3rd Annual National Workshop: Resilient Supply of Critical Minerals

August 9-10, 2023
Rolla, Missouri

Hosted by Missouri University of Science and Technology
criticalminerals.mst.edu
Preferred Citations

Workshop Proceedings


Individual Abstracts (example)


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 and 2022 Workshops

https://criticalminerals.mst.edu/previous-workshops/
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Wednesday, August 9, 2023
The Critical Mineral Potential of the USA
Evaluation of existing, and exploration for new resources

8:30 – 8:40  Welcome and Opening Remarks
Marek Locmelis, Workshop Chair

8:40 – 9:00  Welcome to Missouri S&T
Mo Dehghani, Chancellor, Missouri S&T

9:00 – 9:30  Keynote Speaker
Jeffrey Mauk, USGS

9:30 – 10:00  Keynote Speaker
Adam Simon, University of Michigan

10:00 – 10:30  Oral Presentations (10-Minute Format)
Mike Cochran, Missouri Cobalt
Rona J. Donahoe, University of Alabama
James D. Kubicki, The University of Texas at El Paso

10:30 – 10:45  Break

10:45 – 12:15  Breakout Sessions

12:15 – 13:00  Lunch and Poster Session
Topical Sessions 1 & 2

Mineral Processing and Recycling
Maximizing critical mineral recovery from existing production streams

13:00 – 13:30  Keynote Speaker
Saskia Duyvesteyn, Rio Tinto
Thursday, August 10, 2023

Critical Mineral Policies
Toward effective and responsible governance

8:30 – 8:40 Welcome and Opening Remarks
Marek Locmelis, Workshop Chair

8:40 – 9:00 Welcome to Missouri S&T
Kamal Khayat, Vice Chancellor for Research and Innovation, Missouri S&T

9:00 – 9:30 Keynote Speaker
Thomas Sonderman, SkyWater Technology

9:30 – 10:00 Keynote Speaker
Michelle Michot Foss, Rice University’s Baker Institute

10:00 – 10:30 Keynote Speaker
Alex Silberman, US Department of Labor
10:30 – 10:45  Break

10:45 – 12:15  Breakout Sessions

12:15 – 13:00  Lunch and Poster Session
Topical Sessions 3 & 4

Resource Sustainability
Ethical and environmentally sustainable supply of critical minerals

13:00 – 13:30  Keynote Speaker
Roderick G. Eggert, Colorado School of Mines

13:30 – 14:00  Keynote Speaker
José M. Cerrato, University of New Mexico

14:00 – 14:30  Oral Presentations
Saurav Kumar Dubey, South Dakota School of Mines and Technology
Emma J. Hunt, Furman University
Randy Vander Wal, Penn State University

14:30 – 14:45  Break

14:45 – 16:15  Breakout Sessions

16:15 – 16:30  Workshop Wrap-up
Sessions 1-4

16:30 – 17:30  Field Trip Introduction Session

Friday, August 11, 2023
Field Trip to Pb-Zn Mining Operations
Doe Run Company, Southeastern Missouri

7:00 – 15:00  Field Trip to Brushy Creek Mine
Limited to 15 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.
Kennedy Experimental Mine Building

12350 Spencer Rd, Rolla, MO 65401

The workshop dinner will be held on August 9th 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 Missouri Cobalt, LLC

The workshop dinner on August 9th is sponsored by Missouri Cobalt, LLC, of Fredericktown, Missouri. Stacy Hastie (Chief Executive Officer) of Missouri Cobalt will be giving a talk during the dinner.

Established in 2018, Missouri Cobalt, LLC is dedicated to providing a clean and reliable supply of critical and strategic minerals. Learn more about their mission and current projects with the code below.

Learn more about Missouri Cobalt
Parking and Check-In

Visitor parking near the Missouri S&T Havener Center is **not available** due to construction. Parking for the Workshop will be available all day at the Gale Bullman Multi-Purpose Building (Lot X).

Alternatively, paid parking meters are available in most lots around campus, see the below QR code for the 2022-2023 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.

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**Parking Lot Locations at Missouri S&T**

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August 9-10, 2023
Uncertainties in translating U.S. critical mineral resources to domestic supply

Translating U.S. critical mineral resources to domestic supply entails a series of steps—from quantifying resources and reserves, to mining, to metallurgy, to refining, to supply; and this presentation will discuss all of these constraints. Quantifying the national endowment of critical mineral resources might simply involve adding up all publicly available resource data for each commodity. However, the quality of those resource estimates varies widely, from reserves at operating mines, where production of concentrates or commodities can be reasonably assumed, to resources that are far less well-constrained. In this presentation, we will explore methods to objectively classify resource estimates to produce a range of resource values that more reasonably reflects the certainty of those resource estimates. We illustrate this spectrum of relative certainty with specific examples for some critical minerals.

After resources have been identified, the next step is to obtain mining permits, and then build the mine. Environmental, social, and governmental factors play an increasingly significant role in this step, and concerns related to these factors have delayed or halted large projects in the U.S.

Ultimately, metallurgy and refining control whether critical minerals are supplied from U.S. deposits, or from materials that are produced overseas. For example, if concentrates from a U.S. mine are shipped overseas for processing to metal, and that metal is then imported to the U.S., the USGS National Minerals Information Center counts that as imported material. Although many of the above points are intuitively obvious to members of the global Earth resources community, there are important issues here that must be communicated to non-specialists. Chief among those is that resources and supply are not synonymous, and there is no one size fits all translation of the former to the latter. Instead, each link in the chain from resources through refining must be unbroken for domestic resources to become domestic supplies.

Biography | Jeff Mauk has a BSc degree in Biology and Geology from the University of North Carolina at Chapel Hill, an MSc degree in Geology from the University of Montana, a Ph.D. in
Geology from the University of Michigan, and seven years of industry experience as an exploration and mine geologist. He led the Mineral Deposit Research Group at the University of Auckland in New Zealand for nineteen years. He is currently a Research Geologist at the U.S. Geological Survey in Denver Colorado, and an Associate Editor for Ore Geology Reviews.

Adam C. Simon, University of Michigan
Arthur F. Thurnau Professor of Earth & Environmental Sciences
Director, Michigan Research and Discovery Scholars (MRADS)

The Transition to Renewable Energy: Truths and Consequences

There is growing support for the transition from a global energy infrastructure dependent on coal, natural gas, and oil to one entirely reliant on a combination of battery electric vehicles, photovoltaic solar, wind turbines, and grid-scale battery storage. Manufacturing and deploying these renewable energy resources requires dozens of natural resources, including copper, lithium, nickel, tellurium, cobalt, indium, tin, chromium, and many, many others. Where do these resources come from? Is there enough? Will they be available on the timescale we need? What are the economic constraints on their availability? What are the environmental permitting constraints on the timeframe for production and delivery to market? What are the political constraints on their availability? Please join me for a presentation where I answer these questions and more.

Biography | Adam C. Simon is Arthur F. Thurnau Professor of Earth & Environmental Sciences at the University of Michigan. He earned degrees in geology and geochemistry from the University of Maryland and Stony Brook University and was a postdoctoral fellow at The Johns Hopkins University. His scholarly work focuses on the global flow of energy and mineral resources with an emphasis on the geologic availability of energy critical metals. Adam has co-authored the textbooks Mineral Resources, Economics and the Environment, and Earth Materials: Components of a Diverse Planet and published extensively in the field of energy and mineral resources. Adam has done research and given invited lectures on all seven continents, including a TEDX talk in 2022.

He has earned numerous awards for undergraduate teaching including the University of Michigan Provost's Teaching Innovation Prize.
Unlocking new resources through full-value copper mining

Full-value copper mining is motivating Rio Tinto to view traditional copper production through a new lens and opening a gateway to strategic and critical mineral production previously unrealized. Through investment, development, demonstration and implementation of new technology and strategic partnerships, Rio Tinto is helping create a new critical mineral industrial ecosystem to unlock previously unrealized resources for the domestic supply chain.

Biography | Saskia Duyvesteyn is the Chief Advisor Research & Development for the Rio Tinto Copper product group managing the portfolio of innovation projects across the entire value stream including ore body knowledge, underground & surface mining, mineral processing & metallurgy, tailings and digital projects. Saskia has over 20 years of experience in operational, technical and leadership roles based in Nevada, California and Utah for a range a commodities, including copper, gold, silver, borates, molybdenum and other critical minerals. Prior to her career in mining, Saskia was an assistant professor at the University of Utah’s Department of Metallurgical Engineering. Saskia has a Ph.D. in Extractive Metallurgy & Mineral Processing and a Master of Science in Minerals Engineering from the University of California, Berkeley. She has a Bachelor of Science in Materials Science & Engineering from Massachusetts Institute of Technology. She is also a Senior RioExpert.
Developing the critical minerals workforce: roadblocks and opportunities.

There can be no critical minerals production without a trained workforce, particularly mining engineers, extractive metallurgists, and other professionals. However, in recent years it has proven increasingly difficult to attract students into the relevant majors. This talk reports on the results to date of a 4-year University of Arizona study examining students’ motivations and choice of engineering majors, analyzes the main roadblocks to increased enrollment, and suggests possible ways to improve.

Results from surveys of the freshman engineering class indicate that the primary problem is the low public profile of the mineral resources professions compared to other engineering majors. Upon entering college, few engineering students know about mining and even fewer find it interesting. In contrast, large numbers of students tend to default to majors that they know more about (aerospace engineering) or whose function in society is more obvious in today’s world (mechanical and electrical/computer engineering). Exposure in the freshman class greatly enhances knowledge and interest in mining engineering, but is less effective at attracting majors. Motivations behind major choice and stated career goals have remained more or less static over the 4 years of the study. Sheer interest and the desire for a high-paying job are still the main motivations behind choice of major, both cited by 20 to 25% of responses. Most students enter their freshman year with their interests already pre-formed toward major choice; only about 30% report changing majors after exposure to other options. This handicaps mining, since its low public profile means low interest among incoming freshmen, and almost any engineering major can lead to a high-paying job.

These results suggest that the principal barrier to workforce development is public understanding of mineral resources, particularly in the K-12 years. This could be addressed by enhanced outreach to K-12 teachers, and by seeking the inclusion of more mineral resources-related material in state K-12 science teaching standards.

Biography | Isabel Barton is an assistant professor of mining and geological engineering at the University of Arizona. Her major area of research is geometallurgy, integrating geology, mineralogy, and extractive metallurgy to understand how rock and mineral properties affect process behavior. In collaboration with ASU and with the UA School for Mining & Mineral Resources, School of Anthropology, and Aerospace Engineering department, she is also running an NSF-funded study of recruitment practices to enhance and diversify engineering disciplines.
Supply Chain Challenges in the Semiconductor Manufacturing Industry: Why Critical Materials are Vital to the Nation’s Future

The semiconductor manufacturing industry is the backbone of modern technology, enabling the development of cutting-edge electronic devices. However, recent times have witnessed a significant rise in supply chain challenges amplified by the surge in demand for electronic devices, geopolitical tensions and the lingering impact of the COVID-19 pandemic. As a result, semiconductor manufacturers are facing prolonged lead times, dwindling inventories and escalating costs, impacting their ability to meet market demands. This talk will provide an overview of the key challenges faced by the semiconductor manufacturing industry. We will discuss the intricacies of securing critical raw materials, the impact of supply chain dependencies, and the vulnerabilities exposed by geopolitical factors. In addition, we will explore the ripple effects of these challenges on downstream industries and end consumers, highlighting the implications for the technology landscape and the global economy.

Biography | Thomas Sonderman is the president and CEO of SkyWater Technology. He joined the company in 2017, driving successful business transformation and transitioning SkyWater from an integrated device manufacturer to a pure play foundry. He has effectively diversified SkyWater’s customer base by defining new product markets and target customers while simultaneously improving operational efficiencies.

A widely recognized subject matter expert, Mr. Sonderman is the author of 50 patents and a highly sought-after industry speaker. He received a Bachelor of Science degree in chemical engineering from Missouri University of Science Technology and a Master of Science degree in electrical engineering from National Technological University.
New Sheriffs in Town? *Part Deux, In Which the Minerals Wild West Gets Wilder*

A reprise and update from the 2022 workshop on the major driving forces influencing minerals and materials policies and governance worldwide, including mining industry trends and issues, geopolitical forces, emerging supply-demand tensions and the ever present ESG drumbeat. A new consideration is defense industry priorities in an age of “weaponized” energy and metals. Alternatives including acceleration of advanced carbon materials (carbon nanotubes) and recycling and its “agonistes” are touched on. Hang on to your saddlehorns!

**Biography** | Michelle Michot Foss, Ph.D., is a fellow in energy, minerals, and materials at Rice University’s Baker Institute, developing policies and conducting research to help build capacity on non-fuel minerals supply chains. She has nearly 40 years of experience in senior positions in energy (oil, gas/LNG, electric power) and environmental research, consulting, and investment banking, with early-career exposure to mining and mined land reclamation.

Over the past three decades, Michot Foss developed and directed research on energy value chain economics and commercial frameworks to support worldwide investment while serving in several positions at The University of Texas at Austin and the University of Houston. She previously served as the chief energy economist and head of the Bureau of Economic Geology's Center for Energy Economics at the University of Texas at Austin. She was also a UH Shell Interdisciplinary Scholar with grants on North American gas and power integration and national oil companies. Her career research highlights include reviewing oil, gas, and minerals markets for local, national, and international government bodies, including the Texas Comptroller, U.S. Energy Information Agency, U.S. Department of Energy, World Bank, Japan’s External Trade Organization, and other institutions.

Michot Foss also led a university-based LNG industry consortium for North America. In addition, she implemented energy development assistance and engagement programs sponsored by USAID and the Department of State’s Bureau of Energy Resources in more than 20 countries and regions, including Central Asia, Ukraine, West Africa, Uganda, India, Bangladesh, and Mexico. She built and led the New Era in the Oil, Gas & Power Value Creation program for energy sector professionals from more than 40 countries. She also was previously a director of research at Simmons & Company International and at Rice Center.

Michot Foss remains an executive instructor for the Texas Executive Education program at UT’s McCombs School of Business, and she was named an Exxon Mobil Instructor of Excellence.
Identifying Labor Risks in Critical Mineral Supply Chains

Critical minerals like cobalt, lithium, and nickel play a vital role in renewable energy technology. Yet around the world, these minerals are sometimes extracted under harsh conditions including child labor, forced labor, and other violations of workers’ rights. Meanwhile, supply chain transparency and traceability—key approaches that help companies identify and mitigate risks of child and forced labor in their supply chains—remain limited in the critical mineral sector. This presentation will discuss the Department of Labor’s Bureau of International Labor Affairs (ILAB)’s supply chain research through the lens of our work in the cobalt-electric vehicle supply chain. It will start with the latest research and risk factors related to child labor in the Democratic Republic of the Congo, drawing from ILAB’s international child labor and forced labor reports. Next, the presentation will describe ILAB’s methodology that examines how raw material inputs produced by children are processed, traded, and ultimately made part of products that can end up in American stores and households. The presentation will conclude with a call for additional information and research at the intersection of labor conditions and critical minerals mining and processing.

Biography | Alex Silberman is an International Relations Specialist with the U.S. Department of Labor’s Bureau of International Labor Affairs (ILAB). He works in ILAB’s Office of Child Labor,
Forced Labor, and Human Trafficking, where he researches labor exploitation in critical mineral and energy supply chains to inform DOL’s International Child Labor & Forced Labor Reports.

Prior to joining the Department of Labor, Alex led The Ethical Recruitment Agency (TERA), a migrant worker recruitment company that enabled workers to travel and work abroad safely. Alex previously led research and projects for Seefar across the Middle East, Afghanistan, East Africa, Southeast Asia, and Europe. As a recognized subject matter expert on migration and forced labor, he has delivered projects for a range of government and non-government stakeholders including the European Commission, U.K., Norway, International Organization for Migration, Danish Refugee Council, the Global Fund to End Modern Slavery, The Coca-Cola Company, and the Macquarie Foundation. Alex received his B.A. and M.P.P from Georgetown University and a certificate from the Institute for the Study of International Migration.

Roderick G. Eggert, Colorado School of Mines
Viola Vestal Coulter Foundation Chair in Mineral Economics
Deputy Director, Critical Minerals Institute (U.S. DOE)

Key considerations in thinking about public policy toward critical minerals and materials

For the last 40 years or so, US public policy has been anchored around commitments to globalization and letting the market decide where and how capital should be deployed among the various economic sectors. To be sure, there have been many exceptions. But the starting point for most policy discussions has been to favor open international markets and to keep government out of the business of favoring specific sectors or companies. The pandemic and the associated supply-chain concerns throughout the economy have forced us to reconsider both globalization (maybe it is not entirely good?) and industrial policy (maybe it is not entirely bad?). In this broad context, this talk asks, what type of industrial policy should the US pursue toward rare earths and other critical minerals and materials?

Biography | Roderick G. Eggert is Viola Vestal Coulter Foundation Chair in Mineral Economics at Colorado School of Mines, where he has taught since 1986. He also is Deputy Director of the Critical Materials Institute, an energy innovation hub (research consortium, led by the Ames Laboratory) established by the U.S. Department of Energy in 2013 to accelerate innovation in energy materials.
He chairs the Independent Advisory Board of the UKRI Circular Economy Centre for Technology Metals (United Kingdom) and serves on the Advisory Board of the international Rare Earth Industry Association.

His research and teaching focus on mineral economics and public policy. He chaired the U.S. National Research Council committee that wrote the 2008 book Minerals, Critical Minerals, and the US Economy (National Academies Press). He has testified on mineral issues to committees of the U.S. Senate and House of Representatives, the Canadian House of Commons and European Parliament.

He has a B.A. in earth sciences from Dartmouth College, a M.S. in geochemistry and mineralogy from Penn State University, and a Ph.D. in mineral economics also from Penn State.

José M. Cerrato, University of New Mexico

Associate Professor, Department of Civil, Construction & Environmental Engineering
Associate Director, Center for Water and the Environment
Deputy Director, UNM METALS Superfund Research Center

Metal mixtures in uranium mine wastes from tribal lands

Metal mixtures in uranium(U) mine wastes from sites located in tribal land in the Southwestern US were investigated by integrating laboratory experiments, microscopy, and spectroscopy. Metal release from these mine wastes could pose potential health risks for neighboring communities. Spectroscopy analyses suggest that U-vanadium(V) and U-organic-rich phases are present in abandoned mine wastes; the dissolution of these phases is relevant to U, arsenic(As), and V transport. Potential remediation approaches for mixtures of U and As using naturally occurring calcium(Ca)-bearing minerals are currently being researched for the immobilization of these metal mixtures. Additionally, Ca in carbonate water at circumneutral pH facilitates the transport of U in plant roots which could be useful for metal uptake. These results are relevant for the transport and remediation of metal mixtures in the proximity of mine wastes and mineralized deposits.

Biography | José M. Cerrato is Associate Professor at the University of New Mexico. He obtained a B.S. in Civil Engineering from the National Autonomous University of Honduras, and M.S. and Ph.D. in Environmental Engineering from Virginia Tech. He was also a Postdoctoral Researcher in Washington University in St Louis. He serves as Associate Director of the UNM Center for Water and the Environment, and is affiliated to the UNM METALS Superfund Research Center. His
research interest is related to biogeochemical processes occurring at molecular and macro scales at the interface of water and energy. He has been a recipient of the National Science Foundation (NSF) CAREER Award, and Fulbright U.S. Scholar Senior Research Award to Spain.
Oral Presentations will be held in St. Pat's Ballroom A.

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

10:00–10:10  Missouri Cobalt Madison Mine Project - Helping to Fill the US Critical Minerals Vacuum

*Presented by Mike Cochran*

The Madison Mine Project is a brownfield site in southeastern Missouri. Planning and Development of a new Underground Mine, Flotation Mill, and Hydrometallurgical facility began in 2021 after 3 years of cleanup of over 100 years of historic mining activities. This presentation will cover the history of the mining area, cleanup activities completed and current progress towards a fully integrated critical metals facility in southeast Missouri.

10:10–10:20  Assessment of Coal-Associated Sediments, Wastes and Byproducts in the Southern Appalachian Basin as CM-REE Feedstock Materials

*Presented by Rona J. Donahoe*

Identifying new domestic resources for REE and other CM is considered essential to protect the U.S. economy from the threat of supply chain disruptions. This study is examining the potential for coal-associated sediments, wastes and byproducts to serve as feedstock materials for the domestic critical mineral supply chain. The goal of the project is to reduce U.S. dependence upon importation of strategic elements critical to the U.S. economy and security. Samples of underclay (N = 14) and roof rock (N = 12) adjacent to coal seams known to have elevated REE contents, coal processing refuse (N = 5), coal mining AMD waste (N = 11), and coal combustion byproduct (N = 82) samples were collected and analyzed for REE, Y, Sc, and Li concentrations by ICP-MS (EPA 200.8) after complete digestion (ASTM D6357), and concentrations were reported on a dry weight basis. Of these potential feedstock materials analyzed for this study, coal ash is the only viable resource for REE (Average Total REE = 473.5 +/- 167.2 ppm, Average Total REE+Y+Sc = 587.8 +/- 208.4 ppm). Of the coal-associated sediments, underclay samples were higher in Average Total REE content (222.6 +/- 34.23 ppm) and Average Total REE+Y+Sc content (270.1 +/- 37.95 ppm) than roof rock samples (Average Total REE =
195.9 +/- 57.5 ppm, Average Total REE+Y+Sc = 237.4 +/- 68.57 ppm). Four of the 14 underclay samples exceeded the ‘ore grade’ Total REE value of 300 ppm. Coal processing refuse samples were lower in Average Total REE (150.5 +/- 68.1 ppm) and Average Total REE+Y+Sc contents (183.1 +/- 83.5 ppm) than in-situ coal-associated sediments, likely due to leaching of the refuse piles by meteoric water. AMD sludge and water samples were lowest in Average Total REE and Total REE+Y+Sc. The average Li concentration of coal ash was 281.3 +/- 122.8 ppm, only slightly higher than the underclay sample average of 217.4 +/- 143.0 ppm. To better understand the extractability of REE and other CM from coal ash and underclay materials, selected samples have been characterized for major and minor mineral contents by XRD and Rietveld refinement, and the trace mineral contents and trace element concentrations of these samples are being determined by SEM/EDX analysis and micro-XRF mapping to determine mineral/REE-CM associations.

10:20–10:30 The Role of Universities in Training Students for the Critical Materials Workforce
Presented by James D. 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
Session 2: Maximizing critical mineral recovery from existing production streams

14:00–14:10  Critical Mineral Recovery from Unconventional Sources: A Case Study of Flat, Alaska, A Historic Placer Operation

Presented by Isabelle Harris

Critical minerals are essential to the United States' economy and national security. Currently, the U.S. is dependent on China and other countries for over 75% of 24 of these minerals, making transitioning the mining of them to the U.S. a strategic priority. Critical minerals are also essential to sustainable development, as outlined by the United Nations in their 17 Goals for Sustainable Development 2050 plan and are crucial to renewable energy technologies for components such as photovoltaic cells, wind turbine magnets, and electric vehicle batteries. As such, there is an urgent need to develop multi-disciplinary, techno-economic workflows for critical mineral recovery from unconventional sources such as mine tailings, achieving the Paris Agreement Goals for Sustainable Development, reducing mining waste, mitigating environmental hazards associated with mine waste, and contributing to a circular economy. To work towards these goals, I am conducting a case study of gold placer mine tailings in Flat, Alaska to develop a workflow to determine the viability of remining tailings and extracting critical elements. The town of Flat is a historic gold mine in the Kuskokwim Mountains that consists of fluvial placer deposits on creeks which flank a mineralized granitic intrusive body. The Flat tailings present potential critical element contents of tungsten, arsenic, chromium, and tin, as well as the non-critical elements gold, silver, mercury, zirconium, and uranium. These elements are associated with or occur in the structure of various mineral phases, such as cassiterite, zircon, chromite, cinnabar, ilmenite, magnetite, monazite, scheelite, stibnite, fluorapatite, tourmaline, and lead-antimony sulfosalts. The first stage of this project involves mineral processing and analytical techniques including x-ray diffraction, ICP-OES-MS, and automated...
mineralogy to define a workflow for processing tailings and determining bulk geochemistry, volume, and weight percent of minerals present. The further geochemical analysis and reprocessing of these tailings may reveal significant additional critical metals that are valuable to the Sustainable Development Scenario goals while contributing to a circular economy.

14:10–14:20

**IMPROVED FLOTATION STRATEGIES FOR THE RECOVERY OF PYRITE-HOSTED GOLD TELLURIDES FROM COPPER TAILINGS**

*Presented by José L. Corchado-Albelo*

U.S. Department of Energy (DOE) classified tellurium (Te) as a “critical mineral” for its importance to solar energy. A substantial increase in Te demand is projected to de-carbonize the electric energy systems, meaning mining and metallurgical industries must increase Te production from existing and inefficient supply chains. For example, 90% of Te associated with copper processing deported to tailings during froth flotation. Recent studies have shown that Te in copper tailing (CT) is hosted as gold-silver tellurides in pyrite that are depressed during the copper flotation process. A substantial increase in domestic production of Te is achievable by improving the recovery of pyrite-hosted tellurides from CT.

This study tested reagent combinations for flotation of CT obtained from a mine in the U.S. The selected reagents include xanthates, thiocarbamates, thiophosphates, and triazine, used as collectors, and terpineol, glycol, and carbinol, used as frother. Characterization studies using TESCAN’s Integrated Mineral Analysis (TIMA) and inductively coupled plasma - mass spectrometry (ICP-MS) were performed to determine the concentration and mineralogy of Te and Au.

TIMA results of CT showed that 93% of the petzite (Ag₃AuTe₂) hosted in pyrite as less than 10 µm inclusions. ICP-MS analysis for the CT was 1 ppm for Te and 0.06 ppm for Au. Pyrite flotation results suggested that xanthate collectors and glycol frothers efficiently recovered Te and Au. The highest Te recovery was 92% using 150 g/t sodium isopropyl xanthate (SIPX) with 50 g/t glycol (OREPREP X-237), and Au recovery was 75%. Results showed the highest Te grade was 12 ppm using 150 g/t thiophosphate (AERO 8989) with 50 g/t carbinol (MIBC), and Au grade was 1.8 ppm. The significant increase in Te concentrate grade, and >90% Te recovery from CT after flotation suggests the feasible recovery of pyrite-hosted gold-silver tellurides with preconcentration strategies and flotation optimization.
Critical mineral recovery from hard-rock acid mine drainage in Idaho Springs, Colorado
Presented by Molly Morgan

The extraction and utilization of critical minerals has become essential for the production of the low-carbon technologies necessary for the energy transition. However, the scarcity, production means, and geopolitical challenges associated with critical mineral production have intensified the global quest for sustainable and economically viable extraction methods. This study presents a case study on the recovery of critical minerals from hard-rock acid mine drainage (ARD) and mine waste in Idaho Springs, Colorado, with a focus on evaluating the potential for critical mineral recovery. The conducted chemical characterization includes significant concentrations of critical minerals, indicating the presence of potentially economically valuable mineral resources. Additionally, analysis reveals the presence of other critical minerals such as lithium, cobalt, and indium, which are vital for the production of batteries, electronics, and solar panels. Acid leaching, bioleaching, and hydrometallurgical methods have shown promising results in the effective recovery of critical minerals. These methods offer potential for scaling up to industrial levels, making the recovery of critical minerals economically feasible. Furthermore, downstream processing techniques, including solvent extraction and precipitation methods, have been evaluated for the further concentration and separation of critical minerals. These techniques allow for the recovery of individual critical minerals, enabling their use in specific applications and reducing reliance on foreign sources. This case study highlights the untapped potential for critical mineral recovery from hard-rock ARD and mine waste, showcasing the opportunity to transform previously considered environmental liabilities into valuable resources. The findings support the development of sustainable strategies for critical mineral extraction, addressing the growing global demand for these essential elements while minimizing environmental impact and promoting domestic resource independence. The successful implementation of such methods would contribute to a more resilient and secure supply chain for critical minerals, supporting the development of a sustainable and low-carbon future.
10:00–10:10  **Tantalum Supply Chain and Challenges of Responsible Sourcing from DRC**  
*Presented by Saurav Kumar Dubey*

The purpose of this presentation will be to give an overview of the Tantalum Supply Chain from the stage of raw material to finished good. Most of the Tantalum production comes from three countries located in the International Great Lakes Region of Africa. These are Democratic Republic of Congo, Rwanda, and Uganda. Among them, DRC is not only the largest producer of Tantalum but is also negatively impacted by the violence propagated by armed groups in the northern and southern regions of Kivu. These regions are known to contain high-grade ore deposits of columbite-tantalite referred to in the metallurgical literature as Coltan. Furthermore, DRC is a difficult regulatory environment for mining companies to operate as it suffers from weak national institutions having limited control over parts of the country due to poor transportation, and energy infrastructure and illegal taxation by non-state armed groups at mine-sites and on key highway transportation routes. The presentation will highlight the presence of several groups of actors involved in the mining of the ore to export of mineral concentrates from DRC to Tantalum smelters. This presentation will divide the entire supply chain actors into upstream and downstream players and highlight the critical role of smelters in the supply chain as being the point beyond which physical tracing of Tantalum to a specific mine becomes challenging. At the upstream level, the role of miners, artisanal-small scale mining cooperatives, negociants or local businessmen and comptoirs or trading hubs and their complex inter-play with the exporters will be discussed. At the downstream level, the role of tantalum smelters, producers of high purity tantalum powder, capacitor manufacturers and OEMs will be discussed from a conflict mineral reporting standpoint. Traceability schemes such as International Tin Supply Chain Initiative and Better Mining Program and potential solutions frameworks will be discussed.
Responsibility in Mining: Educating for Environmental, Social and Economic Awareness

Presented by Emma J. Hunt

That the energy transition will require vast amounts of minerals and mining is becoming well acknowledged. It's generally accepted that the geologic resources exist to meet initial needs, with challenges coming from supply security (Herrington, 2021). Partly, this relates to the inequal distribution of supply. E.g., >50% of the world’s supply of platinum group minerals (PGMs) is within South Africa. Unlike cobalt mining in the DRC, PGM mining in South Africa, is not typically thought of being associated with human rights abuses. Yet, poor living conditions and low salaries drove workers to strike in 2012 with the resulting police action being described as the “Marikana Massacre”, with 44 deaths during the strike (Chetty, 2016). I spent a year working with Lonmin and their Marikana Operations and saw first-hand the difficult conditions underground, in which the miners continue to work. These experiences, combined with working with TANBREEZ, and their prospective rare earth element (REE) operation in Greenland, has highlighted the dichotomy between “clean”, “green” technologies, and the social and environmental damage that can result from the mining of the required elements. To help address the damaging side of mining, as mining can be done well, I developed a course at Furman University to educate future scientists and policy makers on the intersection of mineral resources, economic geology, mining, and sustainability sciences. This contribution will present the course outline along with challenges and successes. References: Chetty, R., 2016, The Marikana Massacre: Insurgency and Counter-Insurgency in South Africa. New Labor Forum, 25, 62–70, https://doi.org/10.1177/1095796016639296 Herrington, R., 2021, Mining our green future. Nature Reviews Materials, 6, 456-458, https://doi.org/10.1038/s41578-021-00325-9

Projected Demand Comparisons Across End Use Sectors With A Focus On NdFeB Magnets

Presented by Randy Vander Wal

Across consumer, defense, manufacturing and power generation sectors, NdFeB rare earth permanent magnets are critical given their superior coercivity. This presentation relates rare earth NdFeB permanent magnet consumption to specific rare earth quantities required across major demand sectors. With total rare earth oxide (TREO) production in 2020 estimated at 240,000 tons, the Nd/Pr oxide demand is consistent with an overall ore fraction of ~ 27%. For the sectors evaluated in the analysis, wind turbines (on- and off-shore), electric vehicles, electric bicycles (EBs)
and scooters, global cell phone and consumer electronics, industrial and service robots, industrial motors, a lower limit for the cumulative Dy demand across all these sectors is 4,300 tons, within 10% of the USGS global production estimate for Dy oxide in 2020. Still, this represents a Dy production 1.8x higher than the historical average for Dy oxide content in the annual rare earth oxide produced globally. While rare earths used for magnets (neodymium, praseodymium, dysprosium, and terbium) constitute only 25% of the total rare earths production volume, they represent 80% to 90% of the total rare earths market value. The economic importance of the rare earths value chain becomes obvious by looking at the emerging electric vehicle market: over the last decade, the evolution of technology has resulted in 95% of EVs using permanent magnet motors by 2019, particularly because they provide the highest energy efficiency which translates into drive range. By 2030, an estimated 40,000 and 70,000 tons of NdFeB magnets on a global level will be required for EVs, depending on the anticipated growth scenario. In proportion, a global EV market worth of about $600-900 billion could depend on securing access to about $2-3 billion NdFeB magnets.
Evaluating the availability of Iridium and Platinum from recycled Proton Exchange Membrane (PEM) Electrolyzers and Fuel Cells

Presented by Abu Ibrahim

The use of iridium (Ir) and platinum (Pt) catalysts in electrolyzer and fuel cell electrodes has grown rapidly in recent years. Recycling end-of-life electrolyzers and fuel cells may be essential to the overall supply of these materials in the coming years. However, more needs to be known about the economic feasibility and the potential quantities available. This article investigates four scenarios for the future role of electrolyzer and fuel cell recycling in supplying Ir and Pt. Scenarios 1 and 2 are based on global and US proton exchange membrane electrolyzer cell (PEMEC) capacity. Both assume a 10-year lifetime for PEMEC, a 50% Ir recycling rate, and 400 kg/GW Ir loadings and 200 kg/GW Pt loadings. Scenario 1 assumes a rise in global Ir demand from 28 to 111 tons and global Pt demand from 14 to 55 tons by 2050. In Scenario 2, US Ir demand will increase from 0.97 to 32 tons, and US Pt demand from 0.48 to 16 tons by 2050. Secondary recycling supply could meet up to one-third of the world's Ir demand and two-thirds of the global Pt requirement. Using different data sets, scenarios 3 and 4 evaluate global and US Proton Exchange Membrane Fuel Cell (PEMFC) capacity. Assuming a five-year lifetime for PEMEC, 95% Iridium recycling rate, and 300 kg/GW Pt loadings, Scenario 3 leads to a steady global demand for Pt until 2028, followed by a sharp increase to a peak of 10.50 tons between 2039 and 2048, while US demand increases from 0.02 tons in 2020 to 1.008 tons in 2050. By 2044, secondary supply could meet the entire global demand for Pt, and US demand could be met by 2050. This study helps improve the understanding of recycling's role in enabling higher levels of hydrogen production through electrolysis. The analysis is preliminary in that it ignores prices and recycling costs, which undoubtedly will influence how much recycling actually occurs.

Estimating Regionalized Life Cycle Land Use Impacts for Critical Minerals LCAs

Presented by Donya Otarod

The importance of life cycle assessment (LCA) of critical minerals in the supply chain is growing as environmental considerations of critical minerals become more important. To comprehensively address the environmental effects of critical mineral supply chains, it is necessary to incorporate land use considerations into LCA studies. Most critical minerals LCA studies have global coverage because critical minerals supply chains tend to be global spanning multiple continents in most cases. Thus, life cycle land use impact assessment should account for factors such as land type and occupation, as well as the duration of land use and changes, which vary from one location to the other. Not all life cycle land use impact assessment methods include
Reducing waste during open pit mining of critical minerals through optimal dig-limit strategies

Presented by Hussam Altalhi

Efficient critical mineral resource management will reduce waste material generated from mining activities. Consequently, reducing its negative impact on the environment. Dig-limits problem is one of the key elements to efficient resource extraction in open pit mines, and it is a crucial factor in determining the profitability of mining operations extracting deeper and lower-grade ores. Therefore, mining companies must aim to define those limits properly to maximize profit and reduce waste. The general problem is defining the most feasible and economic dig-limits on each bench in an open pit mine. However, the specific problem is that ore material can have multiple destinations. This is a decision-making problem that can be solved with operations research methods while accounting for the selectivity of the mining equipment. This poster presents a binary-integer linear programming model of this problem accounting for the equipment size. The poster illustrates the optimization model using three sections of a bench of a block model for a copper-moly deposit with seven material classes. The results show the model efficiently determines dig limits while optimizing the value.

Life-Cycle Assessment of Tellurium from Copper Production

Presented by Ioanna Paschalidou

Tellurium is one of the 50 critical minerals listed by the U.S. Government in 2022. It is a rare element that averages only 3 parts per billion (ppb) in Earth’s upper crust. At least 90% of the annual global supply of Te is reportedly recovered as a by-product of the mining of porphyry copper (Cu) deposits. Given policy initiatives to increase and diversify Te production towards the transition to renewable energy generation, it is important that environmental impacts of Te production are clearly understood to inform decision makers. The literature includes limited information pertaining to environmental impacts of Te recovered as a by-product of Cu ore processing. To address this gap, this research performs LCA modeling of the production of Te as a by-product of anode slimes using SimaPro v9.4 software in compliance with ISO 14040 and 14044. The product system of study is a “cradle-to-gate” system of global concern. The functional unit of the product system is 1kg Te metal at the refinery gate. The work models life-cycle from a combination of primary industrial data and secondary data collected from the Ecoinvent v3.7.1 database and literature review. Mass and economic value-based allocation procedure are performed to determine the life-cycle impacts of Te. Estimates midpoint impact categories from the ReCiPe v1.04 method show that mass allocation yields higher impacts in all categories than economic allocation (economic allocation impacts are 64-85% of the mass allocation impacts). However, the results of ReCiPe impact assessment using system subdivision shows that both
mass and economic allocation impacts overestimate the impacts by orders of magnitude. Sensitivity analysis show that the life-cycle impacts are sensitive to the Te content in the slimes and the Te recovery.

**GHANA REPOSITIONED IN THE GLOBAL MINERAL CRITICALITY DOMAIN**
*Presented by Raymond Kudzawu-D’Pherdd*

The impending unprecedented global population explosion calls for more innovative and commensurate mineral value supply as well as alternative and sustainable sources. The United States is heavily dependent on foreign sources for many of the mineral commodities necessary for America’s economy and security. Of the 35 mineral commodities deemed critical by the Department of the Interior, the United States was 100 percent reliant on foreign sources for 13 in 2019. Across the Atlantic, Ghana is showing a lot of commitment in advancement of Science, Technology, Engineering and Mathematics (STEM) education to develop manpower for the extractive industry. Ghana has developed 20 STEM centers, and 10 model STEM High Schools across the country for this purpose to feed the Universities of Science and Technology, and Mining with the requisite talents for developmental needs of the country. After taking strategic steps in developing integrated aluminum and iron ore corporation (i.e., GIADEC and GIISDEC), Ghana appears to be leading her neighbors in the production of Lithium and other critical minerals. We juxtapose Ghana’s leading position and her century old experience in gold production on the African continent, with the potential of the mobile belt for the extraction of critical minerals. We argue and conclude that, China and Australia are in the lead in the strategic ownership of the critical minerals in Africa, and though United States is desirous of looking away from relying on foreign sources, in the medium term however, Ghana, a country that has repositioned herself in the mineral criticality domain but doesn't have immediate consumption nor value addition scheme, could be a strategic exemption and a new partner that could lead to a snowballing opportunity.

**International Material Criticality in Manufacturing**
*Presented by Maxwell Fleming*

We evaluate material criticality for 12 materials using two main indicators: Economic Importance and Supply Risk. We use the same methodology to compare different nations and regions, with a special focus on the US, EU, Japan and China in order to identify similarities and differences among them. Based on the supply risk indicator, even though the US has the lowest average level of criticality, it faces a great risk for most of the minor metals and a low risk for all major metals. On the other hand, Japan is in the most precarious category for the majority of elements are in the high supply risk category. Despite the perception that China is a dominant supplier of certain materials, it has a significant risk, specifically for major metals as well as minor metals that are battery materials, owing to the fact that china imports a significant amount of raw materials. For the economic importance indicator, major metals rank high in criticality and even though minor metals rank low in criticality, they have greater economic importance in
Selective recovery of zinc from alkaline batteries under basic leaching

Presented by Noelia Muñoz García

Alkaline batteries are widely used as portable and non-rechargeable sources of energy. They are composed of a zinc anode and a manganese dioxide cathode. Batteries have immense potential as environmental-friendly energy sources, in detriment to fossil fuels since they do not produce carbon dioxide (CO2) during use. The main problem with batteries is that they can be a substantial environmental hazard if not appropriately managed. Besides, batteries are potential secondary sources of critical minerals such as Zn, Mn, etc. Therefore, developing robust recycling processes to recover valuables from waste batteries is essential. Hydrometallurgical recycling processes of alkaline batteries start with the chemical dissolution of the metals in the black mass (BM) via leaching. In this initial step, two products are obtained: a solution with the dissolved metals and a solid/sludge residue of the solids that cannot be solubilized. Both streams’ composition depends on the type of leaching agent used. The subsequent stages in the hydrometallurgical recycling process involve purifying the metal-containing solutions to recover pure metal salts. In this work, alkaline leaching of BM was utilized to extract Zn from waste alkaline batteries. The effects of temperature and the type and concentration of alkaline solution were investigated. Moreover, the impact of adding a processing aid such as hydrogen peroxide (H2O2) on the efficiency of Zn extraction was also investigated. Preliminary results after ICP analysis of the solids and the leachates show a low Zn extraction rate (16% w/w) using NH4(OH) 4M at 25ºC and with the addition of H2O2. The extraction of Zn increases (64% w/w) when NaOH 6M at 25ºC is used. It can be concluded that the alkaline solvents selectively dissolve the Zn contained in the BM.

Fantastic Beasts and Where to Find Them: Navigating the Challenges Associated with the Acquisition of Life Cycle Inventory of Critical Minerals

Presented by Philip Duah

The sustainability of critical minerals is increasingly evaluated using Life Cycle Assessment (LCA). Data or Life Cycle Inventory is central to any LCA as the reliability of any LCA results is a function of the quality of the data used for the modeling. Generically, there are two main types of data used in LCA: (1) foreground data and (2) background data. In the context of critical minerals, foreground data represents specific and detailed information that is directly obtained from the main sources involved in the production or extraction of critical minerals. However, unlike foreground data, background data centers on pre-existing data from various sources such as commercial and open-source databases, as well as scientific literature. Access to accurate, reliable, complete, and relevant inventory is often challenging and sometimes may even be unattainable. The objective of this study is to present strategies for addressing data uncertainties,
data acquisition, and data interoperability within the context of LCA of critical minerals. We anticipate our study to offer broader insight into strategies for navigating the complexity of attaining Life Cycle Inventory used for LCA of critical minerals.

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**Role of carbon in the formation of Ni-Cu-PGE mineralization in the Valmaggia ultramafic pipe: Insights from laser-ablation-time-of-flight ICP-MS**  
*Presented by Shelby Clark*

Sulfide minerals and their associated deposits are known to be carriers of critical and strategic minerals, such as gallium, germanium, and the rare-earth elements. Understanding the processes that control sulfide transport and deposition in the deep lithosphere is a critical step in the search for critical-mineral bearing ore deposits in lower crustal rocks. The magmatic sulfide ore-bearing Valmaggia pipe in the Ivrea-Verbano Zone (Italy), an exposed cross section of the subcontinental lithospheric mantle and overlying crust, allows for unique insight into ore-forming processes in the lower crust. Sulfides in the pipe are spatially associated with carbonates and hydrous silicates. Previous studies suggested that the sulfides were physically introduced into the pipe via a bubble-pair transport model, i.e., upward flotation of sulfide droplets attached to vapor bubbles. To further evaluate sulfide ore-forming processes, we integrate new petrographic observations with laser-ablation time-of-flight-ICP-MS trace element mapping of sulfide-carbonate-hydrous silicate relationships. We show that carbonates and hydrous silicates exist in varying sizes, compositions, textures and orientations in relation to sulfide phases, and are not restricted to a singular textural or chemical relationship. Similarly, sulfide textures vary and may or may not exhibit rimming by volatile phases. Our data show that bubble-pair transport cannot fully explain the textural relationships between sulfides and volatile-rich minerals, but rather suggest that at least some of the sulfides and carbonates co-precipitated from the same fluid/melt.

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**The Otter Creek Igneous Complex, NW Iowa: A potential Cr and PGE resource in the midwestern USA.**  
*Presented by Trent Olson*

The Otter Creek Igneous Complex is a buried late Archean layered ultramafic-mafic intrusion in NW Iowa. It was discovered in the 1960s by mineral exploration drilling into one of a series of positive magnetic anomalies found just north of the Spirit Lake Tectonic Zone the Archean Superior craton from the Paleoproterozoic accretions. This elongate trend of magnetic anomalies could be related layered complexes with a strong potential to host critical mineral resources. However, only the anomaly that has been identified as the Otter Creek Igneous Complex has ever been drilled. The Otter Creek Igneous Complex is highly altered with a lower ultramafic series and an upper mafic series, and it is dated at 2713 ± 8 Ma (unpublished industry U-Pb zircon age). The focus of this study is to use whole rock composition and chromite analyses to infer the nature of the parental magma. The secondary focus of this work is to reinvigorate research around the Otter Creek Igneous Complex and those other magnetic anomalies. Chromites in thin chromitite layers are more robust and provide more information about the parental magma. These
chromitite analyses overlap with those found at the komatiite-related late Archean Great Dyke and Inyala intrusions in Zimbabwe. Given the similarities with the komatiitic intrusions in the Belingwe greenstone belt of Zimbabwe and the melt Al2O3/TiO2 estimates, the Otter Creek Igneous Complex was formed from a contaminated komatiite magma that is related to one of the southernmost Neoarchean greenstone belts found in the Superior province. The similarities of the Otter Creek Igneous Complex and the Great Dyke gives us a model for the potential for critical mineral resources to be present in four state intersection of NE, IA, SD, MN. To assess the full potential of these possible intrusions would require additional coring and geophysical studies.
Workshop Panel

16:15 – 17:30  |  August 9, 2023

Join our panelists in discussing one of the most important topics of the workshop: “How to grow the American critical minerals workforce”.

Thomas Sonderman
CEO, SkyWater Technology

Dawn Wellman
Manager of Research and Development, Rio Tinto

Mo Dehghani
Chancellor, Missouri S&T

Amber Steele
Program Director, Missouri Geological Survey

Jeffrey Mauk
Research Geologist, United States Geological Survey

Michelle Michot Foss
Fellow in Energy, Minerals, and Materials, Rice University’s Baker Institute
Workshop Organizing Committee

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Associate Professor, Mining Engineering – Missouri S&T

Michael Moats
Professor and Materials Science & Engineering Chair – Missouri S&T

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Mahelet Fikru
Associate Professor, Economics – Missouri S&T

Mark Fitch
Associate Professor, Civil, Architectural & Environmental Engineering – Missouri S&T

Shelby Clark
PhD Student, Geosciences, Geological and Petroleum Engineering – Missouri S&T