4th Annual National Workshop: Resilient Supply of Critical Minerals

August 7-8, 2024

Rolla, Missouri

Hosted by Missouri University of Science and Technology

criticalminerals.mst.edu

Preferred Citations

Workshop Proceedings

Clark, S., Locmelis, M., Moats, M., Awuah-Offei, K., Alagha, L., Fitch, M., Fikru, M., & Krolikowski, A. (2024): Proceedings of the 4th Annual Workshop on Resilient Supply of Critical Minerals, 7-8 August 2024, Missouri University of Science and Technology, Rolla, Missouri, USA, 45 pages.

Individual Abstracts (example)

Nassar, N. (2024): Quantifying the impact of mineral commodity supply disruptions on the U.S. economy. In: Clark, S., Locmelis, M., Moats, M., Awuah-Offei, K., Alagha, L., Fitch, M., Fikru, M., & Krolikowski, A. (2024): Proceedings of the 4th Annual Workshop on Resilient Supply of Critical Minerals, 7-8 August 2024, Missouri University of Science and Technology, Rolla, Missouri, USA, 45 pages.

Cover: Known critical mineral distribution in the state of Missouri. Rolla, Missouri represented by the blue star. Data courtesy of the Missouri Department of Natural Resources, PUB2912. https://dnr.mo.gov/document-search/other-critical-minerals-missouri-pub2912/pub2912

About the National Workshop on the Resilient Supply of Critical Minerals

The National Workshop on the Resilient Supply of Critical Minerals is an NSF-funded workshop bringing academics, industry professionals, and policy makers together to build a multi-disciplinary task force with the goal of solving the critical minerals and energy crisis facing the United States. In this workshop, research, industrial, and policy needs are discussed, and the state of current research is evaluated through student and researcher participation.

In 2022, the United States Geological Survey released an updated report classifying 50 elements as critical minerals. These elements and minerals are critical to everyday life, making up the critical components of electronics, batteries, green energy, and industry. Despite the criticality of these minerals, the United States is dependent on imports to maintain the supply of critical minerals.

Critical minerals research is at the forefront of national interest and development in the age of green energy. With organizers, keynote speakers, and participants from the fields of geology, geological engineering, mining, environmental engineering, politics, economics, materials science, and social science, this workshop aims to encourage the development of the future critical minerals workforce.

Founded in 1870 as the “Missouri School of Mines and Metallurgy”, the Missouri University of Science and Technology campus in Rolla is an ideal location in the Midwest to host such a workshop. Located in Central Missouri, Missouri S&T is surrounded by ore deposits that host and have the potential to host critical minerals (see cover).

Reports for the 2021- 2023 Workshops

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Agenda

All times are in US Central Time

Wednesday, August 7, 2024

The Critical Mineral Potential of the USA

Evaluation of existing, and exploration for new resources

8:45 – 9:00	Welcome and Opening Remarks *Marek Locmelis, Workshop Chair* *Kamal Khayat, Vice Chancellor for Research and Innovation*
9:00 – 9:30	Keynote Speaker *Nedal Nassar, United States Geological Survey*
9:30 – 10:00	Keynote Speaker *Cheryl Seeger, Missouri Geological Survey*
10:00 – 11:00	Oral Presentations *Matthew McCaughey – Arcadis/Quapaw Nation* *Collin Williams – USGS* *Brandon Sullivan – Doe Run Company* *Zohreh Kazemi Motlagh – New Mexico Institute of Mining and Technology*
11:00 – 11:15	Break
11:15 – 11:45	Open Forum Discussion
11:45 – 13:00	Lunch and Poster Session* *Topical Sessions 1 & 2* **Posters will be displayed in the hall outside St. Pat's Ballroom.*

Critical Minerals Workforce Development

How to grow the US critical minerals workforce

13:00 – 13:30	Keynote Speaker *Leigh Freeman, Leigh Freeman Consultancy*
13:30 – 14:00	Keynote Speaker *Carey Bridges, Missouri Geological Survey*
14:00 – 15:00	Oral Presentations *Daniel LaBrier – Idaho State University* *Emma Hunt – Furman University* *James Kubicki – UTEP* *Gregory Wessel – Geology in the Public Interest*
15:00 – 15:15	Break
15:15 – 15:45	Open Forum Discussions
15:45 – 17:00	Breakout Sessions
17:00 – 19:00	Break
19:00 – 21:00	Workshop Dinner *Sponsored by Tech Hub* *Missouri S&T Experimental Mine*

Learn more about the Missouri S&T Experimental Mine

Thursday, August 8, 2024

Mineral Processing and Recycling

Maximizing critical mineral recovery from existing production streams

8:45 – 9:00	Welcome and Opening Remarks *Marek Locmelis, Workshop Chair* *David Borrok, Vice Provost and Dean (College of Engineering and Computing) – Missouri S&T*

9:00 – 9:30	Keynote Speaker *Sarah Schwarz, Nyrstar*
9:30 – 10:00	Keynote Speaker *Michael L. Free, University of Utah*
10:00 – 11:00	Oral Presentations *Fardis Nakhaei – Missouri S&T* *Long Qi – Ames National Laboratory* *Badri Shyam – Xerion Advanced Battery Corp.* *Nadine Piatak – USGS*
11:00 – 11:15	Break
11:15 – 11:45	Open Forum Discussion
11:45 – 13:00	Lunch and Poster Session *Topical Sessions 3 & 4* **Posters will be displayed in the hall outside St. Pat's Ballroom.*

Policy and Supply Chain Economics

Reshoring critical mineral production

13:00 – 13:30	Keynote Speaker *Beia Spiller, Resources for the Future*
13:30 – 14:00	Keynote Speaker *J. Andrew Grant, Queen's University*
14:00 – 15:00	Oral Presentations *Donya Otarod – Missouri S&T* *Stéphane Goutte – UMI SOURCE, Université Paris-Saclay* *John Kutsch – Thorium Energy Alliance* *James Kennedy – Caldera Holding, LLC*
15:00 – 15:15	Break

15:15 – 15:45 Open Forum Discussion

15:45 – 17:00 Breakout Sessions
Workshop Wrap-up, Sessions 1-4

17:00 – 17:30 Field Trip Introduction Session
Greg Sutton, US Strategic Metals

Friday, August 9, 2023

Field Trip to US Strategic Metals

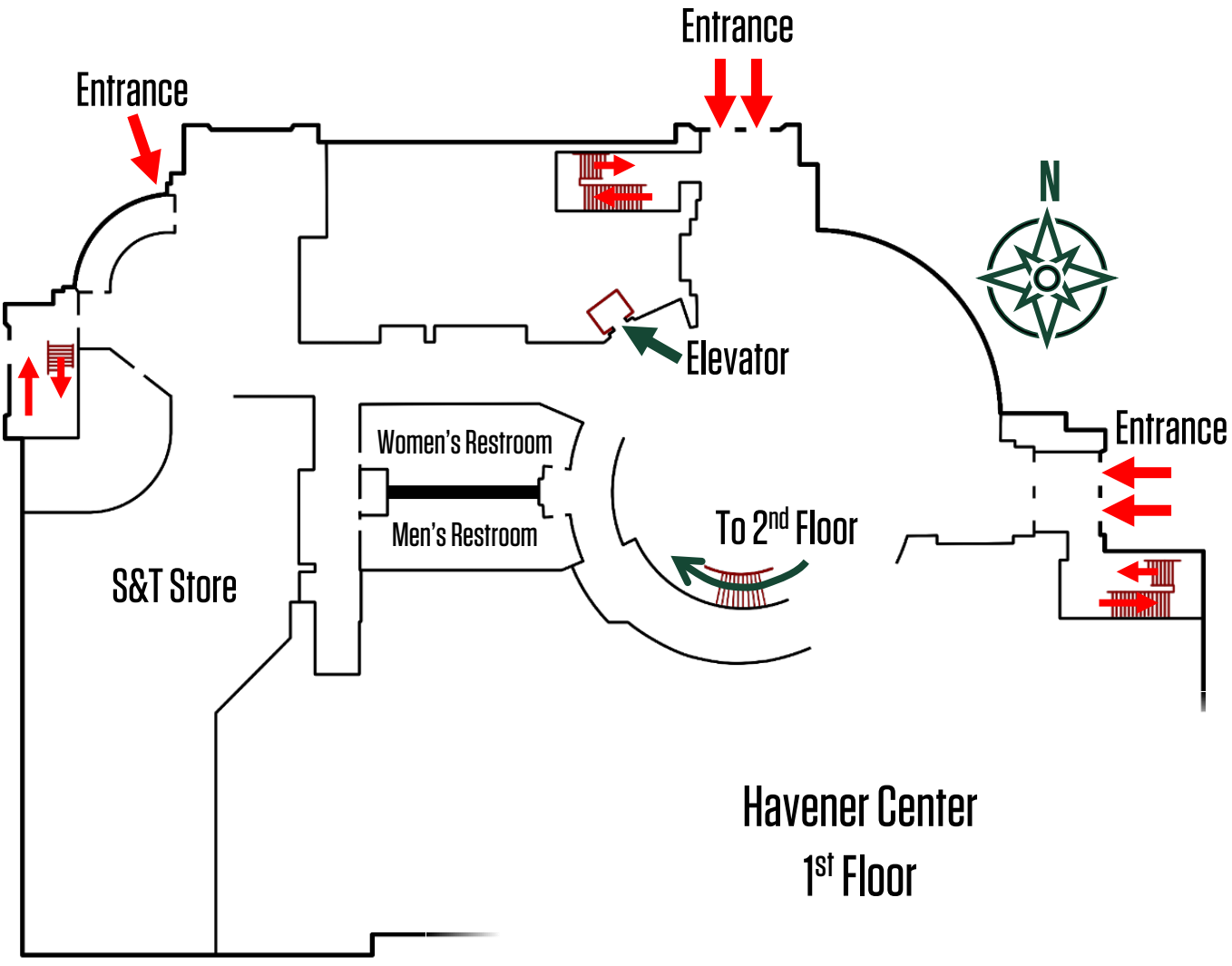
Southeastern Missouri

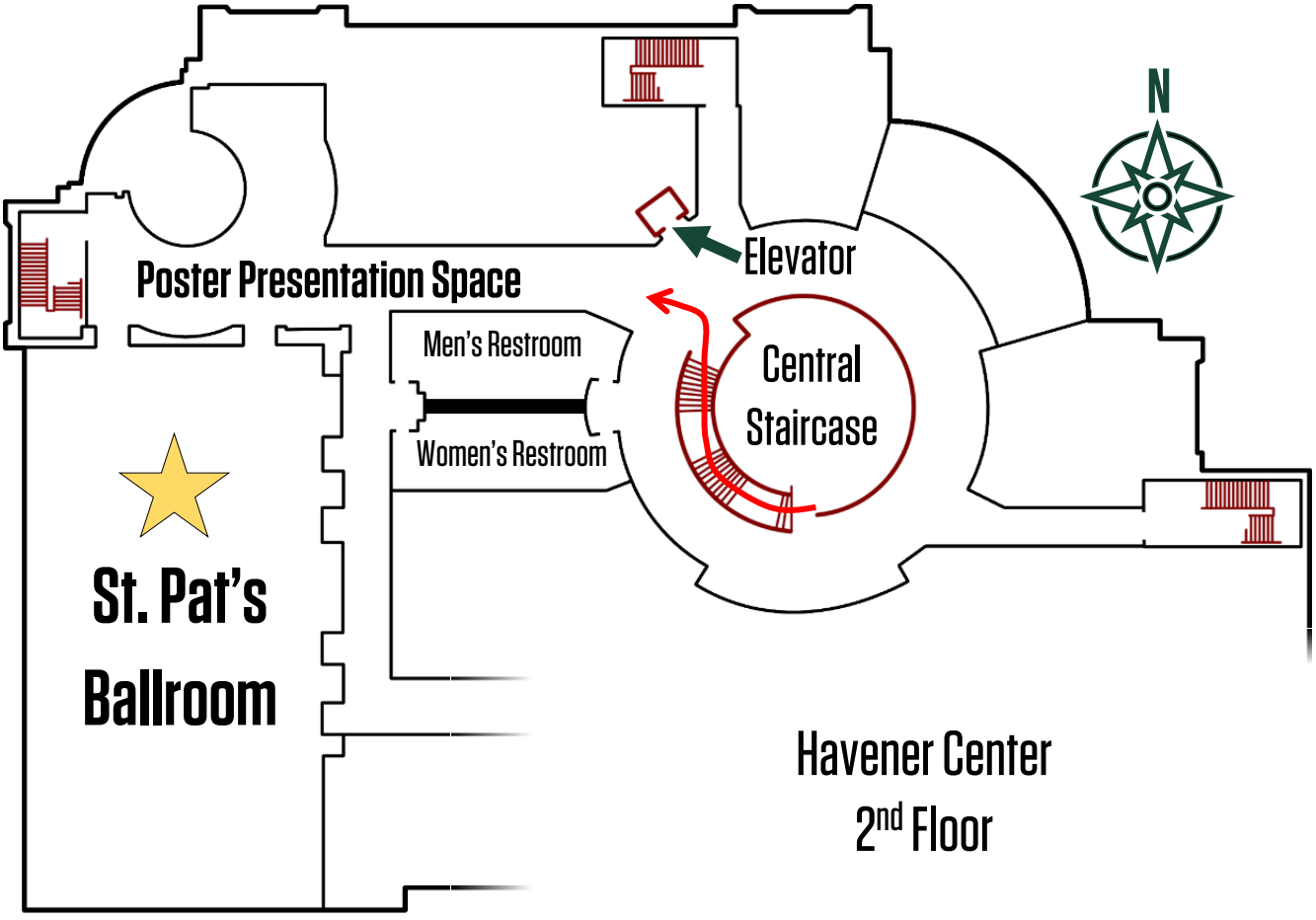
7:00 – 15:00 Field Trip
Limited to 14 attendees

Map of the Havener Center

1346 N Bishop Ave, Rolla, MO 65409

Workshop presentations (oral and poster) will be held on the 2nd floor of the Havener Center. Main workshop presentations will take place in St. Pat's ballroom, and poster presentations will be set up in the hallway outside of the ballroom. Please note that ongoing construction has significantly disrupted the availability of parking near the Havener Center.




N
Elevator
Poster Presentation Space
Men's Restroom
Women's Restroom
Central Staircase
St. Pat's Ballroom
Havener Center
2nd Floor

Kennedy Experimental Mine Building

12350 Spencer Rd, Rolla, MO 65401

The workshop dinner will be held on August 7th at 7:00PM in the Kennedy Experimental Mine Building.

Built in 2016, the Kennedy Experimental Mine Building houses a mine rescue laboratory, classrooms, and historic mining center. This facility, along with the nearby Experimental Mine, is an important teaching center allowing students and researchers in geological, explosives, and mining engineering to conduct research and experiments in a hands-on underground setting.

Workshop Dinner

Sponsored by CM2AE Tech Hub

The workshop dinner on August 7th is sponsored by the Critical Minerals and Materials for Advanced Energy (CM2AE) Tech Hub consortium, led by Missouri S&T.

On October 23, 2023, Missouri S&T was selected as one of 31 Tech Hubs in a program administered by the U.S. Department of Commerce's Economic Development Administration (EDA).

Learn more about the CM2AE Tech Hub here or with the QR code below.

Post-workshop Field Trip

To US Strategic Metals, Fredericktown, Missouri

August 9th | 7:00-15:00

The post-workshop field trip is led by US Strategic Metals (formerly Missouri Cobalt, LLC), of Fredericktown, Missouri. Established in 2018, USSM is dedicated to providing a clean and reliable supply of critical and strategic minerals to support safe and sustainable energy sources. The field trip will center around the mine site at Fredericktown, where the company focuses on cobalt, nickel, and copper reclamation. Learn more about their mission and current projects.

US STRATEGIC METALS

Parking and Check-in

The Workshop will be held in the Havener Center on the Missouri S&T Campus. Visitors may park at the metered parking spots, and an underground parking garage is available for parking near the Havener Center on campus. See the below QR code and link for the 2023-2024 Missouri S&T Parking map.

Street parking is available along St. Patrick's Lane, and is available throughout most of Rolla. Please keep in mind most street parking options besides St. Patrick's Lane have a maximum parking time of 2 hours (marked). Campus lot enforcement hours are between 7:30AM and 4:30PM.

Check-in and same-day registration will be on the second floor of the Havener Center in front of the St. Pat's Ballroom. You must check in to receive a name badge. Travel grant recipients must check in to the registration desk both days of the workshop.

Parking Lot Locations at Missouri S&T

Keynote Speakers

Nedal Nassar, United States Geological Survey

Chief, Minerals Intelligence Research Section

Quantifying the impact of mineral commodity supply disruptions on the U.S. economy

Mineral commodity supply chains have come under increasing strain over the past few years from the COVID-19 pandemic, regional conflicts, trade wars, and resource nationalization. Given the importance of mineral commodities to economic development, national security, and the clean energy transition, assessing the risks associated with their supply disruption has become a priority among major import-dependent countries, with many developing lists that highlight the commodities of most concern to them. While these analyses are useful in that they provide a prioritization, they do not offer results in standard economic terms that can be used to weigh the benefits of undertaking certain policies or incentivizing certain actions against the costs of inaction. Here we present a new model that assesses the economic impact of mineral commodity supply disruptions on the U.S. economy. Specifically, the model estimates the decline in U.S. GDP under various scenarios of supply disruption after accounting for price elasticities and excess production capacity and inventories outside of the restricting or disrupted region. Results of the model for different scenarios of China's export restriction of gallium and germanium will be presented and the model's applicability to other commodities and other scenarios will be discussed. Once expanded to include many commodities, the model can be used to update the U.S. List of Critical Minerals and provide decisionmakers with an economic basis for supporting certain activities and policies.

Biography | As chief of the Minerals Intelligence Research Section at the U.S. Geological Survey, Dr. Nassar and his research team quantify the global stocks and flows of nonfuel mineral commodities at each stage of their life cycle, analyze trends and examine concerns regarding foreign mineral dependencies, develop supply and demand scenarios, and assess the mineral commodity supply risk to the U.S. economy and national security. Dr. Nassar received his Ph.D. from Yale University where he worked on the development and application of a methodology for assessing critical minerals. He has continued that work as a leading member of the U.S. National Science and Technology Council's Critical Minerals Subcommittee. He also serves as co-chair of

the Council of Senior Science Advisors at U.S. Geological Survey and has been on the advisory board of various international research projects. In 2019, he was awarded the Presidential Early Career Award for Scientists and Engineers--the highest honor bestowed by the U.S. Government to outstanding scientists and engineers who are beginning their independent research careers. His research has been published in several high-profile journals and highlighted in major media outlets. He has been called upon to testify before the U.S. Senate and the U.S. House of Representatives, brief senior government officials, and invited to give keynote addresses and present his research at significant venues including The National Academies, the European Commission, and the World Bank. Previously, Dr. Nassar worked as a consultant and as a process development engineer in the semiconductors and data storage industries where he was the recipient of three trade secrets. He also holds a bachelor's degree in chemical engineering from the University of Minnesota, an MBA in sustainable global enterprise from Cornell University, as well as two master's degrees from Yale University.

Cheryl Seeger, Missouri Geological Survey

Registered Geologist

The Missouri Geological Survey and Earth MRI: Critical Minerals at the State Level

The Missouri Geological Survey (MGS) is carrying out multiple USGS Earth MRI critical mineral projects that vary from geologic mapping to geochemical surveys and data preservation and range from Precambrian to Pennsylvanian and potentially younger strata. Data from and for these projects varies from newly collected mapping and geochemistry to MGS-housed drill cores and historic sample and document collections. State geological surveys, including Missouri's, are uniquely situated to collect, process, archive, and publish new and historic critical mineral data. Implementation of these projects and state geological survey data is a crucial part of Earth MRI.

Biography | Cheryl Seeger attended the University of Missouri-Rolla for all three degrees. She discovered ore geology during her Bachelor's degree and never looked back. After a brief stint in

oil shales, she has been with the Missouri Survey for nearly 40 years, starting with an internship during her Master's degree. She and her unit currently are working on multiple grants related to critical minerals geology in Missouri.

Leigh Freeman, Leigh Freeman Consultancy

Consultant
Chairman, Timberline Resources
Senior Mining Advisor, Stanton Chase Global

Critical Minerals Workforce Development – Hiring Strategies

Workforce development challenges are well recognized in the mining industry. They represent the largest obstacle to meeting our responsibility to supply society with necessary natural resources. Topical stories drawn from more than four decades of diverse mining experiences will contextualize data and research relevant to hiring strategies. Mitigation of workforce challenges can be realized with modification of hiring practices, broader development of competencies, some modifications of organizational structures and increased reliance on corporate systems.

Biography | In leadership roles over his 40+ years of experience in over 30 countries Leigh ticked-the-box in exploration, mine development, finance, production and BODs for large and small mining companies. His recent focus is corporate strategies, team building including talent recruitment, minerals education and enjoying his five delightful grandchildren. Leigh serves as chairman of Timberline Resources and as a senior mining advisor to Stanton Chase Global, a large executive recruiting company. He is active in minerals education with three of the mining schools, SME, and National Academy of Sciences. Leigh is an engineering graduate of Montana Tech.

Carey Bridges, Missouri Geological Survey

Director of the Missouri Geological Survey
State Geologist
Registered Geologist

Critical Minerals Workforce Development at a State Geological Survey – Recruitment and Retention

The critical minerals workforce is in high demand to fulfill the ever-increasing opportunities across the sector. With declining enrollment in geoscience and related programs, employers need robust recruitment and retention strategies to attract, develop, and retain team members. While the mission of the organization and intrinsic value of the work is a piece of that puzzle, prospective and new employees are looking for more from their work experience. This presentation will highlight examples of successful strategies and programs implemented at the Missouri Geological Survey to recruit and retain talent, as well as examples of student/employer networking and connections that resulted in permanent hires.

Biography | Carey Bridges, RG is the Director and State Geologist of the Missouri Geological Survey, a division of the Missouri Department of Natural Resources. Bridges holds a Bachelor of Science Degree in Geology from the University of Central Missouri and a Master of Science Degree in Geology from the University of Missouri – Columbia. She is licensed in Missouri as a Registered Geologist. Bridges has over 24 years of experience in a variety of roles with the department managing environmental and geologic investigations in areas of hazardous waste remediation, waste disposal, economic geology, natural resource stewardship, and geologic hazards.

As State Geologist, Bridges works to develop policy that benefits Missouri's interests at the state and federal level related to geologic, soil, and water resource issues. She serves on six state boards and commissions, including the State Oil and Gas Council, the Missouri Mining Commission, the Missouri Board of Geologists Registration, the Well Installation Board, the Industrial Minerals Advisory Council, and the Missouri Board on Geographic Names. In addition, she represents Missouri's interests with the Interstate Oil and Gas Compact Commission. Bridges

is a member of the Association of American State Geologists, a member of the Geological Society of America, a member and recent president of the Association of Missouri Geologists, and serves on the Missouri University of Science and Technology O-Keefe Institute Advisory Board and the University of Missouri Geology Development Board.

Sarah Schwarz, Nyrstar

Technology Manager, Nyrstar Clarksville Smelter

The Nyrstar Clarksville Critical Minerals Project

Nyrstar is an international producer of critical minerals and metals, including high quality zinc, lead and other metals. Nyrstar is proposing to expand its Clarksville, TN, production facility to include state-of-the-art germanium and gallium recovery and processing. The Nyrstar Clarksville Critical Minerals Project (CMP) will establish the only domestic primary production of Ge and Ga, as well as increasing the production of Zn at the Clarksville smelter, currently the only primary Zn refinery in the US.

Biography | Sarah has over 25 years in the mining industry with experience in operations, technical, business improvement and consulting work across all aspects of the value chain. She has worked at numerous processing plants around the world and holds a bachelor degree in Metallurgical Engineering, an MBA in General Business Management and a Ph.D. in Mineral Processing, all from the University of South Australia. Sarah is currently the Technology Manager at the Nyrstar Clarksville Smelter in Tennessee, USA.

Michael L. Free, University of Utah

Department Chair and Professor, Department of Materials Science and Engineering

Low Cost Extraction and Recovery of Critical Minerals from Low Grade Resources

Rare earth elements (REEs) and critical minerals (CMs) are crucial to many modern devices, including many items that are important to clean energy and defense systems. The U.S. imports a large fraction of the REEs/CMs used domestically, creating a significant national security concern and a corresponding interest in finding a variety of domestic sources. One potential feedstock resource is coal waste. The total REEs content of most coal waste and related materials is 200-300 ppm. In order to potentially economically recover REEs/CMs from such low grade resources there needs to be sufficient value in the constituent elements and correspondingly low cost processing methods. This presentation will discuss these issues based on an investigation of low cost mineral processing, extraction, and recovery of REEs from coal waste feedstock materials.

Biography | Michael Free is a Professor in and Chair of the Department of Materials Science and Engineering at the University of Utah in Salt Lake City, Utah. He has performed research and taught courses as a faculty member for more than 27 years. His areas of expertise include hydrometallurgy, electrometallurgy, corrosion, and materials synthesis. He has been the principal investigator of more than 65 research projects funded by more than 20 companies, the Department of Defense, Department of Energy, Office of Naval Research, and the National Science Foundation. He has authored or co-authored more than 260 publications. He has been a paid consultant for 40 organizations. He received a B.S. degree in metallurgical engineering, an M.S. degree in chemical engineering and a Ph.D. degree in metallurgical engineering from the University of Utah. He worked as a Post-Doctoral Associate at the University of Florida in the Departments of Materials Science and Engineering and Chemical Engineering for two years before becoming a faculty member at the University of Utah.

Beia Spiller, Resources for the Future

Director and Fellow, RFF Transportation Program

Community engagement and social justice in mining

The growing demand for minerals for electric vehicles has increased the need to invest in mineral extraction and processing, yet most mineral resources in the United States are located in near proximity to native lands and other disadvantaged populations. Without careful precautions, this increase in extraction could cause undue harm to local communities; furthermore, due to NEPA requirements, local community opposition to the activity has the potential to delay development. To that end, effective and equitable engagement with local communities will be needed to reduce potential harms, compensate local communities for risks (including environmental, social and economic), and reduce opposition delays. This presentation will cover issues such as what effective, meaningful and equitable engagement looks like; challenges that often emerge in the engagement process; how to deal with competing community interests; the role for compensation agreements and how to best structure these; and opportunities that can arise from community engagement. The talk will also present policies that can be enacted to improve collaborative outcomes between communities and mining companies, and discuss the role for research in this space.

Biography | Beia Spiller is a fellow and the director for RFF's Transportation Program. Prior to joining RFF, she was Lead Senior Economist at Environmental Defense Fund, where she worked for almost a decade. She is also a Board member for the Association of Environmental and Resource Economists. Spiller is an energy economist, with experience working on electricity and transportation issues. During her time at EDF, she participated in many electric utility proceedings in NY and CA, with a goal of ushering in a cleaner, more efficient and equitable energy system. She also has many years of experience working in the transportation sector. Her more recent efforts have focused around electric vehicles and environmental justice, exploring some of the most pressing issues around electric car, truck and bus adoption. Her publications range across the energy space, with a large focus on identifying environmental, community and health impacts of renewable energy resources and energy policies.

J. Andrew Grant, Queen's University

Associate Professor, Department of Political Studies

How 'Just' are Mineral Supply Chains in the Just Energy Transition? Insights from the Democratic Republic of Congo

Although the 'just transition' to renewable energy sources is an important strategy to address climate change, relatively little attention has been allocated to how this transition is impacting artisanal miners and community members who reside near the mining sites of 'critical minerals' (e.g., cobalt, copper, lithium, graphite, nickel) and surrounding areas. Concomitantly, it is unclear whether upstream stages of transnational supply chains associated with critical minerals can be reconciled with potential gains for the environment. The Democratic Republic of Congo (DRC) is home to some of the largest reserves of strategic minerals in the world, yet the voices of the very people living near where the mining occurs are rarely incorporated as part of global and regional governance discussions and policy improvement efforts. Based on recently conducted fieldwork in the DRC and other parts of the globe, the presentation engages with and reflects upon the empirical and policy dynamics pertaining to the governance of critical minerals.

Biography | J. Andrew Grant is an Associate Professor in the Department of Political Studies at Queen's University and Early Researcher Award recipient from the Government of Ontario's Ministry of Research and Innovation for his work on security and governance challenges in mineral resource sectors. His latest books are Natural-Resource Based Development in Africa: Panacea or Pandora's Box? (University of Toronto Press, 2022) and Corporate Social Responsibility and Canada's Role in Africa's Extractive Sectors (University of Toronto Press, 2020). His findings based on fieldwork conducted across Africa and other parts of the globe have appeared in journals such as International Affairs, International Journal, International Studies Review, International Studies Perspectives, Journal of Cleaner Production, Extractive Industries and Society, Land Use Policy, and Resources Policy. In 2017, Dr. Grant served as Program Chair for the International Studies Association annual conference, which brought together more than 6,000 scholars and practitioners in Baltimore, MD.

Oral Presentations

Oral Presentations will be held in St. Pat's Ballroom A.

Session 1: Evaluation of existing, and exploration for new resources

10:00–10:15 **Mining Waste Reuse as a U.S. Source of Critical Minerals**
Presented by Matthew McCaughey

1 (Background). While the United States lags behind creating a sustainable supply chain of minerals critical to the energy transition and national defense, today's prices make the economics of new greenfield projects challenging. This raises a question: are their brownfield sources of critical minerals that may be economically viable to recover? Yes. For example, there are thousands of abandoned mine sites nationwide, all containing various volumes of solid mining waste. Due to the advancements in mineral extraction methods and technologies, many waste materials may contain recoverable mineral concentrations; however, the general lack of awareness and guidance has slowed the utilization of mining waste as a source of critical minerals. 2 (Approach). In March 2023, the Interstate Technology and Regulatory Council (ITRC) formed a team to examine the possibilities and best management practices for environmentally safe reprocessing and reuse of mining waste, and the technical and regulatory issues associated with reuse. This presentation will summarize the results of a survey conducted by the ITRC team to solicit feedback on awareness and policies associated with mining waste reuse. Additionally, an overview of an online guidance document and training course (available in early 2025) will be presented. 3 (Results). The survey was distributed to both U.S. state regulators serving as ITRC representatives, and environmental representatives of all federally recognized tribal nations (as of May 2023). There were 36 responses (80% states, 20% tribes). Awareness of community support, government commitments, and existing reuse policies were low (6 to 29%), while responses were higher regarding local awareness of critical minerals (37%), and waste reuse projects (49%). The survey findings suggest there is a need for better education and sharing of success stories so that stakeholders can confidently develop policies and engage with waste reuse projects in a manner safe to human health and the environment.

10:15–10:30 **Establishing a Viable Critical Minerals "Stockpile" for the United States Economy**

Presented by Collin Williams

In the late 1930s, the anticipated disruption of global mineral supply chains by a potential world war spurred the United States to take action to secure essential mineral supplies. In support of this, the US Geological Survey and the US Bureau of Mines developed a list of essential minerals for which supplies would be deficient in the event of war and devised a Strategic Minerals Development Program for (1) stockpiling mined materials during peacetime and (2) establishing an "underground stockpile" of sub-commercial mineral deposits which could be mined during wartime. The "underground stockpile" concept involved characterizing deposits so that new mining could be underway within 2 years, with the traditional stockpile covering demand in the meantime. Although the traditional stockpile continues as the National Defense Stockpile (NDS), sub-commercial deposit characterization work wound down during the Cold War.Today, the vulnerability of global mineral supply chains when the United States is more dependent than ever on importshighlights the need for a new plan to secure essential minerals. Although the NDS can meet near-term defense needs, meeting broad economic needs is an unresolved problem. A return to the "underground stockpile" is not a viable near-term solution, as developing new mines will take far longer than the 2 years envisioned in the 1930s. Alternative actions are available to provide supplies of critical minerals in the event of a crisis. These involve developing and deploying technologies that can (1) extract byproduct critical minerals from active mining operations, (2) extract critical minerals from large volumes of mine waste at active mining sites, (3) ensure that inactive critical mineral mines can be brought back online on short notice, (4) increase the effectiveness of recycling. These actions can secure near-term requirements while ongoing research and development efforts identify resources for the longer term.

10:30–10:45 **Unleashing the World Class Critical Mineral Potential of Southeast Missouri**

Presented by Brandon Sullivan

The materials science revolution has fundamentally transformed the supply and demand for metals and minerals. Harnessing the power of innovation, The Doe Run Company is poised to revolutionize the extraction and recovery of critical minerals from its Missouri resources in the Viburnum Trend which have historically produced lead, copper, and zinc. From its database of more than 500,000 core samples, Doe Run has identified significant deposits of cobalt and nickel, predominately in an extension of the Buick mine and the Boss and Higdon deposits. In these deposits, cobalt and nickel can account for 15%-50% of the contained value of ore. At the Boss deposit, our drilling campaign intercepted the highest-grade cobalt, copper, and gold mineralization yet seen in this deposit style in Missouri. At Higdon, drilling results yielded the doubling of our cobalt resource, making it one of the largest in the U.S. Traditional mineral processing techniques do not lend themselves to efficient value recovery from these deposits. Doe Run's drilling campaigns, block models, geometallurgical studies, bench testing and pilot plant-level studies, focuses on better characterizing the occurrence of critical minerals in our deposits and developing a hydrometallurgical technology to extract these materials in an economically efficient manner. Work to develop our hydrometallurgical process, enabling the recovery of a suite of critical minerals from various feeds, has positioned us to begin construction of a demonstration-scale hydrometallurgical plant for separation of cobalt and nickel products at our facility in Viburnum – an effort supported by an investment by the Department of Defense through their Defense Production Act Investment Program. By expanding our geological methods and extractive metallurgical capability, therefore increasing the recovered value from our resource base, Doe Run will be an integral part of the U.S. domestic critical mineral supply chain and sustain our 160-year history well into the future.

10:45–11:00 **Geochemistry of Critical Minerals in Mine Wastes at Grant, Sierra, and Socorro Counties, New Mexico**

Presented by Zohreh Kazemi Motlagh

Modern technology's increasing reliance on rare earth elements (REEs) and critical minerals highlights the need for sustainable sources of critical minerals. Critical minerals are non-fuel minerals that are essential to the U.S. economy and national security whose supply chain may be disrupted. Mine wastes could be potential sources of critical minerals. New Mexico has tens of thousands of abandoned mine features that need to be inventoried or prioritized for reclamation. The goal of this project is to characterize and estimate the critical minerals in three mining districts in New Mexico (i.e., Black Hawk district in Grant County, Hillsboro mining district in Sierra County, and Magdalena district in Socorro County) and determine the acid-generating potential. The Black Hawk district is an arsenide five-element vein deposit containing Ag, Ni, Co, As, U, Bi and some other local minerals like Pb, Cu, Zn, W, and Sn. Copper Flat mine in the Hillsboro mining district hosts copper porphyry deposits and the first smelter in the area was built in 1892. Kelly mine in the Magdalena district was discovered and mined for the first time in 1878. Mine waste rock piles (dumps) and tailings are sampled using the USGS sampling procedure based on geological evidence and sampling statistics. Comparative geochemistry of ore and waste samples from the Black Hawk district shows higher concentrations of Co, Ni, As, and Zn in ore samples while Cu is more elevated in waste samples. Pb concentration is above 1% in both. While Ag is more abundant in ore, its concentration is more than 200 ppm in some Alhambra waste samples. Ag and Co values are higher in fine (<2 mm) samples than in coarse (over sieved, >2 mm) samples. Geochemical analysis of different particle size fractions shows that Ag, Co, Bi, As, Cu, Li, Ni, Pb, and Rb concentrations increase in the finer size fractions. Critical minerals found in the Copper Flat tailings include Bi, Co, Cu, Ga, Te, Zn, Zr, and total REE. Fizz and paste pH tests show that Copper Flat tailings and Black Hawk mine waste have a pH close to neutral and are non-acid-generating, making them suitable as backfill materials.

Session 2: How to grow the US critical minerals workforce

14:00–14:15 **Critical Materials Workforce Development at Idaho State University**

Presented by Daniel LaBrier

The growing demand for critical materials (CMs), driven by their applications in modern technologies, has caused the need to search for alternative sources of these elements as their extraction from traditional deposits is currently limited. Due to recent shortcomings in CM availability in the United States, national research efforts are being directed towards finding alternatives that will reduce the dependency of importing CMs. As part of this effort, Idaho State University (ISU) has recently established a focus on critical material research, leveraging expertise in several departments (civil and environmental engineering, geosciences, chemistry, and nuclear engineering, amongst them) to optimize methods for extractions, concentration, separation, and purification of conventional, secondary, and unconventional sources of critical materials. These efforts include emphasizing research that prioritizes the full life cycle integration of mining and recycling techniques and the end-use target for such minerals and related critical materials, along with considerations related to chemical and radiological hazards that have generally burdened the recovery and refinement process. Faculty members at ISU, along with regional partners in the mining and materials industry, and local collaborators at the Idaho National Laboratory, are developing a curriculum that is dedicated towards addressing near-term workforce challenges related to CMs, thereby providing an additional source of skilled researchers, strategists, engineers, and technicians.

14:15–14:30 **Winning hearts and minds: curricula changes to improve attitudes towards mining in the U.S. and attract geoscience majors**

Presented by Emma Hunt

Exploration, mining and processing projects in the U.S. are receiving significant mistrust from the general public, affecting the development of projects. This is likely associated with poor understanding of the industrial move towards responsible mining practices. Polling of my

students, prior to teaching, had results skewed towards negative feelings about mining and processing in the U.S. (5% strongly negative, 35% somewhat negative, 35% neutral).In this presentation I discuss the variety of curricula changes I have introduced through my teaching to both educate the general student body and recruit Earth and Environmental Sciences (EES) and Sustainability Science (SUS) majors. I have improved accessibility, including things as simple as using a screen recorder to record classes, which allows student athletes to complete introductory, general education classes. All EES students at Furman are required to take Mineralogy and Petrology, which covers vital concepts educating our future workforce. Many students struggled with the crystallography, thermodynamics, phase diagrams etc., until I started using my cat to help demonstrate the topics. Through this student's grades improved, and they reported that they feel their learning improved. Perceptions have changed from a class that was dreaded, to a class that even our SUS majors take, because it's fun. Finally, I work towards winning hearts and minds on mining and processing in the U.S. by starting with addressing cases where mining has led to environmental and social justice problems. I feel we can't ignore these, but we can educate on how they have led to changed practices and implementation of responsible mining. After discussing conflict mining in the DRC; the Marikana Massacre in South Africa; along with the cobalt and platinum resources in the U.S., student opinions in my 100-level course changed towards the positive (7% neutral, 67% somewhat positive, 20% strongly positive).

14:30–14:45 **The Role of Universities in Training Students for the Critical Materials Workforce**

Presented by James Kubicki

Financial incentives and the reward system within research universities are designed to obtain external funding from external funding sources, gain the attention and respect of other academics, lead to publications and graduate students. Issues with this emphasis with respect to generating a workforce prepared to deal with challenges in the critical materials supply chain are numerous. This talk will focus on three areas of potential improvement. The selection of topics for theses are not based on industry and national needs, the resulting publications may not have applicability for commercial endeavors, and the students are not educated in related aspects of the supply chain beyond the focus of their

sub-discipline.This author thinks that there is always a need for purely fundamental academic research, but the proportion of such research should be balanced with questions of practical interest and commercial value. If the reviewers of proposals and papers are predominantly academics with limited knowledge of industrial needs, the successful proposal and papers will be biased in the direction of purely academic questions. Increased inclusion of industrial scientists in the review process would be one step towards addressing the problems of thesis topic selection and proposal/publication goals. Students, especially PhD students, are generally trained to be highly specialized experts in a narrow field of interest. Training in other fields that are connected in the supply chain is not valued. Cross-training in science, engineering, business, and sociology is extremely rare and often actively discouraged. In reality, each team member would better served by education that allows them to understand how their specialty connects with others they will be working worth. Creation of interdisciplinary, team-taught courses that explore these connections would be a stride forward in producing a new generation of students better prepared to enter into a business environment.

14:45–15:00 **Critical Minerals Exploitation and Sustainability, Geologically Speaking**

Presented by Gregory Wessel

Projections highlight the need for expanded metal production to facilitate a transition to renewable energy sources, a significant portion of which is expected to come from areas previously untouched by mining activities, including on lands controlled by indigenous groups or considered sacred. Regardless of location, mining proposals can negatively impact rural communities and landscapes, with that harm extending far into the future. The greatest challenge we face is to adapt to the changes we must undergo to become a sustainable part of the ecosystem. The first step is to understand what we mean by “sustainable.” Sustainability is often defined “meeting the needs of the present without compromising the ability of future generations to meet their own needs.” With respect to mining, some authors consider mining sustainable if the profits are used to benefit people in the host country. However, we cannot know what the needs of future generations will be, nor can short-term profits be exchanged for long-term environmental or social damages that

cannot be monetized. Based upon geologic insights for five aspects of development (location, water usage, waste management, site disturbance, and natural habitat), we can propose a definition of sustainability that can be used to judge human developments of all types: "Sustainability, geologically speaking, requires managing Earth's resources to meet current needs without affecting future availability or quality. It requires eliminating all environmental impacts, maintaining and expanding ecosystem health, and ensuring a long-term balance between economic activity, environmental restoration, social/environmental justice and societal well-being through full-cost accounting." In this paper, we will review several past and current mining proposals and consider the conflicts that made them newsworthy and that prevent them from being sustainable. Resolution to conflicts like these requires all sides to come together around a forward-thinking stance that values place, people, justice, and future generations.

Session 3: Maximizing critical mineral recovery from existing production streams

10:00–10:15

Progress, Challenges, and Perspectives of Critical Elements Recovery from Sulfide Tailings

Presented by Fardis Nakhaei

Modern industries that are involved in the design and development of high-technology products rely heavily on the availability of critical materials. As a result, there has been a growing global interest in the exploration and development of diversified productions processes to meet the future demand for these essential elements. Due to the continuous depletion of primary sources and associated supply risks, the reprocessing of secondary repositories has emerged as a promising solution. This approach offers both economic and environmental advantages by providing a sustainable supply of critical metals and addressing significant environmental concerns. One significant source of critical elements is the tailings generated from the physical beneficiation and downstream processing (extractive metallurgy) of polymetallic sulfide minerals which is the focus of this review.This review article provides a systematic understanding of the potential recovery of selected critical elements, namely -Sb, Bi, In, Ga, Ge, and Te from the sulfide ore supply chain and assess the feasibility of recovering them from tailings. It also discusses the main separation processes for these elements with specific emphasis on froth flotation and hydrometallurgy

practices that involve physical separation, leaching, precipitation, solvent extraction, and ion exchange techniques. Furthermore, the review addresses the various challenges and opportunities, as well as emerging trends that are likely to influence future research directions in this field. The insights gained from this analysis are invaluable for researchers aiming to devise effective methods for extracting these critical elements from non-traditional and unconventional resources.

10:15–10:30

Agile Synthesis and Automated, High-Throughput Evaluation of Diglycolamides for Liquid-Liquid Extraction of Rare-Earth Elements

Presented by Long Qi

Liquid-liquid extraction is one of the most scalable processes to produce rare-earth elements (REEs) from natural and recycled resources. Accelerating the research, development, and deployment (RD&D) of sustainable processes to manufacture REEs requires both facile synthesis of extractive ligands at scale and fast evaluation of process conditions. Here, we establish an integrated RD&D methodology comprised of agile ligand synthesis and automated high-throughput extraction studies. Using diglycolamides (DGAs) as an example, a novel green synthesis via solvent-free melt-amidation reaction is developed and marked as a significant advancement with its simplicity, high yield, and purity, providing a practical solution for large-scale REE extraction processes. This aspect is further complemented by the sustainability of the process, as evidenced by a significant 67% reduction in greenhouse gas emissions based on life cycle analysis. Furthermore, we investigate the structure-activity relationship of various alkyl-substituted DGAs using an automated, high-throughput workflow for liquid-liquid extraction, achieving over 180 runs in 48 hours. The high-throughput workflow for liquid-liquid extraction accelerates the development of a workflow for separating light and heavy REEs, paving the way for other critical materials separation processes.

10:30–10:45

Low-cost and low-emissions processing of battery materials using a molten salt technology platform

Presented by Badri Shyam

Xerion Advanced Battery Corp. of Dayton, Ohio, will present an overview of its patented DirectPlate™ molten salt-based process for refining of battery-grade cobalt metal from crude feedstocks and will briefly describe production of related high-voltage cathode LCO materials for the Li-ion battery industry. Xerion's process, as an alternative to traditional hydrometallurgical ore processing, bypasses several steps of manufacturing resulting in lower energy requirements, water usage, wastes and CO2 emissions. By eliminating the use of organic solvents and operating at atmospheric pressure, this manufacturing process is inherently safer for operating personnel and lower risk for all stakeholders. Xerion will summarize key aspects of the battery performance resulting from the highly-oriented cathode structure resulting from the DirectPlate™ manufacturing process. Finally, Xerion will also describe its development of a cobalt-based ceramic membrane for direct-lithium extraction (DLE) of lithium-containing brines.

10:45–11:00

Mineralogical controls on the distribution of critical minerals in mining value and waste streams

Presented by Nadine Piatek

The host mineralogy of critical mineral (CM) commodities controls their partitioning into value or waste streams during ore processing, at times leading to CM-enriched mine waste. Further, at legacy sites, weathering of mine waste may redistribute CMs in secondary minerals. Determining CM mineralogical hosts is a key step in evaluating potential for CM recovery from mine waste. CMs not associated with the targeted commodities likely end up in tailings after flotation because froth flotation, a physical separation process, does not alter mineralogy. For example, elemental mass-balance calculations for one set of monthly composite samples from a flotation mill at an active porphyry Cu-Mo-Au mine in UT show that approximately half or more of the critical minerals Bi, Co, Ni, REEs and Te report to tailings. Calculations using modal mineralogy and mineral chemistry reveal pyrite hosts a significant portion of Co, Ni and Te in tailings, where CMs occur within the pyrite structure

and as nanometer- and micrometer-sized inclusions. Therefore, the generation of a pyrite concentrate to mitigate acidic drainage may also concentrate CMs.At legacy sites, weathering of mine waste may mineralogically redistribute CMs. The majority of Ge and Zn in legacy Zn surficial mine waste (chat) from the Tar Creek Superfund site in OK is hosted in the secondary mineral hemimorphite ($Zn_4Si_2O_7(OH)_2 \cdot H_2O$) instead of the original host sphalerite (White et al., 2022). Additionally, fine-grained material (<20 µm) is more enriched in Ge and Zn than coarse fractions. Interestingly, active reprocessing of chat to recover coarse material for aggregate potentially results in residual fine-grained waste enriched in Ge and Zn. Recovery strategies from fine material would need to target hemimorphite in addition to sphalerite to optimize recovery. Ultimate CM deportment thus depends on site-specific ore characteristics, ore processing design, and surface weathering. White et al. (2022) Appl. Geochemistry, 143:105341, https://doi.org/10.1016/j.apgeochem.2022.105341

Session 4: Reshoring critical mineral production

14:00–14:15

Integrating Mining Activities and Biodiversity Impact Assessment in Life Cycle Analysis of Critical Mineral Supply Chains

Presented by Donya Otarod

Critical minerals are fundamental for the energy transition and national security. Maintaining a stable and diverse supply of these minerals is crucial for a country's ability to transition to cleaner energy sources, develop advanced technologies, and ensure national security in a globally interconnected and competitive landscape. However, extracting these critical minerals sustainably is imperative to mitigate both environmental and social repercussions. Life Cycle Assessment (LCA) has proven invaluable in evaluating the environmental impacts of alternative methods for producing and processing critical minerals. Although a significant amount of research focuses on mining LCAs, most focus on climate change impacts and other impact categories, such as the environmental impact of land use, are often neglected and inadequately addressed. Currently, there is no universally accepted method for assessing life cycle land use impacts and it is not clear which land use assessment method is best suited for critical mineral supply chains. This

research aims to bridge this gap by comparing methods that incorporate regional and global characterization factors and discussing their differences and advantages. The research will also identify gaps in land use inventories in LCA, thereby enhancing our understanding of the land use impacts within critical mineral supply chains. This research will lead to more accurate life cycle land use impact assessment.

14:15–14:30 **Exogenous supply risk for offshore wind turbines deployment: evidence from rare earth permanent magnets supply**

Presented by Stéphane Goutte

The path to achieving Net Zero Emissions by 2050 largely relies on reducing CO2 emissions from the energy sectors. Decarbonising the energy systems requires the large-scale expansion of low-carbon electricity, including the development of wind power capacity. However, the energy transition is mineral intensive, and dependencies on a few producing countries may lead to new geopolitical tensions. Among the required minerals rare earth elements (REEs), mainly produced in China, are core components of clean energy technologies such as wind turbines and electric vehicles through their application in rare earth permanent magnets (REPM). This paper investigates the impact of geopolitical risk and climate policy uncertainty on the export of rare earth permanent magnets from China, the first global supplier. A panel data analysis is conducted using Chinese national export data between 2017 and 2022. The results suggest that climate and geopolitical risk positively impact rare earth permanent magnets supply.

14:30–14:45 **Licensing Progress for Thorium Side Stream By-products of RE Metals Refining**

Presented by John Kutsch

Thorium Energy Alliance is in the mid process of the licensing of a facility for handling, storing and sales of thorium products that are derived from the Rare Earth metal processing process. This is being done in conjunction with Caldera Mining & Metals at the Pea Ridge Mine in Sullivan Mo. We believe that it would be invaluable for the attendees to understand the process, scope, needs, time and costs involved in doing

this most necessary step of the Critical Materials refining process. Without a license for handling the Thorium and other side stream by-products, there will be no Rare Earth metals processing anywhere in the USA. Your membership and attendees need to understand this issue - we would like to share our experience with them.

14:45–15:00 **Update on U.S. Policy & Projects for Rare Earths**

Presented by James Kennedy

Provide an update on U.S. policy related to rare earths and current status of relevant projects.

Posters

Poster presentations will be held during the lunch break from 11:45–13:00 on Day 1 and Day 2.

11:45–13:00 | August 7-8, 2024

Isolation and characterization of a novel iron-oxidizing haloacidophile for biomining
Presented by Connor Crites

Biomining operations (the act of using bacteria/fungi to solubilize ore-metals) are growing in popularity, but low salt-tolerance of these organisms lead to inhibited growth, impacting efficiency and cost. Haloacidophiles look to bridge this gap, but current diversity of these organisms is very small. A novel iron-oxidizing haloacidophile has been isolated from Lake Magic, Australia, a saline lake with high salt content and low pH (2 M and pH 2, respectively). It is hypothesized that this organism may be used for biomining purposes.

Dynamic Rock Testing and Implications for Structural Design Improvements to Mitigate Blast-Induced Ground Vibration
Presented by Harriet Naakai Tetteh

The Minerals Education Coalition in 2021 estimated that an average of 40,630 pounds of mineral product was consumed per person in the United States alone. This quantity re-emphasizes the need for operations to meet growing demands for the $83 billion mineral industry. The consequent effect of this fast-growing demand, especially for energy transition minerals (recording a 2.78% production increase since June 2022) requires that pragmatic steps be taken to maintain social licenses in sensitive mining communities. Blast-induced ground vibration is a manageable phenomenon when monitored and engineered for field-specific conditions. By employing geology, civil and geomechanical considerations for rock fragmentation activities, communities in proximity to mining operations can effectively mitigate structural damage with knowledge of rock structure and behavior under cyclic loading conditions. This study does not only provide solutions to ground vibration issues but also creates an opportunity to expand current mines and set up exploration projects in problematic grounds in the face of switchbacks/pushbacks.

Geological Context of a Typical Cassiterite Deposit: Mayo Darlé, Cameroon

Presented by Jonas Didero Takodjou Wambo

Tin-tungsten (Sn-W) vein and greisen deposits are magmatic-hydrothermal systems that provide a significant portion of the world's tin production and are also an important source of tungsten. The formation of these deposits results from a continuum of magmatic and hydrothermal processes and involves the efficient transport and focusing of mineralizing fluids. This study aims to improve the understanding of the hydrothermal and geological processes involved in the concentration of metals leading to the formation of these deposits. We carried out a multidisciplinary study combining (i) field work, (ii) co-located optical petrography, (iii) whole-rock geochemistry by X-ray fluorescence (XRF) and solution-source inductively coupled plasma-source mass spectrometry (ICP-MS), (iv) scanning electron microscopy (SEM; backscatter imaging and diffraction), mapping XRF, electron microprobe analysis (EPMA), micro-Raman spectroscopy, and laser-ablation ICP-MS to yield comprehensive maps of texture, mineralogy, and major and trace-element chemistry at the individual mineral scale. This methodology was applied to the case of the Lower Eocene Sn-deposit of Mayo-Darlé (NW-Cameroon), which is a reference site for studying the magmatic and hydrothermal processes leading to the formation of this type of deposit. The results obtained suggest that the Mayo-Darlé tin deposit originated from a combination of magmatic-hydrothermal or hydrogenic metal-rich deposits and was deposited during Late Cenozoic intraplate calc-alkaline felsic magmatism through greisenisation of the granitic intrusion. In the area, tin mineralization shows various forms including massive, vein, stockwork and disseminated in highly fractionated granite where the metal is associated with bastnaesite (Bsn-Ce), Columbite (Clb-Fe) and fluorite (Fl). The petrographic study shows that the massive greisens are rich and barren in cassiterite respectively; the stockworks and veins are all mineralized. The mineralogical composition recorded for each form are Qtz+Cst+Mus+Bt+Fl+Rt+Pl for the cassiterite-bearing greisen; Qtz+Mus+Tour+Chl for the barren greisen, Qtz+Mus+Cst+Tour+Chl for the veins and stockworks and Qtz+Kfs+Bt+Fl+Bsn-(Ce)+Ccp+Mus+Mag, Qtz+Cst+Kfs+Pl+Fl+Rt+Mag+ Ilm and Qtz+bt+Clb-(Fe)+Kfs+Pl+Fl +Mus. This study highlights the importance of feedback between magmatism, dynamic permeability, and hydrothermal alteration. These are major mechanisms that can significantly improve the circulation of mineralizing fluids and therefore the formation of large hydrothermal deposits.

Effects of Thermal Combustion on the Characterization of Rare Earth Minerals in Coal Mine Tailings

Presented by Lawrence Ajayi

As demand for green technology grows, the need for rare earth elements (REEs) continues to increase due to their unique magnetic, catalytic, and optical properties. REEs have been found in domestic natural resources in the United States, including different parts of the coal supply chain [1], [2], [3]. However, a key limitation to commercial extraction from coal-related resources is the low concentration of REEs in these raw materials, typically in the ppb or ppm range, resulting in higher extraction costs [2]. Addressing this challenge necessitates an understanding of both the physical and chemical methodologies capable of concentrating REEs. This understanding of capable methods requires the identification of REE-bearing minerals in coal tailings, assessing the impact of thermal treatments on these minerals, and evaluating the distribution of these minerals across various particle sizes within the coal tailings. Within this context, the specific objectives of this research are to: 1. Investigate the effect of combustion temperatures on REE-bearing minerals' identification and phase state in coal tailings. 2. Determine the mineral distribution of REE-bearing minerals within coal tailings particle sizes. Coal tailings from two mines in the Midwest will be analyzed to determine their concentrations of REEs and the minerals that bear these elements. These tailings will be dried and thermogravimetrically analyzed (TGA) to determine the temperature range required for the oxidation of organic constituents i.e., the ashing condition. Subsequently, mineralogical analysis will be conducted on ashed samples using XRD for phase identification, SEM-EDS and XRF for elemental composition and semi-quantitative mineral analyses. This project aims to lay the groundwork for enhanced extraction of rare earth elements (REEs) from coal mining tailings. Its success will not only increase the availability of these critical elements essential for global technology development but also enhance national security of their acquisition.

Innovative pilot-scale process for sustainable rare earth oxide production from coal byproducts: A comprehensive environmental impact assessment

Presented by Mohsen Rabbani

This study developed a pilot-scale process feeding with two different materials resulting from a column leaching process and acid mine drainage (AMD) streams to recover rare earth elements (REEs). A life cycle assessment (LCA) study was done to evaluate the environmental impacts of rare earth production from deleterious material in the form of highly contaminated leachate (HCL) and low-contaminated leachate (LCL). The results indicate that the main contributors to environmental categories that produce RE-hydroxide stages are NaOH and electricity. Also, oxalic acid, Na_2CO_3, and hydrochloric acid significantly contribute to the production stage of individual rare earth oxides (REOs), including solvent extraction (SX) and precipitation steps.

The HCL route has higher environmental impacts than LCL due to higher chemical/energy and H_2SO_4 usage, so 468 and 292 kg of carbon dioxide are generated to produce 1 t of individual REOs from HCL and LCL routes, respectively. Moreover, the carbon dioxide emitted from the process, including the RE-hydroxide production, SX, and REOs production, is less than 10 t CO_2. A sensitivity analysis was also performed to assess the changeability of the environmental footprints of the main inputs in the SX process, as the main stage has a higher contribution to the whole process. This LCA study is the first step toward understanding the environmental influence of new processing methods to produce REEs from coal by-products through a developed pilot-scale process.

CRITICAL MINERALS AND ENVIRONMENTAL SUSTAINABILITY METRICS

Presented by Raymond Kudzawu-D'Pherdd

Environmental metrics are interpreted differently across disciplines, and their integration into mine planning has been insufficient. This lack of early-stage environmental consideration in mine development has led to the gradual acceptance of "sustainable mining," a concept designed to mitigate opposition and align the interests of affected communities and mining corporations. Critical minerals are essential components for the functioning of modern technologies, including electric vehicles, batteries, and renewable energy systems. Given the rising demand for critical minerals, the development of mining-specific environmental metrics becomes essential. We seek to propose a conscious and robust integration of environmental metrics into the mine planning process to achieve sustainability. This strategic approach aims to enhance the sustainability of mining operations, improve operational efficiencies, and strengthen stakeholder relationships. Our analysis highlights water use, energy use, and land use as the categorical environmental metrics, from which all others derive.

Investigation of the relationship between age and critical mineral concentrations in Picher chat pile fines

Presented by Ryken Garren

Activity in the Picher Mining District of northeast Oklahoma has produced large amounts of solid mining waste consisting of coarse-grained "chat" and fine tailings, the cumulative volume of which was estimated to be 31.32 million yd^3 in 2007 (USEPA, 2007). Environmental and human health concerns due to elevated levels of lead, cadmium, and zinc in this waste resulted in the area's designation as a superfund site in 1983. Current remediation focuses on the separation and reuse of chat as aggregate in asphalt; however, recent work suggests that there may be potential for critical mineral recovery from Picher mining waste. Specifically, the apparent redistribution of germanium within chat piles presents an opportunity for the beneficial reuse of the fine fraction, which has previously been neglected (White et al., 2022).

We aim to identify and sample where this redistribution is most likely to have occurred to the greatest extent to establish a correlation between chat pile age and critical mineral presence in the fines. Reprocessing chat involves separating these fines from coarse particles. Therefore, we hypothesize that the oldest chat piles within the district, which have been least rerun and most exposed to weathering, contain higher concentrations of redistributed germanium. Eventually, a more complete characterization of Picher mining waste may lead to more efficient reuse and help offset the costs of environmental remediation in the Tar Creek Superfund Site.United States Environmental Protection Agency, 2007, Record of Decision: Tar Creek OU4 Superfund Site.White, S.J., Piatak, N.M., McAleer, R.J., Hayes, S.M., Seal II, R.R., Schaider, L.A., and Shine, J.P., 2022, Germanium redistribution during weathering of Zn mine wastes: Implications for environmental mobility and recovery of a critical mineral: Applied Geochemistry, v. 143, doi: 10.1016/j.apgeochem.2022.105341.

California Effect and the diffusion of certification standards in Peru's copper mining sector

Presented by Elizabeth Echavarria

Many countries have set economy-wide zero-emission goals in response to the 2016 Paris Agreement, particularly targeting the electricity and automobile sectors. This shift has significantly increased the demand for minerals such as lithium, cobalt, copper, nickel, and rare earth elements essential for producing, distributing, storing, and consuming green energy. However, the extraction of these minerals raises justice concerns due to their scarcity, uneven global distribution, and the socio-environmental impact of their extraction on regions with poor governance and vulnerable communities, including indigenous populations. While producing governments may lack the motivation to impose high standards on mineral extraction, voluntary initiatives have emerged as advocates for alternative governance approaches. Globally, several voluntary programs offer sustainability certifications for companies in the energy-transition-minerals sector, with varying adoption rates. In this paper, I examine whether international trade influences the uptake of voluntary programs, specifically the Copper Mark, ICMM's principles, and Toward Sustainable Mining across copper mining companies operating in Peru, the second largest producer of this mineral globally. Using an event history analysis on a sample of forty Peruvian companies observed from 2018 to 2023, I find that adopting voluntary certifications is more likely among companies exporting to countries with robust social and environmental standards. This finding underscores the global impact of international trade on sustainability efforts in the critical minerals sector.

Opportunities for Public-Private Partnerships for the development of Critical Mineral Resources in developing nations as a support for US Critical Mineral Availability

Presented by Erdoo Mongol

The campaign for sustainable development of critical minerals has continued to gain prominence because their availability is crucial in manufacturing products that are highly important to the technological advancements of modern economies, and in strengthening national security. However, the vulnerability of their supply value chain to disruption in relation to political uncertainties and trade constraints underscores the increasing interest and concerns. While the U.S. Geological Survey and the Department of the Interior have identified up to 50 critical minerals, and all hands are on deck to ensure their resilient supply, it is important to highlight the availability of critical minerals in commercial quantities in other geopolitical zones. In the era of collaborations and networking, it is expedient to diversify the present supply chain sources where possible, to safeguard for the rainy day in the uncertain future. This work highlights the potential of critical minerals in various states across Nigeria, such as Gold, Lithium, Cobalt, Graphite, Bismuth, and Rare Earth Elements (REE), among others. The aim here is to discuss Nigerian Government incentives and opportunities for public-private partnerships and to highlight the utility of non-standard analytical techniques, such as palynology, that can be used to track enrichment zones in geological settings. While developing the available critical minerals in the U.S., it is important to build alliances by diversifying investment options in other mineral-rich zones as a backup plan.

DEVELOPING TECHNOLOGIES FOR MINER SELF-ESCAPE FOR SAFE EXTRACTION OF CRITICAL MINERALS: A CASE STUDY OF HUMAN CENTER DESIGN FOR DEPLOYING REFUGE ALTERNATIVES

Presented by Eugene Gyawu

Underground mining is a major part of the mining and extractive industry in the United States, with over 361 underground mining companies, of which about 36 percent mine critical minerals. However, the safety of mine workers has been of concern over the years. Safety will become even more important as we prepare for an increase in domestic mining of critical mineral in the US to limit the over reliance on foreign supply. One important safety intervention introduced by the 2006 MINER Act is the use of refuge alternatives for miners to shelter in place. However, miners report low confidence in their ability to deploy these life-saving tools. In this study, we investigated the effectiveness of redesigned labels and training instructions for deploying refuge alternatives (RAs) in underground mining emergencies. Our approach involved a three-phase process: an information design review of existing RA deployment steps, creating new labels based on human-centered design principles, and validation through human subject

testing. The human subject testing included 50 participants who were divided into two groups of 25 each, each using either the current or the proposed labels with associated training instructions. The results demonstrated that participants using the proposed labels and training performed significantly better in 14 out of 15 tasks required to deploy the RA. This significant improvement highlights the importance of incorporating human factors into the design of labels for deploying an RA. The findings underscore the importance of human-centered design in enhancing the usability and effectiveness of self-escape technologies in mining contexts, contributing to advancements in mine safety and safe extraction of critical mineral.

Challenges in Formulating "Mineral Security" Policy

Presented by Sangita Gayatri Kannan

There are many calls for policy to strengthen the security of critical mineral availability for the United States. Proposed measures include lowering ostensible barriers to new mining in the US; development of domestic or "friend-shored" mineral processing capacity; tax and tariff measures to discourage imports of critical minerals from sources deemed unfriendly; and expansion of strategic mineral inventories for stabilizing – and supporting – prices of critical minerals to reduce risks of price volatility.
In evaluating such policies, more attention is needed to the differences among different types of mineral availability and price risks, and to the respective roles of markets and government policy to effectively address the risks. In this paper we compare risks associated with (a) traditional exercise of economic market power, (b) geopolitical retaliation, and (c) market instability. We also review evidence available for distinguishing among these risks in practice. We then discuss the strengths and weaknesses of alternative approaches for enhancing US mineral security.

How has legislation and policy affected critical element mining and processing in Missouri?

Presented by Talia Maldonado

The U.S. is facing a 'critical minerals' materials crisis for elements and minerals, that play a vital role for the U.S. economy and national security. As the U.S. works to progress towards energy independence and renewable energy, technology will need to evolve. This necessitates a steady supply of critical minerals. Due to this there is an emphasis on exploring for new U.S. mineral deposits as well as development of new processing techniques to extract more of these critical minerals from existing mines and their waste materials, known as tailings. Currently, this material is wasted, and the small amounts of critical minerals are thrown away. Missouri has barite, bismuth, cobalt, manganese, gallium, germanium, indium, nickel, rare earth elements, tungsten and zinc in a variety of deposits, which could be vital for meeting economic and

national security needs. Legislation and policy have significantly affected mining and processing in Missouri, with increasing regulatory costs leading to closure of all lead smelters in Missouri. Current proposed legislation is working to increase critical mineral mining and processing in Missouri, with many pieces proposing a variety of tax credits, from the Inflation Reduction Act to the proposed the Missouri Defense and Energy Independence Act, SB 1360. This work evaluates the regulatory processes and policy developments that have affected metal production in Missouri as well as investigating development of processing techniques and makes suggestions for how to responsibly proceed in Missouri.

Unconventional Approaches to Support the Critical Minerals Drive of the USA: Case study of Benue State Nigeria

Presented by Raymond Asemakaha

The increasing demand for critical minerals utilization in modern-day technological advancements require innovative and unconventional approaches to sustain supply chains. The United States Geological Survey (USGS) has identified several minerals (such as Lithium, Cobalt, Rare Earth Elements, and Graphite, among others) as 'critical', because of their role in bolstering the economy and national security. While the USGS and other agencies of the US Government are making conscientious efforts to support the resilient supply of the critical minerals, their increasing demand, and supply chain vulnerability calls for the adoption of unconventional strategies. In this regard, international partnerships, and alliances with countries rich in critical minerals would be important to safeguard long-term supply agreements and joint ventures. Benue State is one of the 36 states in Nigeria that is rich in minerals such as Lithium, Coal, Gold, Limestone, Lead-zinc, Uranium, Graphite and Silver, among others. The goal is to highlight investment opportunities at the state level, and to seek collaboration with international organizations towards the development and supply of critical minerals.

Geology and Mineral Resources of Hicks Dome, Hardin County, Illinois

Presented by Laurence M. Nuelle

Hicks Dome is a deep-rooted geological structure in Hardin County, Illinois. Precambrian rocks were uplifted 4,000 feet exposing Middle Devonian rocks at the dome's apex. The dome is cut by igneous dikes, alkalic diatremes, and many faults of limited extent. Some assign a volcanic origin to Hicks Dome. While diatremes vented, evidence is sparse for a volcanic origin as there are no rocks of vent facies or volcaniclastic alluvial facies. There may be an underlying alkalic-carbonatite intrusive that did not breach the surface. Hicks Dome comprises an extensive breccia terrane; all drillholes intersect breccia in thicknesses from 400 to 2,300 feet. Some breccia has flow lineation and upward fining beds of fragments. Some intercepts contain fragments from overlying stratigraphic units, yet the units above are undisturbed suggesting a

lateral component of breccia emplacement. Rock flour-rich breccia hosts a resource of fluorite and coproducts (such as heavy rare earths) at depths of 1,500 feet at the apex to 3,000 feet deep away from the apex. A fluorite cut-off grade of 10% (using a 300 feet search radius from drill-holes) yields an inferred resource of 65.8 million tons of 15.8% fluorite, 4.8% barite, 0.16% BeO, 0.2% Nb_2O_5, 0.3% rare earth plus yttrium oxide, and 1.3% TiO_2. Hicks Dome was subjected to lateritic weathering forming regolith to nearly 280 feet thick at the apex. Upon weathering, rare earths from igneous rocks were incorporated into the regolith forming a resource within the regolith; this resource has not yet been quantified. Hicks Dome, LLC has made available all drill core of hard rock and of regolith to the U. S. Geological Survey and the Illinois State Geological Survey to research the origin of the mineralizing system. Studies at University of Kentucky are underway on the metallurgical recovery of commodities from the breccia and the regolith.

Linear correlations of Gibbs free energy for rare earth element oxide, hydroxide, chloride, fluoride, carbonate, and ferrite minerals and crystalline solids

Presented by Ruigang Pan

Rare Earth Elements (REE) are critical minerals (metals) for the transition from fossil fuels to renewable and clean energy. Accurate thermodynamic properties of REE minerals and other crystalline solids are crucial for geochemical modeling of the solubility, speciation, and transport of REE in ore formation, extraction, chemical processing, and recycling processes. However, the Gibbs free energies of formation (ΔGof, REEX) for these solids from different sources vary by 10s kJ/mol. We applied the Sverjensky linear free energy relationship (LFER) to evaluate their internal consistency and predict the unavailable ΔGof of the REE solids. By considering both the effects of ionic radius size and corresponding aqueous ion properties, the Sverjensky LFER, allows estimates with much accuracy and precision. Here, rREEZ+ represents the Shannon-Prewitt ionic radii (Å) of REEZ+, and ΔGon, REEZ+ denotes the non-solvation contribution to the ΔGof of the aqueous REEZ+ ion. X represents the remainder of the compounds. In this study, the parameters aREEX, bREEX, and βREEX were regressed from ΔGof compilations in the literature for 13 isostructural families. Based on these linear relationships, we recommend a set of internally consistent ΔGof, REEX for 156 end-members of REE oxides, hydroxides, chlorides, fluorides, phosphates, carbonates, hydrous carbonates, and ferrites. These ΔGof, REEX are combined with experimental or predicted values of So, Vo, and Cpo from the literature and incorporated into a new SUPCRT database, which allows the calculations of thermodynamic properties to high P-T conditions (e.g., up to 1000 oC and 5 kb). The log Ksp of REE solid dissociation reactions were incorporated into a modified USGS program PHREEQC for calculations of speciation, solubility, and reactive transport. These thermodynamic databases will also be incorporated into the MINES database to be used together with the GEMS code package in the future.

Enhancing Mining Operations with Intelligent Sensor Networks, Real-Time Geostatistical Models, and Reinforcement Learning

Presented by Jhuleyssy L. Sánchez Aguilar

In the mining industry's value chain, sensors strategically placed across extraction, mineral processing, and final product stages play a pivotal role. This study aims to enhance geostatistical models through sensor data integration with reinforcement learning techniques. The objective is to enable real-time monitoring, accurately assess data requirements for reliable surveillance, and facilitate continuous learning and refinement of the monitoring process.An essential focus of this research lies in assessing control capabilities over these sensors. Leveraging attention mechanisms, a form of machine learning, we can improve resource estimation and understand the impacts of sensor failures or inaccurate data on operations. These mechanisms prioritize and manage less reliable sensors, ensuring the monitoring system remains robust and efficient.Moreover, this investigation explores integrating attention mechanisms to optimize reinforcement learning agent performance. This integration enhances the identification of critical sensors influencing monitoring accuracy and data quality. By sharpening the focus on these pivotal sensors, the overall efficiency and reliability of the monitoring system are bolstered, thereby supporting informed decision-making in mining operations.

Overview of Two Federal Efforts to Assess the Critical Mineral Potential of Mine Waste

Presented by Robert Seal

The U.S. Geological Survey (USGS) is involved in two major efforts to assess the critical mineral potential of mine waste in the United States: (1) in collaboration with other federal agencies through the Federal Mining Dialogue, a consortium of federal agencies focused on best practices at abandoned mine sites, which was motivated by several Executive Orders over the past seven years and culminated in the Energy Act of 2020; and (2) in collaboration with state geological surveys through the USGS Earth Mapping Resources Initiative (Earth MRI) program. The Federal Mining Dialogue created a critical minerals working group focused on addressing emerging mandates related to critical minerals at federally managed sites. This working group identified several abandoned mine candidate sites to explore how to begin down a desired path from waste to resource, while enumerating the various challenges and obstacles encountered along the way. These obstacles are expected to include technical hurdles and issues related to both the legal framework and permitting. The four initial candidate sites are the Tar Creek Superfund site (Oklahoma), the Bonita Peak Superfund site (Colorado), the abandoned Katherine gold-silver mine (Arizona), and the Pine Creek tungsten mine tailings (California). Site

evaluations have started. The USGS Earth MRI program is funding state geological surveys to evaluate the critical mineral potential of mine waste through a proposal-driven program. To ensure that an internally consistent national dataset is being generated, the USGS established required sampling protocols and conducts the geochemical analyses. Over the past three years, 18 proposals from 15 states have been funded, investigating a variety of mine waste types from a diverse set of mineral deposits. These new data from Earth MRI, when combined with existing USGS datasets could improve identification of prospective mine waste sites for specific critical minerals in a geologically-based context.

Market Sector Allocations and Distortions versus Supply Chain Considerations for REEs

Presented by Randy Vander Wal

End uses for rare earth elements include catalysts, magnets, metallurgy, batteries, glass and ceramics additives, phosphors, and polishing compounds. These applications span health care, consumer appliances, electronics, lighting, communications, defense technologies, oil refining, consumer transportation and electric power generation. Presently valued at USD 5.3 billion in 2021, the rare-earth metals market is projected to grow to USD 9.6 billion by 2026, at a 12.3% CAGR. Expected main drivers of this growth are catalysts, permanent magnet and polishing applications. Updated values are presented for REE market sector allocations. While percentage allocations change minimally, absolute tonnage, reflecting demand exhibit marked increases, most notably for catalysts, magnets and phosphors. Historical trends for global and U.S. REE consumption consistently reflect these trends. Relative to global REE product sectors, the U.S. has a disproportionate share of catalysts while lacking significant battery or magnet production by USGS reports. Growth in mature market sectors is driven by the general economy, thus accounting for the demand fluctuations for cerium, lanthanum, and yttrium. Oppositely growth in newer market sectors is driven by policy, economic incentives and technology. Currently EV traction motors and wind turbine generators are driving the high (8-10%) growth in the permanent magnet sector. Growing demand amidst concerns for diversified supply chains, coal and coal byproducts are promising new domestic resources. Usage does not reflect economic value. A prime example are catalysts versus magnets. Catalysts (automotive and FCC) account for ~ 20% of TREO use while magnets, at ~ 29% TREO account for well over 2/3 of the REE overall product value. The economic impact of REEs is vast, accounting for $274 billion in the U.S. and up to a trillion $US globally. But with the U.S. 100% reliant upon REE imports, the supply chain value captured domestically will continue to decrease as China and other countries build up their own integrated supply chains, based on their domestic resources.

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