{10} measurements. The study makes recommendations on how to present the results of the Plewes method in a format that is consistent with its significant uncertainty.

Conclusions

The historical record of tailings dam failures is a stark reminder of the need to critically assess the methods used to investigate the stability of these structures. Accordingly, this paper had a close look at the Plewes method for which the technical literature contains conflicting views regarding its reliability. The results show that the uncertainty of the method is too high for detailed estimates of the state parameter ψ. These results highlight the screening nature of the Plewes method and the need to implement additional methods when assessing the stability of tailings dams. ■

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The coupling effect in the drying section of traveling grate: A CFD and experimental study

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Full-text paper:

Mining, Metallurgy & Exploration (2021) 38:1239–1246, https://doi.org/10.1007/s42461-021-00398-8

Keywords: Traveling grate, CFD, Drying section, Iron ore pellet

To read the full text of this paper (free for SME members), see the beginning of this section for step-by-step instructions.

Special Extended Abstract

Traveling grate is a widely used process for iron ore pellet production, but the thermal state of pellets in the drying section is still unclear. In this study, the temperature distribution of the drying section was investigated using computational fluid dynamics (CFD). The results indicate there is a coupling effect in the drying section of a traveling grate. Gas with higher temperature in down-draught drying (DDD) transfers heat to the up-draught drying (UDD) through the gap of the insulation board, and the temperature gradient of the pellet bed changes before reaching the insulation board. The characteristics of pellet bed expected to appear in DDD are displayed in UDD in advance. To verify the model, a contrast experiment was conducted.

Introduction

Iron ore pellets are one of the main materials of the ironmaking process, and production is increasing. Due to large capacity and higher thermal efficiency through the recycling of hot waste gas, grate-kiln is a widely used process for iron ore pellet production. As shown in Fig. 1a, in a typical grate-kiln-cooler pellet production system, green pellets enter the induration system by feeding onto the grate, then go through the grate, kiln and cooler successively and are finally unloaded as finished pellets. The traveling grate has four parts: UDD, DDD, temperate preheating (TPH) and preheating (PH), with temperatures of 250, 350, 750 and 1050 °C, respectively [1]. The inherent moisture of green pellets is removed in UDD and DDD, and the pellets are oxidized in TPH and PH, with the carbonate decomposing. The four sections are mutually independent but mutually influential.

Research on the temperature field in a traveling grate has been mostly based on the energy balance and mass balance, which are mainly used to reveal the thermal energy distribution inside the material [2,3]. Realizing stable control of the drying-section temperature field in a traveling grate has been challenging. For in-depth research into the drying effect in a traveling grate, especially the coupling effect between the UDD and DDD, a mathematical model of the pellet-drying process in traveling grate was established in this work. The space temperature distribution and the temperature change of pellets were analyzed and discussed. Finally, a contrast experiment was conducted to verify the model.

Simulation and experiment

Table 1 shows the thermodynamic parameters of the drying section (UDD and DDD) for a traveling grate with throughput of 240 t/h. The temperature gradient in the width direction of the traveling grate is ignored, giving a simulated 2D model 24 m long (the UDD and DDD are 9 and 15 m, respectively) and 4 m high (Fig. 1b). A CFD flow solver based on the finite volume method (ANSYS Fluent) is used to solve the Reynolds-averaged Navier-Stokes (RANS)

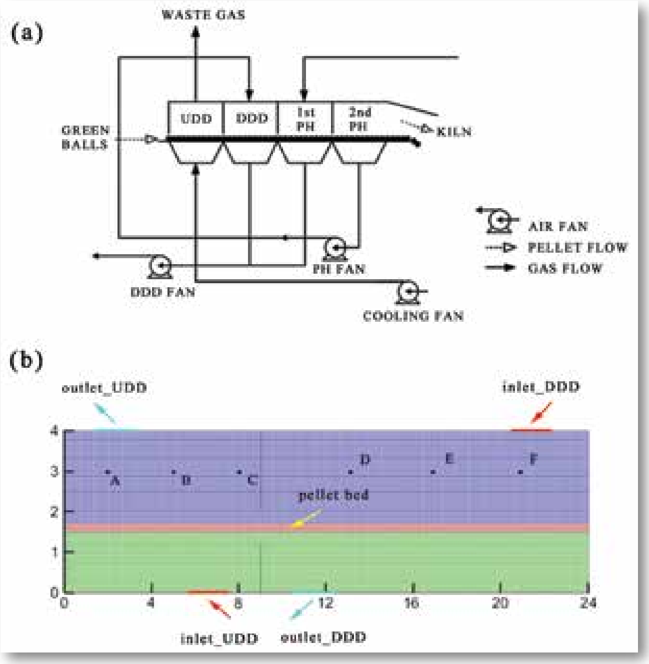

Fig. 1 Schematics of (a) a typical traveling grate system and (b) computational domain.

Table 1 — Simulation parameters.

Parameter	Value
Pellet initial humidity (kg/m³)	189.2
Pellet critical humidity (kg/m³)	132.44
Pellets layer thickness (m)	0.02
Pellet diameter (m)	0.0012
Pellet porosity	0.25
Pellets layer porosity	0.39
Pellet density (kg/m³)	2200
Pellet and gas initial temperature (K)	293
UDD gas temperature (K)	473
DDD gas temperature (K)	623
UDD gas flow rate (m/s)	1.45
DDD gas flow rate (m/s)	1.65
Gas density (kg/m³)	1.093
Gas constant (J/mol·K)	8.314
Pellet specific surface area (m²/m³)	375
Water density/(kg/m³)	1000
Molar mass of water (kg/mol)	0.018
Grate plate thermal conductivity (J/m·s·K)	16.27

equations and the energy equation. To ensure the stability of the value, after considering the calculation accuracy and efficiency, the simulation time step is set to 0.05 s.

The design of the structure of the laboratory-scale experimental setup mirrors that of a real traveling grate with throughput of 120 t/h. The shell of the equipment is made of stainless steel with length of 3,900 mm, height of 1,300 mm and width of 550 mm, within which the UDD is 927 mm long and the DDD is 1,473 mm long.

Results and discussion

Figure 2 shows the computed results for gas temperature at the points marked in Fig. 1b. For comparison, the measured results of the corresponding points are also presented. As shown in Fig. 2a, the curves of A and B are more flat than C during the initial period in the UDD, which indicates that the heating rates at locations A and B are lower than at C. Due to the temperature gradient increasing gradually in the velocity direction of the grate, and part of the high-temperature gas from the DDD getting into the UDD through the insulation board, the temperature around location C rose to 440 K in 30 s. In about 60 to 90 s, the heating rates of all three locations first decreased and then increased, due to the water evaporation of pellets, which absorbs a lot of heat. This is consistent with the experimental results in the UDD.

Figure 2b shows the temperature profile of different points in the DDD. The temperatures at E and F became stable quickly, while that at D needed more time. Compared with the ideal model of CFD, much heat is lost during the high-temperature experiment, most of which is heat leakage due to the unenclosed drying section. Although the overall

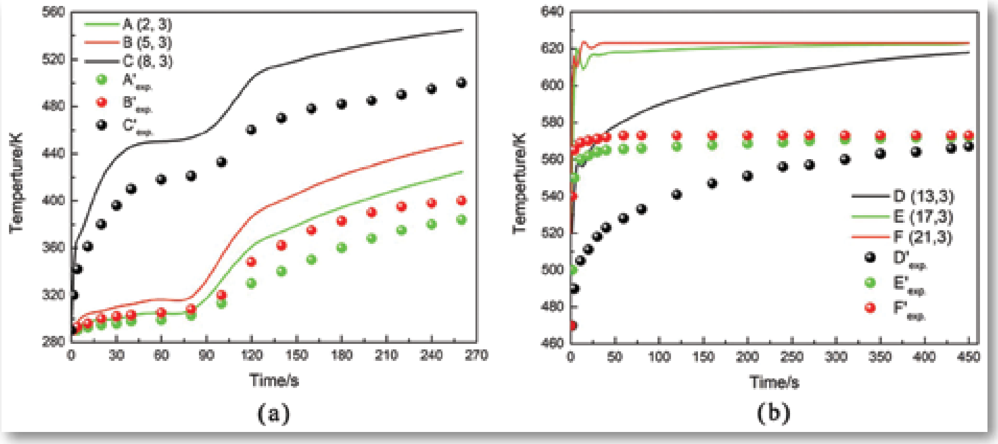

Fig. 2 Computed and measured results of gas temperature at different points of the (a) UDD and (b) DDD.

temperature in the experiment is lower than the computed results, the same rules and conclusions can be obtained from the experimental data, verifying the CFD model.

Conclusion

The temperature distribution of the drying section in a traveling grate was investigated using CFD. Based on the analysis of velocity and temperature distribution in the drying section, a coupling effect was found between the UDD and DDD. The space temperature in the drying section was analyzed by comparing the computed and measured results at different points. Though with some limitations, a similar changing rule of temperature curves can be observed from the simulation and the experiment. ■

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The passive fire protection of mining vehicles in underground hard-rock mines

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Full-text paper:

Mining, Metallurgy & Exploration (2021) 38:609–622, https://doi.org/10.1007/s42461-020-00359-7

Keywords: Fire protection, Mining vehicle, Ignition, Underground mine, Fire spread

To read the full text of this paper (free for SME members), see the beginning of this section for step-by-step instructions.

Special Extended Abstract

Vehicle fires in underground mines pose a certain risk for which measures to prevent or mitigate the fires are highly important. Fire protection measures can be divided into active and passive measures, where active measures require an external power to work in the event of a fire, and passive measures could include an existing partition preventing fire spread. As passive fire protection does not rely on activation, it is expected to provide high reliability and a robust solution, and should be considered during the design process. This paper investigates passive fire protection measures that could be implemented in the design of mining vehicles. It was found that passive fire protection should include the use of several measures simultaneously to ensure fire protection throughout the different phases of a fire. Threshold distances for fuel components were calculated, and it was found that combining hydraulic hoses and electrical cables resulted in larger threshold distances. A pool fire along the underside of a vehicle will pose a certain risk, and passive measures should be focused on ignition prevention, making high demands on the insulation/shielding along the underside. Any occurring tire fire may pose a challenge, and the priority should be on preventing ignition. Potential measures include shielding the wheelhouse and applying fire-resistant sealings.

Table 1 — Critical heat flux of various solid, combustible components [1].

Combustible component	Critical heat flux [kW/m²]
Tire (natural rubber)	17.1
Electrical cable	4.0
Hydraulic hose	6.2
Driver seat	1.3

Background

Several studies on fires in underground mines showed that vehicles and mobile equipment are the dominant sources of fire in hard-rock mines but also pose a risk in coal mines. Earlier studies on fires in mining vehicles have focused on the fire's behavior and the impact on the surroundings. Looking into measures to prevent vehicle fires or mitigate their effects is just as important. Fire protection measures can be divided into active and passive measures, where passive fire protection measures could include a fire wall, a fire-resistant material, an opening for ventilating fire gases, and so on. This paper focuses on the design of mining vehicles with respect to passive fire protection measures. Different vehicle sections and fuel items are analyzed, applying data from full-scale fire experiments, cone calorimeter tests as well as statistical data.

Earlier work on fire protection of mining vehicles and heavy-duty vehicles in general was limited, focusing mainly on active fire protection systems. In the few publications found where passive fire protection on vehicles was investigated, they were mainly aimed at the post-collision scenario with an ensuing fire. Fire protection measures on a passenger car or a bus above ground are focused on ensuring the safe evacuation of passengers. Fire protection measures on a mining vehicle may also be aimed at mitigating the effects on the surroundings, allowing for safe evacuation of the affected part of the mine, or enabling a firefighting operation. Even though this paper focuses on mining vehicles in underground hard-rock mines, its findings may, in many cases, also be applied to mining vehicles in coal and surface mines.

Results and discussion

As fires on mining vehicles are most likely to start in the engine bay, passive measures should be aimed at preventing fires from occurring and from spreading beyond the engine bay. The choice of material could be a key component, preferably selecting fire-resistant materials and substances. Whenever possible, steel piping should be considered. If nonfire-resistant cables are used, fire-resistant sleeves can be employed to remedy the deficiency. Fuel lines or hydraulic hoses that are highly likely to leak or burst in a post-collision scenario should be repositioned or equipped with mechanical protection. Hot components that could be exposed to an oil spray or leakage should be shielded.

The reliance on external heat flux for continued fire spread makes passive measures on hydraulic hoses a viable option. Other than the passive measures listed for the engine bay, any shielding measures along the lengths of hydraulic hoses could be key. Given the transient nature of the line fire and the limited fuel load, an adequate measure could be a fire sleeve mounted on a hydraulic hose.

The risk of electrical cable fires is similar to that of hydraulic hose fires, as are the passive measures. Threshold distances for several configurations of electrical cables and hydraulic hoses were calculated, and it was found that the resulting thresholds of the bundles of electrical cables were smaller than those for the hydraulic hoses, despite the lower critical heat flux (Table 1). A combination of hydraulic hoses and electrical cables will result in larger threshold distances due to the higher flame heights of the hose fires and the lower critical heat flux of the nonfire-resistant electrical cables.

Pool fires could be prevented by making sure that sharp or pointed objects near the tanks are avoided, that tanks are located away from the perimeter, and that lids or any opening devices are made of noncombustible material. Other measures comprise abrasion protection of attached hoses, and mechanical protection of tanks and attached hoses and lines. Tanks should be located away from hot surfaces, hot surfaces shielded, and no hot surfaces located in the possible path of a leakage. The autoignition temperature of diesel should be used as a benchmark. Minimizing the area of the pool and directing the leakage in a desired direction could include a containment device underneath the tank and attached hoses/lines where the leaking liquid is collected and prevented from causing a pool fire underneath the vehicle.

Given the constantly present longitudinal ventilation in an underground mine drift, the ventilation flow will push the flames and fire gases underneath the vehicle and affect large parts of the vehicle in the flow direction. Figure 1 shows the lower section of a drilling rig used in full-scale fire experiments [2]. The hydraulic hoses are largely unprotected with respect to the pool fire and will contribute to the fire spread along the vehicle. Preventing the ignition of hydraulic hoses and cables would include insulating and shielding the hoses and cables. Preventing the ignition of tires could be achieved by channeling the flow of flames and fire gases along the length of the vehicle and preventing the flames and gases from spreading sideways to the tires.

Fig. 1 The lower section of a drilling rig.

Given the high critical heat flux value for a tire (Table 1), passive measures could have a large impact on the ignition prevention of the tires. If possible, no hydraulic hoses or cables should run through the wheelhouse. If the wheelhouse cannot be shielded from hoses and cables, fire-resistant sealings should be applied at the boundaries. Mudguards should cover as much as possible on the sides.

Preventing the ignition of the cab would include the use of fire-resistant interior materials and fire-resistant glass. Fire-resistant sealings should be applied to prevent fire spreading to the cab by avenues such as cables or hoses. Protective measures for headlights could include protective covers on the sides and upper section, and using headlights with lower surface temperature, minimizing the risk of ignition.

While several risks are addressed in this paper, there are additional risks that should be investigated in any future work. These include, for example, alternative types of fuel seen on mining vehicles or the risk when refueling a vehicle.

Conclusions

Passive fire protection measures are generally expected to provide high reliability and should be considered during the design process. Robust solutions should be regarded as a priority, given the harsh environment of mining, in particular underground mining. Passive fire protection may include the use of several measures simultaneously to ensure fire protection throughout the different phases of a fire.

The presented passive fire protection measures include the application of threshold distances (hydraulic hoses and electrical cables), insulation and shielding of fuel items (such as engine bay and hydraulic hoses), the steering of flames and fire gases (tires), fire-resistant sealings (such as at the engine bay and wheelhouse), fire-resistant materials (such as at the engine bay and tanks), and repositioning or mechanical protection (such as at the engine bay and tanks). ■

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MEC outreach supports
SME members and Scouts alike

by Dan O'Connor, MEC Committee Chair

The purpose of the MEC is to educate K-12 students, teachers and the general public about the importance of mining and the minerals, and this year has not been any different in fulfilling that mission. Except, this year has been very different, and those differences have changed how we think about education and informing the general public about the importance of mining. It has revealed possibilities we had not considered before. We must embrace what is in front of us and focus our energy on not only creating new and innovative content that is relatable and tangible, but also mobile and borderless. Just like everyone else, MEC has taken leaps forward and found that the additional virtual educational landscape has broken down geographic boundaries and allowed us to create learning and leadership opportunities where they have not existed before.

MEC Committee Chair and SME member Dan O'Connor contributes to SME and to the community through his volunteerism and outreach. Through his work in scouting he helps to promote the mining industry by providing education around careers and the importance of mined minerals. MEC is proud to have O'Connor as a part of the team and is excited to share his insights on what it means to him to be a part of the MEC Committee.

A great example of this is the MEC's involvement with the BSA's Mining in Society merit badge. This form of education is very important to me, as I strongly believe in Scouting and the leadership it creates. Scouting BSA's Mining in Society merit badge is such a great tool to educate and inform middle-school and high-school scouts about the importance of mining and how it is integrated into each of their lives. Not only does it emphasize the importance of mining, but it highlights the need for mining professionals in our industry. What better group to pitch this to, than a group that likes the outdoors and is in a program that is designed around developing leadership skills? This last year we were unable to have the merit badge sessions in person, so virtual merit badge sessions were held to accommodate the Scouts. We have had several merit badge sessions in several different states, all of which fill up as soon as they became available. In some councils we have had several hundred scouts sign up. I really believe this merit badge will have a lasting positive impact on these young leaders, and in these cases, it was all done virtually. Another great example is Move Mining, which was held virtually this year, and found great success allowing participants to be involved in the competition remotely from all over the world. As we move into the

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Ambreen Ahmed, Bronx, NY
Azeez Akinbo, Rolla, MO
Steven Apanian, Woodbury, MN
Rommel Benjhi Arrieta Zapata, Lima, Peru
Avery, Boulder, CO
Seyed Reza Azimi, Canning Vale, WAS Australia
Dianna L Barba, Sun Valley, CA
Lane Boyd, Ashburn, VA
Jordan Brough, Knoxville, TN
Rafal Bulatewicz, Tarzana, CA
Michael Bywalec, Taylor, MI
Tony Christian Canahua Choqueza, Lima, Peru
Esther Clement, Fort Collins, CO
Walter Contreras, Los Angeles, CA
Dominique Cottrell, Yreka, CA
Seth Cude, Rapid City, SD
Steven Day, Deerfield Beach, FL
Adam De Jong, Las Vegas, NV
Alvaro Rodolfo De La Cruz Acuña, Lima, Peru
Will Dennis, Raleigh, NC
Nicholas Deporzio, Cambridge, MA
Luigi Di Geso, Deerfield Beach, FL
Nicolas Duchemin, Miami Beach, FL
Shae Duddempudi, Alexandria, VA
Thomas Dunham, Elgin, IL
Cody Edwards, Alamo Heights, TX

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The Ph.D. Fellowship and Career Development Grant

programs continue to be successful

by Niki Humphrey, SME Foundation Manager

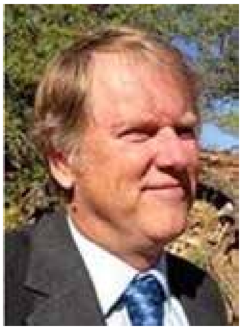
How do you address the long-term challenges that threaten the sustainability of U.S. mining and mineral processing/extractive metallurgy academic degree granting programs, as well as the looming future labor deficiencies associated with retirements over the next two decades? These were the questions that were posed by a very insightful group of forward-thinkers who knew that without a viable plan, the future of academia, particularly in the shrinking U.S. engineering schools offering mining and mineral processing/extractive metallurgy academic degree granting programs, would leave future B.S./M.S. engineering students pursuing these degrees, potentially without available faculty to meet future industry demands. And so, the Ph.D. Fellowship and Career Development Grant Program was developed to "Rebuild the Faculty Pipeline."

However, this challenge has not come without a cost, and a high cost at that. Nearing the end of the 10-year program, 32 participants are anticipated to benefit from the program at an estimated cost of nearly $8.5 million. An investment, to be sure. However, tangible results are already being seen as participants have been launched and are successfully meeting industry demands as engineers who pursue academic careers, and as tenure-track faculty eligible to replace the anticipated faculty attrition in university mining schools.

One of the recent Ph.D. success stories we now celebrate is Gail Heath, Ph.D., who was working as a research scientist for the Department of Energy's National Laboratory Complex. Of course the work was exciting and fulfilling. Nevertheless, in addition, he began teaching at local universities and came to realize that he needed to share his experiences on a broader scale so that he could help prepare other students for unbelievable opportunities and careers much like he had been afforded.

He decided to take a sabbatical from the Idaho National Laboratory, moved his family to their farm in Utah, and traveled to Tucson to the University of Arizona and investigated his options. Ultimately, Heath decided to stay and earn a Ph.D. so he could move toward his goal of helping students achieve the successes that he has been able to enjoy.

Heath said, "(He) started school in 2014 and finished with a Ph.D. this year. It was a slow process." However, he kept his goal in sight and was focused. Although he had to do consulting on the side to help fund the endeavor, that's when he applied for and received our generous support from the SME Foundation's Ph.D. Fellowship Grant along with several other endowments, grants and the help of several mining companies which supplied research opportunities, mentoring and guidance. He also had the opportunity to teach multiple courses for the Mining and Geological Engineering Department. In the fall he will be starting a full-time teaching position with the University of Arizona and, of course, he is very excited about the future.



Gail Heath

Since the Ph.D. Fellowship Program began in 2015, it has grown to 14 Ph.D. Fellowship Awardees with one additional Lou Henry Hoover WAAIME Ph.D. Fellowship. Four awardees have received their Ph.D.s, three anticipate defending their thesis and hope to receive their Ph.D.s this year, three have dropped from the program, and five are on track for completing their Ph.D. programs. We look forward to celebrating these successes as we now celebrate with Heath.

Since the program began, 10 Freeport-McMoRan Career Development Grants have been awarded. Six of these recipients have received tenure, while the other four awardees continue to be on track in their professional development as we look forward to celebrating their successes, as well.

These successes are all to be celebrated, to be sure, because they were achieved by hard work and determination. See their names below. Those who are in process of achieving their goals will do so as they apply the same fortitude and perseverance they have shown since receiving their grants. However, we could not have provided any of these opportunities financially without our faithful Corporate Roundtable Partners, Legacy Donors, corporate donors and individual donors who believed in this program. We truly thank you and are grateful for your investment in the success of the next generation of educators and the future workforce of our industry.

Contributions that support the Ph.D. Fellowship and Career Development Grant Program help to rebuild the faculty pipeline, protect our mining engineering schools and strengthen our industry. Any donation is appreciated and very much needed. Your investment continues to provide support to fund Ph.D. students planning academic careers and university professors working toward achieving tenure.

Your investment in the Academic Grant program and other SME Foundation programs will result in significant success. When you invest in the success of the future leaders of the mining and minerals industry, you won't regret it. Your support makes a difference.

For more information, go to www.smefoundation.org.

Ph.D. Fellowship Successes – (year Ph.D. received)

- 2021 – SME Ph.D. Fellowship Grant – Gail L. Heath, University of Arizona
- 2019 – SME Ph.D. Fellowship Grant – Danielle Rocha, Colorado School of Mines
- 2018 – SME Ph.D. Fellowship Grant – Richard M.

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Is mining sustainable?

Balancing demand and requirement for minerals will be critical

by David M. Abbott Jr., Consulting Mining Geologist and Geoscience Ethics Columnist

The exploration for and extraction of natural resources have become the target of numerous organizations who view those activities as basically destructive elements that potentially threaten the future of the earth itself. The International Association for the Promotion of Geoethics (IAPG) reflects this negative attitude toward the extractive industries in the membership of its more than 20 associated societies, which include internationally known societies such as Association of Engineering and Environmental Geologists (AEG), American Geoscience Institute (AGI), American Geophysical Union (AGU), European Federation of Geologists (EFG), Geological Society of America (GSA) and the Geological Society of London (GSL). Conspicuously absent from this list are AAPG, AusIMM, CIM, IMM, SEconG, SME and SAIMM (IMM is an abbreviation for "Institute of Mining and Metallurgy"; the groups are Australasian, Canadian, British and South African) – the major international extractive professional societies. As Bohle and DiCapua (2019) note, "The recent development of the concept 'geoethics' is a response by geoscientists to shape deeper engagement with their professional responsibilities and the wider societal relevance of geosciences. This introductory chapter outlines the development of geoethics to date, as a 'virtue ethics' focusing primarily on the role of the geoscientist, describes its meaning and function in relation to neighboring fields and explores how to situate geoethics in relation to a wider range of issues that require ethical consideration." Those promoting geoethics apparently take pains to avoid learning about the many ways the extractive industries' professional societies address the environmental and social-licensing aspects of their activities.

"Ensuring sustainability of economic and social activities in order to assure future generations' supply of energy and other natural resources" is the ninth of the IAPG's Fundamental Values of Geoethics. Unfortunately, this statement fails to transparently and forthrightly acknowledge the depletability of individual natural resource deposits, thus inhibiting a fully integral and transparent discussion of this geoethics value statement's goal of sustainability. The most commonly cited definition of "sustainable development" comes from the U.N. Brundtland Commission (1987) report and states, "Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Thus, there are no limits on the life of a "sustainable development" as commonly used and understood. The problem is that individual mineral deposits are finite in size whether that size is defined as in situ size or as economically limited by a cut-off grade. Mineral deposits are consequently depletable, and any extraction of a particular deposit will eventually lead to its exhaustion. Thus, by definition, the mining of a particular deposit cannot be sustainable. In this sense, the answer to the title's question, "Is mining sustainable?" is "No."

But future generations will need mineral products. As the Minerals Education Coalition's annually updated Mineral Baby reminds us, people consume mineral products during their lifetimes. These mineral products can come either from recycling or from new production from mines. Because 100-percent recycling does not occur for any mineral product and because of expanding population, much of the required mineral products for future generations must be newly mined, including from new mines that replace depleted deposits. Because near-surface deposits mostly have been identified and the highest-grade deposits have been or are being mined, increasing amounts of underground mining from increasing depths can be expected.

Substitution of one mineral product for another also can meet future needs. For example, in 1966 I learned that the recycling of automotive batteries accounted for about 50 percent of the annual lead consumption. This was during the period when lead was still used in gasoline and as the primary white pigment in paint, neither of which was a recyclable use. Titanium dioxide (TiO_2) has now replaced lead oxide as the primary white pigment, gasoline is unleaded and batteries are still recycled (73 percent of 2020 domestic lead consumption). But we still use a lot of newly mined lead. Pandora, the world's largest producer of diamonds will now use manufactured diamonds rather than mined diamonds. Innovation of all aspects of mining technology will also help in the exploration for and identification of new deposits and in their extraction using improved technologies. The increasing electrification, automation, and remote control of mining vehicles are examples. Articles on these topics are regular features of *Mining Engineering*.

Balancing the requirements and demand for newly mined mineral products and environmental-protection and social-licensing issues is an important requirement for the sustainability of the mining industry. On one hand, developing a long-term mineral supply should encourage maximum extraction of a deposit's valuable constituents by

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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 2021 is Matt Blattman.

MEC: Merit badge educates Scouts

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future it will be important for us to utilize the tools we have learned this year to allow us to reach more future miners for our industry.

It is very important to express how the MEC committee and subcommittees are the reason for the success we have seen recently. It helps to have a group that is so connected and understand that education is constantly changing, and with the diversity in backgrounds and levels of experiences in the committee, it lends to some great ideas and creates a very motivating atmosphere. We are adapting like everyone else to utilize this new virtual landscape and we can focus more on what and how we are teaching, and be less concerned with when and where the teaching occurs.

I feel that much of the success the MEC has seen, and what it has become, is from the members' love for the industry and their passion to educate. We should be grateful that an outlet like this exists, because many educators and industry professional have benefited greatly from its presence as a resource to demonstrate the importance of our industry and what it creates. For anyone reading this who finds that you are motivated to get involved to help keep MEC strong, please reach out to us. We would love to hear from you. We have the opportunity to educate and influence the future leaders of our industry. The fun part is teaching them what we love — the important part is that they know why we love it. ■

New Members

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Kathy Ehrig, Blackwood, Sa Australia
Danielle Foley, Ely, NV
Shaun Forsberg, Mount Juliet, TN
Robert Frutchey, New Philadelphia, OH
Kamal Gautam, Bay Point, CA
Kirstin Girdner, Tucson, AZ
Jason Goss, Montgomery, TX
Rob Gould, Seattle, WA
Erman Deimer Gutierrez Segura, Cajamarca, Peru
Carlos G Gutierrez, Lima, Peru
David Haag, Phoenix, AZ
Bernd Hagenah, New York, NY
Charles Hanskat, Plymouth, MI
James Hawkins, Fayetteville, AR
James Hawn, Alexandria, VA
Robert (al) Heintzelman, New Baden, IL
Alan Henderson, South Jordan, UT
Carole Henry, Alexandria, VA
Victor Hernandez, Norwalk, CA
Leland Huffman, Cheyenne, WY
Tom Iseley, West Lafayette, IN
Sidney Iwata, Las Vegas, NV
Chelsea Jackson, Los Angeles, CA
Allen Jensson, Kent, WA
Adam Kassam, Huntersville, NC
Ellis Kennedy, Berkeley, CA
Todd Kilduff, Red Bank, NJ
Celal Kirandag, New York, NY
Richard Krok, Salt Lake City, UT
Chad Lamb, Sturgis, KY
Matthew Laureano, Golden, CO
Jeremy Leonard, St George, UT
Tim Lewis, Smyrna, GA
Wei Liao, West Lafayette, IN
Barry Lindler, Castle Rock, CO
Howard Linn, Fairmont, WV
Shawn Lu, Houston, TX
Danny Madden, Cleveland, OH
Ryan Mair, Thornville, OH
Percy Jhoan Mantilla Matta, Lima, Peru
Robert Marshall, Sylmar, CA
John Mayfield, MT Morris, PA
Donald McCarthy, Tucson, AZ
Juanita McCord, Ely, NV
Paul McDermott, Sierra Madre, CA
Andrew McGlenn, Mercer Island, WA
Marcus McKinney, Mc Lean, VA
Miler Rolando Mendoza Francisco, Lima, Peru
Justin Merrill, Ely, NV
Saba Molaei, Tehran, Islamic Republic of Iran
Jim Moldovan, Roanoke, TX
William Monville, Oconomowoc, WI
Wes Morrison, Reston, VA
Myles Musselman, Collinsville, OK
Florida Nasategay, Sparks, NV
Andrew Nigro, Hartsdale, NY
Asao Nomura, Casa Grande, AZ
Eric Ostfeld, Seattle, WA
Doug Payne, Las Vegas, NV
David Peasah, Accra, Ghana
Nathan Peterson, Granbury, TX
Michael Pethers, Rolesville, NC
Swathi Prabhu, Los Angeles, CA
Shelley Burg Reseigh, Dallas, TX
John Roberts, Salt Lake City, UT
Robert Roos, Omaha, NE
Edison Jesus Rubina Valderrama, Lima, Peru
Michael Ryder, Sewickley, PA
Heidy Sanchez, Las Vegas, NV
Sofia Sandoval, Rancho Cucamonga, CA
Collin Schroeder, Westlake, OH
Jasmine Shoning, Ely, NV
Kenny Shoning, Ely, NV
Winston Simmonds, Pittsburgh, PA
Thomas Sims, Cypress, TX
Kevin Slemko, Salt Lake City, UT
Jeff Tatum, Menomonee Falls, WI
Allison Taylor, Saint Louis, MO
Haywood Thomson, Seabrook, TX
Glen Townley, Riceboro, GA
Quang Tran, Roanoke, TX
Leonid Troitski, Vienna, VA
Thomas Tuozzolo, Hanover, MD
Jake Van Baarsel, Riverside, CA
Phillip Vanzale, Long Beach, CA
Liliana Vazquez Cabañas, Ciudad Nezahualcoyotl, Mex Mexico
Ronoel Vega, Lima, Peru
Edward Villada Cardona, Bello, Ant, Colombia
Gustavo Villon, LIMA, Peru
Gillian Wagner, Alexandria, VA
Will Wright, Sarasota, FL
Jenna Wundrack, Billings, MO
John C.J. Yen, Riverside, CA
Brian Young, Concord, CA
Ming Zhang, Tenafly, NJ
Scott Zylstra, Laguna Niguel, CA

Decarbonization should make nonferrous metallurgists smile

by Michael Moats, Professor, Metallurgical Engineering, and Director, Thomas J. O'Keefe Institute for the Sustainable Supply of Strategic Minerals, Missouri University of Science and Technology

The world seems to be hurtling toward, or is already in, an energy transition from fossil fuels to green and renewable sources. While this statement is highly politically charged, I believe nonferrous metallurgists should smile every time they hear the word "decarbonization."

In May 2021, the International Energy Agency (IEA) reported estimates of the metal needed to decarbonize the world's energy systems. The IEA states, "Our bottom-up assessment suggests that a concerted effort to reach the goals of the Paris Agreement (climate stabilization at "well below 2 °C global temperature rise," as in the IEA Sustainable Development Scenario [SDS]) would mean a quadrupling of mineral requirements for clean-energy technologies by 2040. An even faster transition, to hit net zero globally by 2050, would require six times more mineral inputs in 2040 than today." While not exactly the same values, the IEA estimates are similar to early reports by the World Bank in 2017 and 2020.

The switch from coal and natural gas to solar and wind will increase nonferrous metal requirements for electrical energy generation up to six-fold on a kilogram per megawatt basis. The largest tonnage increases are related to copper (for any "green" energy) and zinc (for wind power). Likewise, electric vehicles will require three to five times more nonferrous metals than conventional cars, with increases in copper, nickel, manganese, cobalt and lithium.

While the overall world trend on the future needs for nonferrous metals are reasons to smile, the ability of the United States to supply its nonferrous needs based on current smelter and refinery capacities is not. Over the last 25 years, according to U.S. Geological Survey (USGS) Commodity Summary data, the number of primary aluminum smelters have decreased from 22 to seven, primary copper refineries from seven to three (maybe two with a recent shutdown), zinc refineries from three to one, and lead smelters from three to zero. Over the same period, China has increased aluminum production 20-fold, lead 12-fold, copper six-fold, and zinc by 50 percent. During the same period, Europe and Japan have reasonably maintained their nonferrous metal production capacity. Is the U.S. decline the result of U.S. smelters being originally located near mines and not transportation hubs, or government policy, or economic pressures caused by globalization or lack of industrial development? Regardless of the reasons, the United States is highly dependent on other countries for the supply of nonferrous metals.

The U.S. reliance on imported nonferrous metals propagates into dependencies for some critical minerals. Critical minerals, such as tellurium, indium, gallium, germanium and bismuth, are captured during the processing of nonferrous metals. Onshoring of the smelting and refining of nonferrous metals will assist in reducing the country's critical-mineral list.

Hopefully, policymakers will encourage domestic metal production through incentives to build new smelters/refineries. These incentives could include Title III funding similar to what is used for beryllium production, engaging in off-take agreements with the Defense Logistics Agency to supply the nation's defense stockpile, and provide financing for companies to purchase partial ownership of foreign mines with the requirement that concentrates are imported and processed domestically.

It appears that we live in an exciting time with the potential for entrepreneurial endeavors to improve and create new processes that produce the nonferrous and critical metals needed for decarbonization. It is a time for nonferrous metallurgists to smile because their skills are needed and will likely be in demand. ■

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 views of the authors. It is not an official position of SME or the division. Comments by readers will be referred to the division for response. The division chair in 2021 is Garland Davis.**

Foundation: Ph.D. programs continue to thrive

(continued on page 119)

LaDouceur, Montana Tech
- 2017 – SME Ph.D. Fellowship Grant – Joshua Werner, University of Utah

Currently Funded by: FREEPORT-MCMORAN

Career Development Grant Tenure Successes – (year tenure achieved)
- 2021 SME Career Development Grant – Andrea J. Brickey, South Dakota School of Mines
- 2020 Freeport-McMoRan, Inc. Career Development Grant - Jaeheon Lee, University of Arizona
- 2020 SME Career Development Grant – Aaron Noble, Virginia Tech
- 2019 Freeport-McMoRan, Inc. Career Development Grant – Shimin Liu, Penn State
- 2018 SME Career Development Grant – Charles K. Kocsis, University of Nevada, Reno
- 2017 SME Career Development Grant – Emily Sarver, Virginia Tech. ■

Neil James Eurick

Neil James Eurick's life journey began in Butte, MT in 1956, when he was born the third child of four to Carl and Doris Eurick. He was raised in the family home on Elm Street next door to his grandparents. This was a perfect setting for him and it became the local hangout for all the neighbor kids who became his friends. At a very young age, he became his grandfather Pat's "apprentice" who taught him the basics of plumbing, electrical, welding and working on vehicles, which he really enjoyed. Eurick then graduated to become his dad's right hand man who repaired lawnmowers and chainsaws at home in addition to his full-time boilermaker job. During his high school years, Eurick continued his passion as a mechanic in the family-owned motorcycle and snowmobile dealership which eventually closed when mining in Butte shut down. He followed his dad on one last job as a boilermaker's assistant cutting up old, greasy haul trucks in sub-zero weather. The elder Eurick always laughed that this is when Neil realized there might be a better way to make a living. He enrolled in Montana Tech and received a Bachelor of Science degree in society & technology in 1983. After graduation, Eurick and his long-time friend Bob Cohan both landed jobs in Denver, CO with defense contractor Martin Marietta. Eurick would move on from this job to further his career as a consultant involved with business development, direct sales and project management with a variety of companies specializing in the mining industry. His titles along the way ranged from marketing manager, vice president business development to president and CEO of environmental. He traveled throughout the country and eventually the world. Eurick was well known and respected in the U.S. mining industry and was always the life of the party at conventions and gatherings where he was the master of ceremonies at several events. But his greatest achievement while in Denver was meeting a girl named Debbie Garcia. They fell in love and became husband and wife in 1992 at the Copper Mountain Ski Lodge. Together they purchased a home in Littleton, CO and welcomed their first son Carl. A few years later the family grew with the addition of Ryan. Eurick was a great dad and was actively involved with the boy's love of sports. He was a baseball coach for both and was always in the stands rooting them on in football, cross country, golf or any other events they had an interest in. Neil and Debbie taught them the value of an education and both boys would go on to graduate from college. Carl was recruited by the Army to specialize in National Security and Ryan will soon pursue his business career in San Diego, CA. Neil loved the outdoors and enjoyed hunting, panning for gold and especially snowmobiles. This love began with the family winter outings when he was young and escalated with the family's snowmobile and motorcycle business. He was always fine-tuning his sleds to go faster and competed in several Snocross races resulting in one proud win. Eurick's hunting passion began when he was young with his mom and dad and continued on with him in Colorado. While Neil may have left Butte, Butte never left him. He was proud of his "blue collar" background and the town he was raised in. His closest friends in Denver were all from Butte and those that remained there he kept in touch with during visits home. Cohan, Mike Kadillak, Tom Holman, Dan Mazzola and numerous others were a very special part of his life. Sadly Neil's journey on Earth was cut short with a cancer diagnosis in 2019. He was surrounded by his immediate family and best friend Bob when he passed away at home on March 27. On that day we lost a loving son, a caring husband and father, a fantastic brother and the best friend you will ever find. We can only pray that there are snowmobiles and hunting in Heaven. He was preceded in death by his grandparents Pat and Bonnie Eurick of Butte, MT, Charles and Erma Ambill of Pittsburgh, PA, his father Carl Eurick Jr. and friend Dan Mazzola of Butte, MT. He is survived by his mother, Doris Eurick of Butte, wife Debbie Eurick and sons Carl and Ryan of Littleton, CO. His sister and brothers Lynn Clark (Tim) Butte, Glenn Eurick (Sheri) Salt Lake, Ken Eurick (Marla) Whitehall, MT plus numerous nephews and nieces. A private graveside service was recently held in Littleton, Colorado with close family and friends in attendance. ■

Rock in the Box

(continued from page 120)

keeping the costs of production low. On the other hand, minimizing costs for environmental- and social-impact mitigation can result in unacceptable levels of adverse impacts for those living near the deposit. However, the costs for environmental- and social-impact mitigation increase the cut-off grade, the minimum grade that allows for profitable extraction. Dialog between the mining industry and the various environmental- and social-impact stakeholders is the key to finding the unique appropriate balance for each mineral deposit. The dialog among the various stakeholders about a particular deposit should recognize society's need for mineral products as an important, socially desirable requirement.

The facts that future generations will need newly mined mineral products and that extraction of individual mineral deposits is not a sustainable activity are things about which the mining industry must educate the general public. Public education about the need to balance the costs of the environmental and social impacts of mining with the need for future generations' need for minerals is required for the sustainability of the mining industry. ■

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Marc LeVier is the nominee for SME President in 2023

Marc LeVier has an extensive background in the mining industry with more than 45 years of experience. He has B.S. and M.S. degrees in metallurgical engineering from Michigan Technological University and a doctorate of science (honors) from Montana Tech at the University of Montana.

LeVier has worked for mining companies in operations and in the development of new mineral deposits including base metals, precious metals, iron ore, uranium and rare earths. He retired in 2011 after a long career at Newmont Mining Corp., where he was the global director of metallurgical R&D. His research teams delivered innovative solutions and process technology for new mineral deposits, which significantly increased the profitability and global operations portfolio of Newmont.

After Newmont, LeVier became the chief executive officer, president and director of Texas Rare Earth Resources Corp. and later, the chief executive officer, president and director of Great Western Minerals Group Ltd. He provided leadership in the development of multidisciplinary project teams and successful advancement of the projects. LeVier is currently president of K. Marc LeVier & Associates Inc., which provides services to the mining industry.

Marc LeVier

Nominees for the 2022 SME Board of Directors

RICHARD LAMBERT is technical director, U.S. Mining Advisory at SLR Consulting, where he is responsible for the operations of the company's U.S. mining consulting practice. He is a senior mining executive with more than 40 years of experience in all aspects of mine development, from permitting to closure. His experience includes the development and operation of openpit mines, startups, the preparation and implementation of feasibility studies, due diligence, M&A and management consulting. He was employed by Fortune 500 mining companies for the first 17 years of his career, including Phelps Dodge, Kennecott, NERCO and Exxon Minerals. Since then, he has been providing mining contracting and consulting services.

Richard Lambert

Lambert holds a B.S. in mining engineering from the Mackay School of Mines at the University of Nevada-Reno and an M.B.A from Boise State University.

As a consultant, he has been involved with more than 120 mining properties around the world. He has led teams of mining experts in reserve audits for major mining companies and been involved as the independent engineer on many large mining project financings exceeding $1 billion (Esperanza, Antucoya, Caserones, Quebrada Blanca and Constancia). He has contributed his time and talents to SME over many years, serving on numerous committees and boards. He is a contributor to the SME Foundation and was recognized for his support as a John T. Boyd Challenge recipient in 2014. Lambert has been an active member of SME since 1975.

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 of one hundred (100) members or more 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.

BARBARA K. NIELSEN has more than 35 years of progressive leadership in permitting, characterization, remediation and reclamation at a variety of sites. She has experience as a regulator, as a consultant and in industry. For the past 15 years, Nielsen has worked for Freeport-McMoRan Inc. as the manager of remediation projects in Phoenix, AZ. Several projects that she managed have received state and national honors: the Colorado Environmental Leadership Program Bronze Award; the U.S. Bureau of Land Management highest honors Hardrock Minerals Environmental Award; and from the American Council of Engineering Companies – The National Recognition Award for an Arizona project, the Arizona Chapter

Barbara Nielsen

Engineering Excellence Award, and the Washington Chapter Silver Award. She is currently the university team lead for Freeport at South Dakota School of Mines and Technology (SDSM&T) and also serves on the Geology and Geological Engineering Department advisory board. Nielsen is past chair of SME's Environmental Division Executive Committee and also serves on the SME Government and Public Affairs Committee, Board of Directors (BOD) Internship Program Committee and the newly formed BOD Environmental Stewardship Strategic Committee. She holds a degree in geological engineering from SDSM&T.

Coal & Energy Division officer nominees

CHAIR

SUSAN B. BEALKO is corporate safety director at GMS Mine Repair & Maintenance, the largest underground coal contractor in the nation, where she is responsible for compliance, safety and training.

Bealko has 28 years of experience in coal mining through her work in engineering, production and mine safety. She holds a mining engineering degree from The Pennsylvania State University, a master's degree in safety management from West Virginia University and a master's degree in public health from the University of Pittsburgh. She also holds mine foreman certification papers in Pennsylvania, West Virginia and Ohio.


Susan Bealko

Bealko began her mining career in 1991 working at Consol Energy's Bailey Mine as an industrial engineer. In 2002, she joined the NIOSH Pittsburgh Research Center as a mining engineer and gained international mining experience. Bealko received the 2015 Coal & Energy Division Distinguished Member Award, 2010 SME Local Section Hero of the Month Award and 2004 J.W. Woomer Young Engineer Award, and served as chair of the SME Pittsburgh Section from 2009 to 2010. She is one of the frontrunners in the creation of eastern U.S. collegiate mine-rescue teams and is a mentor to young coal-mining professionals.

VICE CHAIR

TATHAGATA GHOSH is an associate professor of mining engineering at the University of Alaska-Fairbanks (UAF). He earned his undergraduate degree in mining engineering from the Indian Institute of Engineering Science and Technology, Shibpur (previously known as Bengal Engineering and Science University), India, and his M.S. in mechanical engineering from the AGH University of Science and Technology, Krakow, Poland. He received his Ph.D. in mining engineering from the University of Kentucky. Prior to pursuing graduate studies, Ghosh worked for Tega Industries in Kolkata, India, providing processing solutions to the Indian minerals industry. He also worked as a mining-engineering consultant with International Mining Consultants and was involved in mine planning, pit expansion and exploration projects. At the University of Kentucky, he was involved in several projects funded by the U.S. Department of Energy, the U.S. State Department and industry.

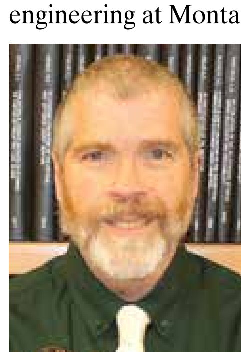
Ghosh's areas of interest include mineral processing, computational fluid dynamics, numerical modeling, process optimization, rare earth elements from coal, fine coal processing, clean coal and advanced beneficiation technologies. In the last 16 years, he has been involved in several federal-, state- and industry-sponsored projects worth more than $10 million. He received the 2016 Invent Alaska Award and is an SME Young Leader, class of 2016. He received the 2021 SME Industrial Minerals & Aggregates Division's Outstanding Young Scientist Award. Ghosh serves on the editorial board of the *International Journal of Coal Preparation and Utilization* and is a technical peer reviewer for several journals. He has been published in major mining journals and conference publications and was a co-editor of the proceedings of the 37th APCOM. He serves on the Coal & Energy (C&E) Division Executive Committee and chaired the 2021 C&E Program Committee.


Tathagata Ghosh

Currently, Ghosh is chair of the Mining Department and director of the Mineral Industry Research Lab at UAF.

SECRETARY/TREASURER

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 B.S. and M.S. degrees in mining engineering from Penn State and a Ph.D. in mining engineering from the University of Kentucky. He is a registered professional engineer in Pennsylvania.


Paul Conrad

Conrad has more than 39 years of engineering work experience in the mining, civil, hydraulic, environmental, construction, permitting and research engineering fields, including 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 numerous peer-reviewed publications with his graduate students and research collaborators.

Conrad has been active in SME. This is his second time serving on the C&E Executive Committee, and he has routinely chaired technical sessions at SME conferences for the division. He is currently a member of several C&E division committees and is also an ABET program evaluator for mining-engineering programs.

PROGRAM CHAIR

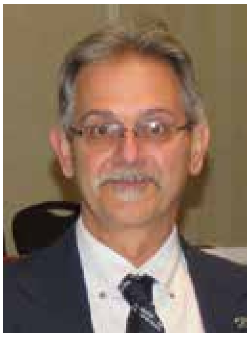

Steven Schafrik

STEVEN J. SCHAFRIK is an associate professor of mining engineering at the University of Kentucky. He is active in SME, serving in many roles, including chair of the Central Appalachian Section and on the C&E Executive Committee. He teaches mine design software, electronics and programming. His research includes dust mitigation, data management and underground equipment automation.

PROGRAM VICE CHAIR

EDWARD F. ZEGLEN JR., P.E., has been working in various capacities at GMS Mine Repair & Maintenance since November 2016. Tasks include project management, mine coordinator and shift foreman, mine examiner and chief mining engineer.

Zeglen has more than 42 years of experience in the coal-mining industry and had retired as the chief engineer with Alpha Natural Resources, Pa. Services Corp. For the last five years, he was the senior manager underground mine engineering for Alpha, with primary responsibilities for mine engineering and mine ventilation–surveys and modeling. He had two assistants and covered approximately 20 company mines and held ventilation training classes for those operations.


Edward Zeglen Jr.

Zeglen has a B.S. in mining engineering from the Penn State University. He is a registered professional engineer in Pennsylvania and holds mine foreman certificates in Pennsylvania and Utah. He has been active in mine rescue for 33 years and is currently coach/mentor of the Penn State student team. He has held various engineering positions, from co-op student engineer to engineering manager. He has also held operations positions, including safety supervisor, assistant mine foreman production and outby, and general mine foreman.

He 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 currently serves on the Board of Directors of the Pittsburgh Coal Mining Institute of America and is past chairman of the Pittsburgh Chapter of SME.

Environmental Division officer nominees

CHAIR


Lisa Gonzales

LISA GONZALES is a principal engineer at Arcadis. She is a licensed professional engineer and has more than 20 years of experience specializing in mine reclamation closure and multidisciplinary environmental and engineering projects for mining clients. Her technical background and project experience include CERCLA and RCRA sites, smelter facilities remediation, voluntary clean-up sites, site characterizations and radiologically impacted site closures.

Gonzales has been active in SME for several years, chairing the Environmental Division student poster contest, as Program Committee Chair and as Secretary. She also serves on the SME Professional Engineers Exam Committee.

VICE CHAIR

JEN PEPE is a senior engineer at Golder Associates with 30 years of experience in site characterization and remedial design, including 26 years specializing in characterization and closure issues for mines in the western United States and northern Mexico. Her technical background is in field investigations at sites involving soil and groundwater impacts, development and implementation of remediation and closure alternatives, water management, and water balance modeling. She has been active in SME for more than 15 years, and


Jen Pepe

recently coordinated the Environmental Division's student poster contest.

SECRETARY

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 include 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 served on the Environmental Division Scholarship Committee and as Program Committee Chair.


Annelia Tinklenberg

PROGRAM COMMITTEE CHAIR

OMAR SMITH is a senior civil engineer at Wood. He has more than 13 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, 3D computer-aided design, construction quality assurance, and quantity takeoff/cost estimates. He has served on the SME Tucson Section board for the last 10 years and is in his third term as chair. He recently served on the SME Student Member Affairs Committee as an Environmental Division representative.


Omar Smith

Health & Safety Division officer nominees

CHAIR

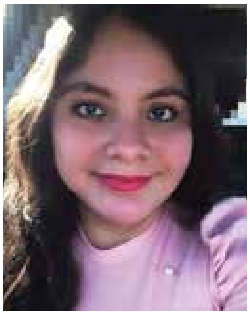
EMILY J. HAAS is a research health scientist at the National Institute for Occupational Safety and Health. She conducts research studies in safety, health and risk management in areas specific to leadership and communication to discover ways to strengthen safety culture and worker performance. Her research solutions have achieved high impact with companies adopting best practices and improving their health and safety management systems.

Haas has authored more than 60 publications, 48 of which she is the primary author. She has provided more than 75 technical presentations, including workshops and keynotes, at international mining conferences.


Emily Haas

CHAIR ELECT

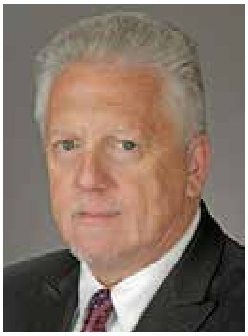
PALOMA LAZARO recently received her Ph.D. from the Mining & Geological Engineering Department of the University of Arizona in Tucson, AZ. Her research was focused on heat-stress and strain-assessment modeling in underground and surface mines. She has a master's degree in industrial risks and environmental management from the University of Poitiers, France. She has extensive experience as an industrial hygienist and an environmental and health engineer in the United States and internationally from Rio Tinto's boron operations in California; with Alcoa Aluminum in Peru and Brazil; and with Constellium and Assa Abloy in France.


Paloma Lazaro

SECRETARY

PATRICK JAMES is the head of health, safety, environment and risk for Vale Base Metals. He provides strategic direction and guidance to the company in the areas of health, safety, environment and risk. His focus includes the continuous improvement of systems, processes and ongoing business transformation to influence best-in-class performance.

James has more than 35 years of experience in the mining, metals, aggregate/cement and power-generation industries. His career included leadership roles at Rio Tinto, Lehigh Hanson, PacifiCorp and Cementation Americas. These roles have included multiple accountabilities throughout the United States and Canada as well as international experience in South America, Europe, Mongolia, Indonesia, South Africa and Australia. James has undergraduate and


Patrick James

graduate degrees from the University of Wyoming, and his professional certifications include the Certified Safety Professional, Associate Safety Professional and Certified Mine Safety Professional.

COMMUNICATIONS CHAIR

PEDRAM ROGHANCHI is a Freeport-McMoRan endowed assistant professor of mineral engineering at the New Mexico Institute of Mining and Technology, where he is the director of the Occupational Health and Safety Lab (OHSL). His research interests encompass several areas of mining engineering, including occupational health, dust control, mine ventilation and surface and underground mining. The OHSL 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. He is a co-author of more than 40 peer-reviewed journal and conference publications.

Pedram Roghanchi

Industrial Minerals & Aggregates Division officer nominees

CHAIR

NIKHIL GUPTA has been an SME professional member since 2011 and actively involved with the society, including chairing sessions at SME annual conferences and serving on various committees, including the Industrial Minerals & Aggregates Division (IM&AD) Executive Committee, 2019 SME Program Committee and chair of the IM&AD Technical and Program Committee. He received the 2017 IM&AD Outstanding Young Scientist Award and 2016 Coal & Energy Division J.W. Woomer Award for his professional contributions to the mining industry.

Nikhil Gupta

Gupta has successfully completed multiple pilot-scale demonstration in field test programs with the focus on fine and ultrafine minerals recovery and dewatering; dry separation methodologies; and process design and optimization. He holds a Ph.D. (2014) and an M.S. (2011) in mining engineering from Virginia Tech and a B.S. (2008) in minerals engineering with first-class honors from the Indian School of Mines.

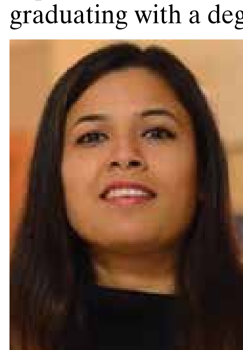
Raghav Dube

VICE CHAIR

RAGHAV DUBE graduated with an M.S. in mining and mineral engineering from the University of Kentucky in 2012 and a bachelor's degree in mineral engineering from the Indian School of Mines in 2009. He is currently working in Denver as a senior process metallurgist in the Outotec Plant Solution team, where he is responsible for mineral-processing plant design, startup and commissioning. Dube started his career in 2009 at an iron-ore processing plant and joined Outotec in 2012 as an expert systems specialist. He has about 10 years of experience in the mineral-processing industry, including laboratory test work; pilot-plant operation; modeling and simulating plant flowsheets; and startup and commissioning of greenfield plant projects.

SECRETARY/TREASURER

RIDDHIKA JAIN has more than 10 years of experience in the mining and aggregates industry. After graduating with a degree in fuel and mineral engineering from the Indian Institute of Technology – Dhanbad in 2010, she worked at Sandvik Asia Pvt. Ltd., Gurgaon as a technical sales engineer.



Riddhika Jain

Jain obtained her M.S. in mining engineering from Virginia Tech in 2013, where she also worked as a graduate research assistant. She and her advisor developed the HHS process for concentrating ultrafine minerals. Since then, she has been working at Outotec USA Inc., first as product development manager for flotation and now as product manager for Outotec HIGmill.

PROGRAM CHAIR-AGGREGATES

PATRICK JACOMET has more than 30 years of experience in the aggregates, construction materials and testing industry. After graduating from Earlham College in Richmond, IN, Jacomet obtained a master's degree from Ball State University before going to work for Bowser-Morner in Dayton, OH, for seven years as supervisor of construction materials testing. He was then employed by

Patrick Jacomet

Martin Marietta for seven years as technical engineer–project specialist for research and development and quality control. He started at the Ohio Aggregates & Industrial Minerals Association in 1999, where he currently serves as executive director. Jacomet works closely with the Ohio General Assembly, Ohio Department of Transportation, Ohio EPA, Mine Safety and Health Administration, and Ohio Department of Natural Resources to ensure that Ohio's mining industry remains a safe, environmentally conscious and community friendly part of Ohio's economy.

Jacomet serves on the board of Skills USA Ohio, co-chairs the ASTM Subcommittee D 04.51 on aggregate specifications and is chair of SME's Minerals Education Coalition. He was named NSSGA State Aggregate Association Director of the Year in 2014.

PROGRAM CHAIR-INDUSTRIAL MINERALS

GAURAV SONI is a proposal manager (plant solution) at Metso Outotec in Denver. He has an M.S. (2013) in mining and mineral engineering from Virginia Tech and a B.Tech. (2009) in mineral engineering from IIT(ISM), Dhanbad. He is a certified project manager with Project Management Institute and is currently pursuing a weekend M.B.A. program 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 operations.

TECHNICAL COMMITTEE CHAIR

Tushar Gupta

TUSHAR GUPTA received his Ph.D. (2021) from the University of Kentucky, M.S.(2016) from the University of Alaska Fairbanks, and B.Tech. (2012) in mining engineering from the Indian School of Mines Dhanbad, India. He began his career as an assistant mine manager at Coal India Limited before starting his graduate studies. He has more than seven years of research experience in mineral processing, including extraction of rare earth elements from low-grade feedstocks.

Gupta is a member of the SME Young Leaders Committee class of 2019 and has been associated with the IM&AD for the last five years. He chaired several technical sessions and served on the IM&AD Scholarship Committee. He received the 2021 Raja V. and Geetha V. Ramani Graduate Thesis Award, the 2020 Mineral & Metallurgical Processing Division Scholarship for outstanding graduate and the 2019 Gerald V. Henderson Memorial Scholarship.

MEMBERSHIP COMMITTEE CHAIR

DAVID BIEBER is the manager of geology and survey for the West Division of Martin Marietta, and an adjunct professor of industrial minerals in the Mining Engineering Department of the Colorado School of Mines (CSM). He has approximately 40 years of professional experience, which includes work as a consultant, miner, college professor and regulatory inspector. His areas of expertise include mining geology and engineering; mine sustainability and reclamation; and mineral resource evaluation.

David Bieber

Bieber has also worked in engineering and environmental geophysics; environmental investigation, remediation, compliance and permitting; engineering geology; hydrogeology; assessment of naturally occurring hazardous geologic materials (heavy metals, crystalline silica, asbestiform minerals); and construction quality control and quality assurance. He received his undergraduate education in geology at CSM and M.S. in geology from the University of Colorado. He is licensed as a professional geologist, professional geophysicist, certified engineering geologist and certified hydrogeologist.

Bieber is past chair of SME's Colorado Section and past president of the Association of Environmental and Engineering Geologists. He served on the executive committee of the American Geosciences Institute and as a director of the Forum on the Geology of Industrial Minerals.

Kathryn Kosloski

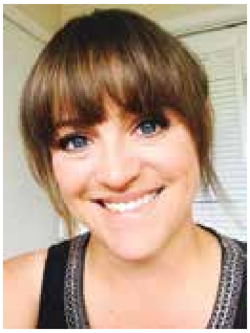
SCHOLARSHIP COMMITTEE CHAIR

KATHRYN KOSLOSKI is a plant manager at Luck Stone, based in Atlanta, GA. After graduating from Virginia Tech's Mining and Minerals Engineering Department in 2012, she began her career with the mining engineering group at Luck Stone and has since moved into the operations division. She is currently helping lead the acquisition of Luck Stone's first quarry in Georgia.

Kosloski is an active member of SME and currently serves the Minerals Education Coalition, Student Design Team Committee and the IM&AD in different capacities.

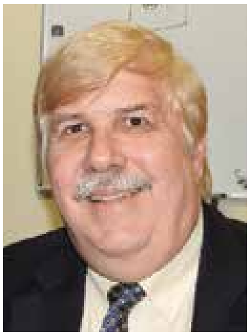
FGIM STEERING COMMITTEE CHAIR

SALLIE GAILLARD is a quarry manager at United States Gypsum Co. (USG) in central Iowa. After receiving her M.S. from Virginia Tech's Mining and Minerals Engineering Department in 2017, she began her career with USG in Fort Dodge, IA, as a mining engineer. She then moved to Alabaster, MI, to aid in the startup of a new quarry operation. Gaillard is an active member of SME's IM&AD and the newly incorporated Forum on the Geology of Industrial Minerals.



Sallie Gaillard

FGIM STEERING COMMITTEE CHAIR ELECT



Steven Stokowski

STEVEN STOKOWSKI, a registered professional geologist, is a materials geologist and the owner of Stone Products Consultants. His primary professional interests are aggregates and petrography.

Stokowski has extensive geological and petrographic experience across the United States. He has an M.S. in geology from the South Dakota School of Mines and Technology and a B.S. in geology from George Washington University. He received the 2014 Herbert C. Hoover Award from the Washington, DC, Section of SME and the 2017 Robert W. Piekarz Award from the IM&AD, and served as chair of IM&AD. He is registered or certified as a geologist in Georgia, Maine, Virginia and other states.

Mineral & Metallurgical Processing Division officer nominees

CHAIR

RONEL KAPPES is director, Processing with Newmont's Processing and Metallurgy Technical Services team located in Englewood, CO. She earned a baccalaureate degree in chemical engineering from Potchefstroom University, South Africa, in 1998 and a Ph.D. in metallurgical engineering from the University of Utah in 2003. She is a qualified professional member of the Mining and Metallurgical Society of America and a member of the board of AMIRA International.

Ronel Kappes

Kappes received the Mineral & Metallurgical Processing Division's (MPD) Outstanding Young Engineer award in 2009. She was on the editorial board of the *Minerals & Metallurgical Processing* journal and is now executive editor of SME's *Mining, Metallurgy & Exploration* journal.

Kappes has extensive flotation development experience in a variety of commodities, including copper, gold, platinum-group metals, molybdenum, lead and zinc. In her current role, she supports Newmont's global flotation portfolio.

ASSOCIATE CHAIR

DAVID MEADOWS graduated from the Camborne School of Mines, England, with a B.S. (Hons) in mineral processing technology. He has 36 years of diversified international experience in mineral processing. He started his career in operational roles in the gold and diamond mining industry in South Africa with Johannesburg Consolidated Investments and DeBeers Consolidated Mines. He worked for Bechtel Mining and Metals at its headquarters in San Francisco, CA with assignments in Brisbane, Santiago and Belo Horizonte. He spent four years with Phelps Dodge on new-project development and worked on Cerro Verde I commissioning, El Abra Sulfolix, Climax Moly's new concentrator and Tenke Fungurume in the Democratic Republic of the Congo.

David Meadows

In 2008, Meadows joined FLSmidth, leading its process technology group globally and participating in the growth of its world-class metallurgical/mineralogical testing laboratory. He returned to Bechtel Mining and Metals as manager of Technology and provides leadership on process and plant design across copper/gold and other commodities. In 2018, he became a Bechtel Fellow.

Meadows has published more than 35 technical papers and presentations. He is a chartered engineer, a chartered scientist in the UK, and a fellow and member of the board of directors of the Institute of Materials, Minerals and Mining. He has qualified person status in the United States.

FIRST VICE CHAIR

JAEHEON LEE is an associate professor in the Department of Mining and Geological Engineering at the University of Arizona in Tucson, AZ. He earned his B.S. and M.S. degrees with an emphasis on extractive metallurgy and chemical metallurgy from Korea University in Seoul, Korea. He received his Ph.D. from the University of Arizona in 2003.


Jaeheon Lee

Before he returned to Tucson as a faculty member, Lee worked as a metallurgical engineer at Newmont's Malozemoff Technical Facility in Denver, CO and at Barrick Gold's North America regional office in Salt Lake City, UT. He was involved in R&D projects for gold and copper deposits around the world. His technical expertise and research interests are in ore characterization and extractive metallurgy of precious and base metals, and he is an expert in biohydrometallurgical processes for the treatment of refractory sulfide minerals. Additionally, he is interested in metal recovery from electronic wastes, lithium-ion batteries and other recycled resources using environmentally friendly alternative chemicals.

Lee has chaired or served on several SME committees and is currently a member of the scientific committee for the International Biohydrometallurgy Symposium. He received an SME Career Development Grant in 2018 and Freeport McMoRan Copper & Gold's Academic-Industry Mining Fellowship in 2017 and 2018.

SECOND VICE CHAIR

TARUN BHAMBHANI is principal scientist at Solvay Mining Solutions. He has worked at the company for 14 years in the development of novel reagents to solve challenging separations and enable step-change in the flotation outcome. His contributions include the development of novel collectors for gold, platinum-group metals, oxide copper and modifiers for problematic gangue. His work has included collaborations between industry and academia to study pathways for deleterious effects and solutions for difficult-to-treat ores.


Tarun Bhambhani

Bhambhani has lectured extensively on the role of chemistry in flotation at mining companies and plants. He has organized several SME flotation sessions and symposia, served on research, membership and scholarship committees, and authored more than 40 papers. He is an associate editor on the editorial board of SME's *Mining, Metallurgy & Exploration* journal and received MPD's Outstanding Young Engineer Award in 2013. He was a co-organizer of the Sulfide Flotation Symposium at the Extraction 2018 conference. He has a bachelor's degree in mining and minerals engineering from Virginia Tech and a Ph.D. from Columbia University.

SECRETARY-TREASURER

AARON NOBLE is an associate professor in the Mining and Minerals Engineering Department of Virginia Tech and the associate director for the Center for Advanced Separation Technologies. His instruction and research are in the general areas of mineral processing, process economics and mine pollution control. Since 2014, he has acquired a personal share of research funding totaling nearly $5.7 million, with specific topics in process simulation and optimization, critical material and rare-earth-element processing, and extraterrestrial mining operations.


Aaron Noble

Noble has B.S., M.S. and Ph.D. degrees from Virginia Tech, all in mining and minerals engineering. He is an inaugural recipient of the SME Academic Career Development Grant (2015). He has also received the J.W. Woomer Award (2019), the MPD Outstanding Young Engineer Award (2018), the Rossiter W. Raymond Award (2017) and the Stefanko Best Paper Award. He was a Henry Krumb Lecturer in 2016 and 2018.

TECHNICAL PROGRAM ASSOCIATE

KIMBERLY MILLS is the chief process engineer at Devin Mills Consulting based in Evergreen, CO. She earned her B.S. and Ph.D. 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 metals, precious metals and industrial minerals.


Kimberly Mills

Mills received the 2014 MPD Outstanding Young Engineer Award. She currently serves as chair of the Student Member Affairs Committee, the Ivan B. Rahn and Mineral Industry Education committees and has served on several MPD award committees. She also serves as a member of the CSM Mining Engineering Department Industry Advisory Council.

MEMBERSHIP ASSOCIATE


Nick Gow

NICK GOW is laboratory manager for Forte Analytical, a mineral-processing laboratory based in Fort Collins, CO. He earned B.S. degrees in metallurgical engineering and chemistry and a 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 metallurgical engineering.

Gow has a decade of experience in hands-on metallurgical testing, equipment design and manufacturing, with a focus on mineral-processing feasibility, and is registered as a qualified professional for processing. His experience includes design and due diligence of metallurgical testing campaigns for processes including comminution, gravity, flotation and leaching of base and precious metals.

Gow started his career with the Dawson Metallurgical Laboratory of FLSmidth as a laboratory engineer. Later, he worked as a metallurgical consultant for Barr Engineering in Salt Lake City, UT and Forte Dynamics in Fort Collins, CO, routinely conducting site audits for operations both domestic and international. In 2020, he started Forte Analytical from the ground up, as a complementary service to the engineering and consulting services offered by Forte Dynamics.

Additionally, Gow serves as a research faculty member at the Colorado School of Mines and is active in SME. He previously chaired the Young Leaders and Student Member Affairs committees. In 2020, Gow debuted the new SME Metallic Student Design Competition and continues to serve as the program chair. He is co-chair of the upcoming Hydrometallurgy 2023 and World Gold 2025 conferences.

Mining & Exploration Division officer nominees

CHAIR

GREGORY F. SUTTON is a project manager at Cementation USA. He oversees underground mine development and construction projects in the eastern United States. He has a broad range of experience in technical, operational and managerial roles. His underground hard-rock experience includes mine planning and design, construction, mine operation, development and project management with extraction methods including cut and fill, vertical crater retreat, room and pillar, and pillar extraction.


Gregory Sutton

In 1988, Sutton earned a B.S. in mining engineering from the University of Missouri-Rolla, now Missouri University of Science and Technology (M&ST). In 2018, he completed his M.B.A. at M&ST. He started his career at Homestake Mining Co.'s historic gold mine in Lead, SD as a mine planning engineer and supervisor. He later held various positions of responsibility at The Doe Run Co., including mine engineer, mine general supervisor, mine superintendent and general mine manager. He started his current role at Cementation in 2015.

CHAIR ELECT

BRAD M. DUNN is a senior mining geologist at Barr Engineering Co., where he specializes in mine grade control and mine operations consulting. Prior to consulting, he worked in hard-rock and openpit operations, most recently for Oceana Gold Corp. in New Zealand. Dunn started his career as a gold fire assayer and has since held roles as grade-control technician, mining supervisor, grade-control geologist and senior mining geologist for operations in New Zealand, Australia, Indonesia, Canada and the United States.


Brad Dunn

Dunn served the Mining & Exploration (M&E) Division as program area manager for geosciences in 2017 and 2018. He has also served on the SME Research Committee. He holds a bachelor's degree in geology from the University of Otago, New Zealand, and is a certified professional geologist with the American Institute of Professional Geologists.

VICE CHAIR PROGRAMS

DON DWYER of Elko, NV, earned his B.S. in mining engineering from the University of Missouri-Rolla in 2002. Since 2018, he has been the mine manager at SSR Mining's Marigold Mine. Prior to that, he was employed at Barrick for approximately 11 years working in both underground and surface operations at the Goldstrike and Cortez properties. While at Barrick he held positions of mining engineer, front-

Don Dwyer

line supervisor, general foreman, maintenance superintendent and openpit manager. Dwyer also worked abroad for a year with Barrick as an area manager for the construction of a mine in the Andes Mountains of Chile and Argentina. Before Barrick, he worked for Teck Cominco American at their Pend Oreille underground operation in Washington state, where he held roles of mining engineer and front-line supervisor.

Dwyer is a member of the Mines and Metallurgy Academy advisory board at the Missouri University of Science and Technology (formerly University of Missouri-Rolla). He is active in SME, serving on strategic committees and on the M&E Executive Committee.

SECRETARY

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. 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.

Lia Walker

VICE CHAIR PROGRAM PLANNING

JENESSA HAARALA has more than 15 years of experience as an underground mine 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 served as an officer of the Northeastern Nevada Section, spoken and chaired at multiple annual conferences, served as an M&E program area manager, served on the Sustainable Development Committee and received the M&E Outstanding Young Professional Award in 2018.

Jenessa Haarala

Haarala has worked in gold, copper and contractor business development in Nevada, New Zealand and Utah. She has helped start up several new mines and specializes in leading and developing engineering teams responsible for design, scheduling, ventilation, reserves and budgets. She is passionate about promoting inclusion in the mining industry. Haarala currently works as an independent consultant based in Salt Lake City, UT.

ASSISTANT VICE CHAIR PROGRAM PLANNING

DANIEL ROSENBACH is the business development manager for HD Drilling Resolution. He has been involved in the mining industry for 15 years and graduated with a degree in mining engineering from the Colorado School of Mines in 2011. He began full-time employment at Atlas Copco upon graduation and served the company in Pikeville, KY; Carlin, NV; Denver, CO; and Duluth, MN. In 2020 he helped establish HD Drilling Resolution, where he performs drilling consultation and drilling consumable sales.

Daniel Rosenbach

Rosenbach has remained an active member of SME since he joined while in college in 2005. He has presented a paper and chaired three technical sessions, was an M&E program area manager for technology in 2018, and began as secretary of the M&E Executive Committee in 2021.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.

WAAIME Division officer nominees

CHAIR AND WESTERN REPRESENTATIVE

WINNELL BURT was born in Chicago, IL, moved to Arizona at the age of six and grew up on a cattle ranch. She graduated from San Manuel High school in 1971 and the University of Arizona in 1973. In 1976, she married Christopher Burt, who worked for Magma Copper Co. in Superior, AZ while she taught in the elementary school. After her husband transferred to Magma Copper in San

Division Officer Nominations

Winnell Burt

Manuel in 1982, Burt joined the WAAIME AZ/T-SM section. She then joined the WAAIME UT-N section in 2001 when her husband's job took them to Utah, serving several years as secretary and chairman. She became involved at the national level in 2003 and served in numerous capacities until 2008, when WAAIME became a division of SME.

Burt rejoined the AZ-T/SM section in 2007 when she and her husband retired in Tucson. She serves her local section as their treasurer, chairman, and national and local scholarship chair and is the group's national representative. She served on the WAAIME Executive Committee in 2009 and was chair in 2010 as well.

Burt and her husband have been married for 45 years and enjoy sailing, traveling the world and spending time with their two children, their children's spouses and their four grandchildren, who all live close by.

EASTERN REPRESENTATIVE AND SCHOLARSHIP CHAIR

Lydia Hull

LYDIA HULL was raised in a mining environment in West Virginia. Her father, Steve Kish, retired as a foreman from Consol and received The Old Timers Award. Her husband, Larry, graduated from Virginia Tech with a mining degree and received an award from WAAIME, WV-S, as the outstanding top student of his class. That began her involvement with WAAIME.

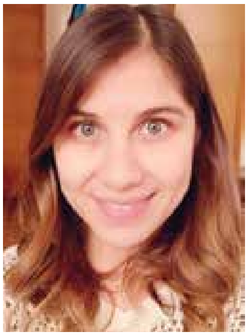
Working as an registered nurse, and with frequent moves (17 at last count), limited her time to be as active as she would have liked. That changed with their move to Peters Township, and her work with the WAAIME PA-W section.

Hull has worked exclusively with the scholarship committee and served as local chair and national chair for several years. She enjoys seeing the students journey through college and then in their chosen industry occupations. It is this interaction between the WAAIME members and students that makes the WAAIME process successful and rewarding for her. The interaction emphasizes the important role that WAAIME members play in the success of these students. Helping them is her passion.

INTERNATIONAL REPRESENTATIVE

KATHERINE PINOCHET is a 33-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 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 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.



Katherine Pinochet

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. She is scheduled to complete a postgraduate specialization on ground water hydrology in 2022.

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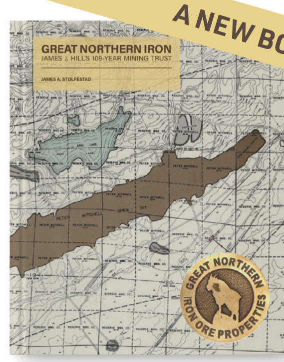

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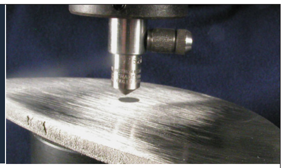

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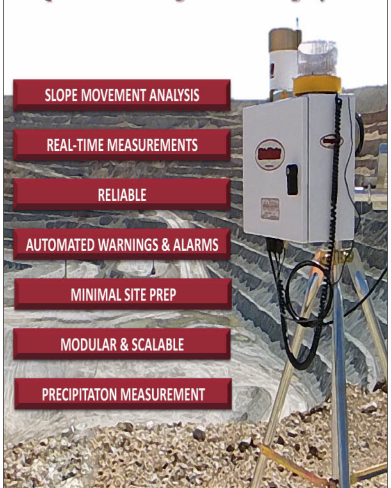

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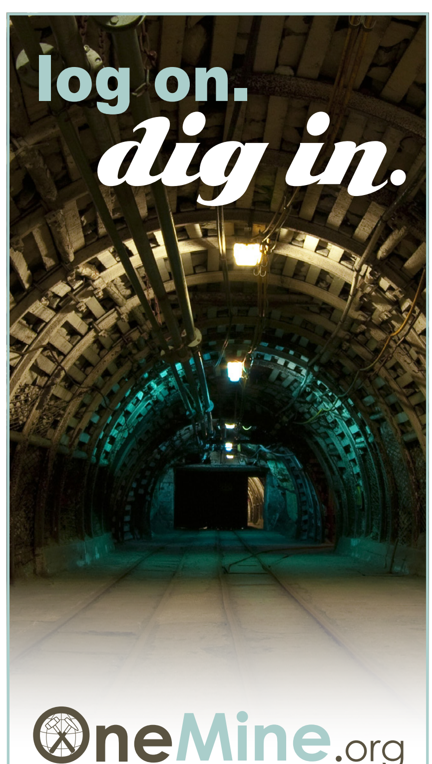

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Industrial minerals are the backbone of society

William Gleason
Editor

Annual review of 43 minerals

Mining Engineering's annual Industrial Minerals Review is a comprehensive look at some areas of the mining industry that don't normally get a lot of attention outside of the mining sector.

When is the last time you scrolled through the news feed of a major media website and found an article about barite or zeolites. Yet these industrial minerals, 43 of which are summarized in this issue beginning on page 42, are hugely important to keeping modern society humming along. Perhaps industrial minerals are not as sexy as gold or diamonds or as entrenched in the political discussions as coal and a host of critical minerals, but industrial minerals are the backbone of modern society.

According to the U.S. Geological Survey and published in the May issue of *Mining Engineering.* "the value of output of industrial minerals and materials from mines in the United States was $54.6 billion, 4 percent lower than it was in 2019. More than 6,500 companies contributed to this output, producing from more than 12,000 mines, quarries and processing facilities. Overall in 2020, the production of industrial minerals, by tonnage, decreased by 3 percent compared with that in 2019. In addition to mined materials, the United States is a major producer of industrial minerals that are recovered from processes other than mining. These materials, including iron and steel slag, nitrogen, sulfur and synthetic gypsum, contributed an estimated additional $3.9 billion of value to the industrial minerals industry."

The reviews in this issue provide a deeper look not just at the specific minerals, but often give insight to the health of other areas of the national and international economies such as the U.S. housing market, domestic and international oil and gas production, infrastructure such as roads, bridges and tunnels and even the demand for common products like beer or toothpaste. In case you're wondering, diatomite (page 55) is an excellent raw material for filtration, absorbent and filler applications. The purification of beer, liquors and wine is among the largest end uses of diatomite. In short, the next time you enjoy a drink, you are also helping to support one sector of the mining industry.

Of course, no review of 2020 would be complete without looking at the impact of the COVID-19 pandemic and in these pages many of the reviews include such notes.

No industry or person was left untouched by the pandemic in one way or another. In regard to industrial mineral production and delivery, one of the lasting effects from the pandemic could be turned into a positive as COVID-19 shed light on the vulnerabilities of the global supply chain.

Mike O'Driscoll, director and co-founder of IMFORMED — Industrial Mineral Forums & Research Ltd, UK; writes in the section's introduction on page 42 that "in that it (the pandemic) both educated and reinforced the vital role of industrial minerals in industrial manufacturing processes and everyday products and applications.

"As mineral supply chains struggled to meet market demand for most of 2020, industrial minerals' "essentiality" and "criticality" soon became apparent and has since informed consuming industries and governments worldwide of their vulnerable supply lines and overreliance on limited overseas sources."

On page 8, we see the possible results of this as the Biden administration announced plans to create a strategic task force that will aim to address near-term supply chain issues affecting a number of industries, including mining.

This issue would not be possible without the efforts of SME's Industrial Minerals & Aggregates Division. And a special thanks goes to annual review editor Jim Norman from Tetra Tech Geo, and chair of the technical committee, Riddhka Jain, from Metso Outotec. Their efforts to pull these reviews together are greatly appreciated by the editors of *Mining Engineering* and provide a wonderful benefit to the readers of *Mining Engineering*. ■

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