Summary Report:

2nd Annual Workshop: Resilient Supply of Critical Minerals

August 4-5, 2022

Hosted by:
Missouri University of Science and Technology

criticalminerals.mst.edu

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Preferred Citations:

Summary Report

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Individual Abstracts (example)

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Acknowledgements and Disclaimer

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The workshop was initially planned for May 2020 on the Missouri S&T campus, Rolla, Missouri, USA. However, owing to the global COVID-19 pandemic, the format of the workshop was changed to a virtual workshop series. The first virtual workshop was conducted on August 2-3, 2021. The findings report for the first workshop is accessible through the workshop website https://criticalminerals.mst.edu/. The second annual workshop was conducted virtually on August 4-5, 2022, and the workshop demographics and content are summarized in this report. The content summarized here is solely based on presentations and discussions during the workshop. The views and opinions presented here, and in the recorded presentations, do not necessarily reflect those of the workshop organizers who prepared the report.

Executive Summary

On August 4-5, 2022, the Thomas J. O'Keefe Institute for Sustainable Supply of Strategic Minerals at Missouri University of Science and Technology (Missouri S&T) hosted the 2nd annual national workshop on 'Resilient Supply of Critical Minerals' funded by the National Science Foundation (NSF). The workshop was convened via Zoom and attracted 346 registrants, including 171 registrants from academia (62 students), 88 registrants from government agencies, and 87 registrants from the private sector. The workshop was free to attend for everyone who registered. On day 1 of the workshop, 152 unique viewers logged into the sessions. Day 2 had 111 unique viewers. Four topical sessions were covered:

A. The Critical Mineral Potential of the USA: Evaluation of existing, and exploration for new resources (Day 1). Keynote speaker: Jeffrey Mauk, United States Geological Survey.

B. Mineral Processing and Recycling: Maximizing critical mineral recovery from existing production streams (Day 1). Keynote speaker: Karin Olson Hoal, Cornell University.

C. Critical Mineral Policies: Toward effective and responsible governance (Day 2). Keynote speaker: Michelle Michot Foss, Rice University's Baker Institute for Public Policy.

D. Resource Sustainability: Ethical and environmentally sustainable supply of critical minerals (Day 2). Keynote speaker: Debra Struhsacker, Professional Geologist, Environmental Permitting & Government Relations Consultant.

Each topical session was composed of one keynote lecture and three invited presentations. The sessions concluded with a Q/A discussion with all presenters. Recordings of selected presentations are available from the workshop website: https://criticalminerals.mst.edu/2022-presentation-videos/. The third annual workshop on 'Resilient Supply of Critical 'Minerals' will be held in the summer of 2023 on the Missouri S&T campus, Rolla, Missouri, USA. The dates will be announced in January 2023.

Introduction

On June 4, 2019, the U.S. Department of Commerce released the strategic report "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals". The report outlines six Calls to Action that, if executed, will reduce the vulnerability of the United States to critical mineral supply disruptions. These six Calls to Action are:

1. Advance Transformational Research, Development, and Deployment Across Critical Mineral Supply Chains.
2. Strengthen America's Critical Mineral Supply Chains and Defense Industrial Base.
3. Enhance International Trade and Cooperation Related to Critical Minerals.
4. Improve Understanding of Domestic Critical Mineral Resources.

5. Improve Access to Domestic Critical Mineral Resources on Federal Lands and Reduce Federal Permitting Timeframes.
6. Grow the American Critical Minerals Workforce.

In 2020, the Thomas J. O'Keefe Institute for Sustainable Supply of Strategic Minerals at Missouri University of Science and Technology (Missouri S&T) received funding from the National Science Foundation (NSF) to host a workshop on the Missouri S&T campus (Rolla, Missouri) to identify research needs associated with these Calls to Action. Initially scheduled for May 2020, the in-person workshop was cancelled because of the global COVID-19 pandemic. Consequently, the format of the workshop was changed to a two-part virtual workshop series. The first virtual workshop was conducted was conducted on August 2-3, 2021, via Zoom. The findings report for the first workshop is accessible through the workshop website: https://criticalminerals.mst.edu/previous-workshops/. The second virtual workshop was conducted on August 4-5,2022, via Zoom.

Workshop Content

The second annual workshop was divided into four themed topical sessions that reflect the most pressing research and workforce development needs identified during the first workshop:

Day 1:

Session A: The Critical Mineral Potential of the USA: Evaluation of existing, and exploration for new resources.

Keynote speaker: Jeffrey Mauk (U.S. Geological Survey).

Presentation title: Critical Mineral Potential of the U.S.: Evaluation of Known Resources of Aluminum, Arsenic, Beryllium, Chromium, Cobalt, Fluorspar, Gallium, Germanium, Graphite, Indium, Lithium, Manganese, Niobium, Platinum-Group Elements, Rare-Earth Elements, Tantalum, Tellurium, Tin, Titanium, Tungsten, Uranium, and Vanadium.

Session B: Mineral Processing & Recycling: Maximizing critical mineral recovery from existing production streams.

Keynote speaker: Karin Olson Hoal, Cornell University.

Presentation title: New Directions for the Mineral Resources Industry: Geomet, Adaptivity, and a Bigger Tent.

Day 2:

Session C: Critical Mineral Policies: Toward effective and responsible governance.

Keynote speaker: Michelle Michot Foss, Rice University's Baker Institute for Public Policy.

Presentation title: New Sheriffs in Town? Governing the Minerals Wild West.

Session D: Resource Sustainability: Ethical and environmentally sustainable supply of critical minerals.

Keynote speaker: Debra Struhsacker, Professional Geologist, Environmental Permitting & Government Relations Consultant.

Presentation title: How Policies, Legislation, and Litigation Could Reduce Domestic Mining of Critical Minerals

The full list of speakers, as well as the title and abstract of their presentations, can be found in Appendices 1 and 2.

Workshop Demographics

A total of 346 people registered for the workshop, including 171 participants from academia, 88 from government agencies at the federal and state levels, and 87 from the private sector (Fig. 1). The workshop was free to attend for everyone who registered. The registrants stated the following broad fields of occupation during the registration process: Faculty (n=70), researcher (n=70), student (n=62), postdoctoral fellow (n=12), and other / not specified (n=132; Fig. 1). Registrants were from 41 countries (Fig. 2) representing all continents except Antarctica (Fig. 3).

Most participants were from the United States (n=263; 76%, Fig. 2, 3). Other represented countries include the United Kingdom (n=17; 4.9%), Canada (n=14; 4.0%); India (n=10; 2.9%), South Africa (n=6; 1.7%) and Australia (n=4; 1.2%). Further, three participants (=0.9%) from each of the following countries registered: Chile, China, France, Germany, as well as two people from Iran (=0.6%). One participant each (=0.3%) registered from Brazil, Cameroon, Columbia, Finland, Ghana, Italy, Mongolia, Nigeria, Oman, Puerto Rico, Russia, Spain, Sweden, Taiwan, Turkey, and the United Arab Emirates. Two registrants (= 0.6%) did not state a country of residence.

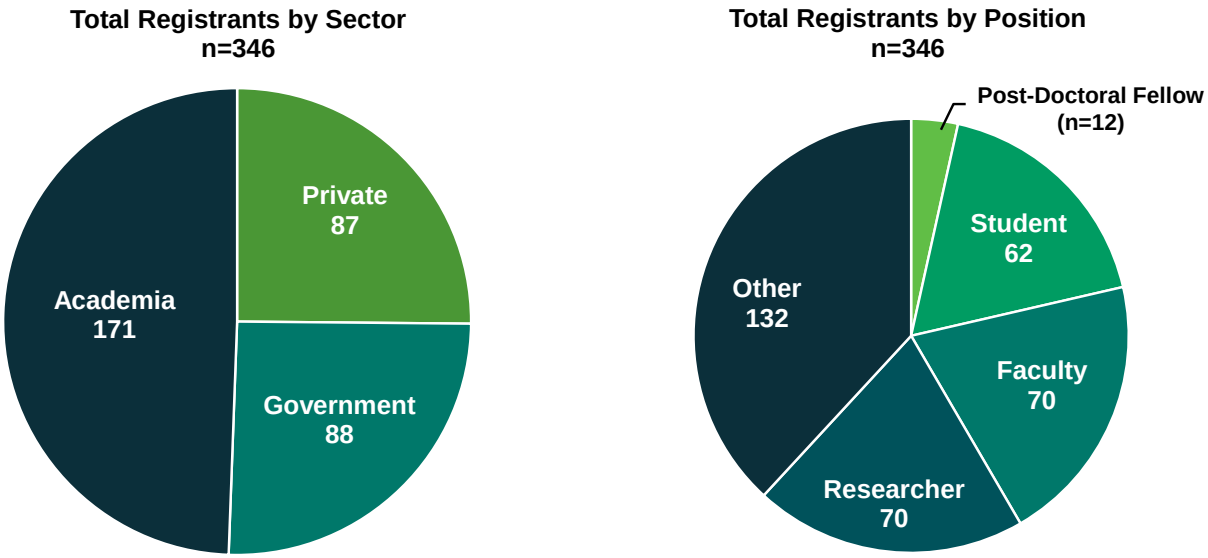

Figure 1: Breakdown of workshop participants based on sector of employment and position currently held.

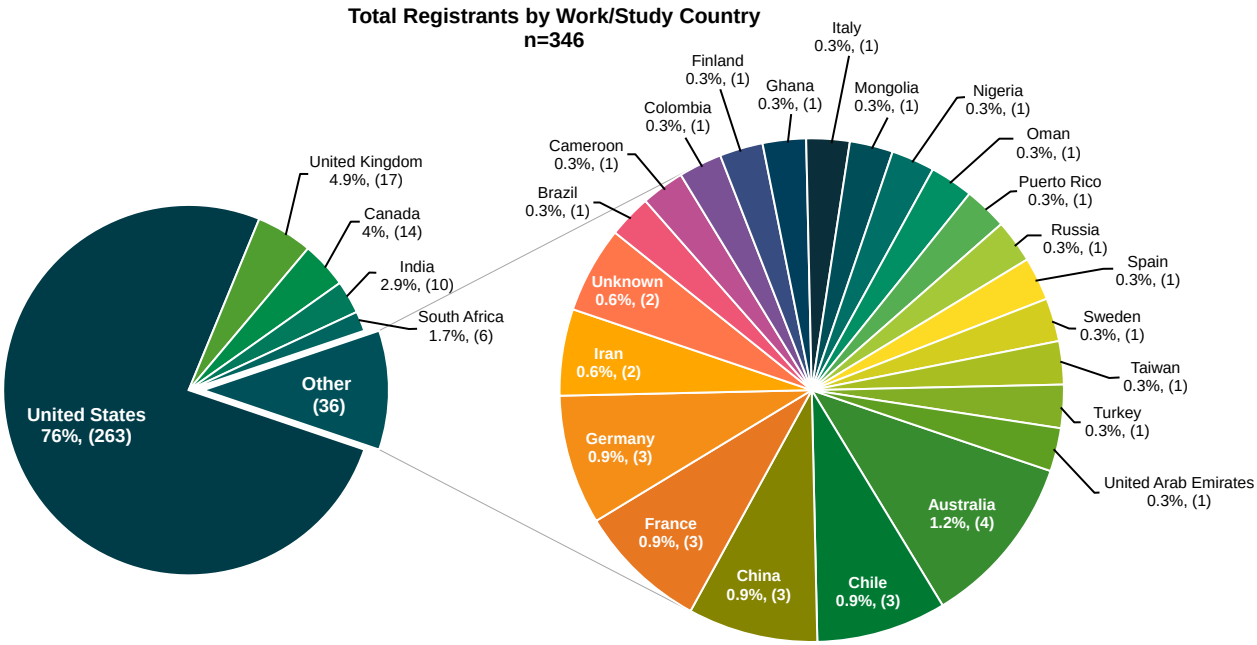

Figure 2: Workshop participants by country of residence.

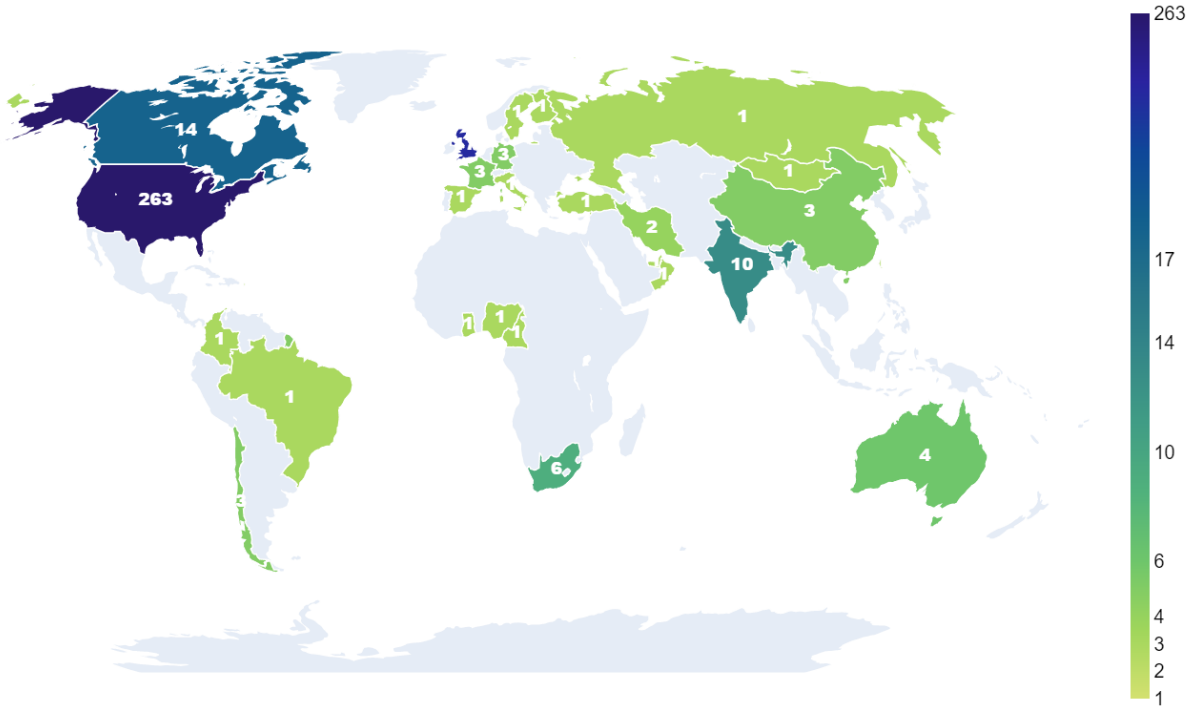

Figure 3: Global distribution of the countries of residence of the workshop registrants.

On day 1 of the workshop, 152 unique viewers logged into the sessions. A total of 136 sign-ins were from the United States (=89.5%). Sign-ins from other countries include the United Kingdom (n=4, 2.6%); Canada (n=3, 2.0%), Chile (n=2; 1.3%) and one visitor (=0.7%) from each of the following countries: Australia, France, India, Indonesia, Jamaica, Netherlands, Switzerland.

During the second day of the workshop, 111 unique viewers logged into the sessions. Ninety-eight viewers (= 88.3%) were from the United States, 3 from the United Kingdom (=2.7%), 2 from Canada (=1.8%), 2 from France (=1.8%) and one each (=0.9%) from the following countries: Chile, Ghana, Indonesia, Jamaica, Netherland, Switzerland.

It is noted that the countries of residence that registrants stated during the registration process do not entirely match the actual countries from which viewers signed-in during the workshop. The discrepancy either reflects sign-ins during travelling, use of VPNs and/or shared links between different viewers. The drop-off in the number of registrants vs. actual viewers (i.e., 346 registrants, 152 unique viewers on day 1, 111 unique viewers on day 2) is what is commonly expected for no-cost virtual workshops. To allow registrants to view selected workshop presentations on demand, professionally edited recordings are available on the workshop website: https://criticalminerals.mst.edu/2022-presentation-videos. Eight presenters consented to uploading their presentation that were watched for a combined total of 107 times (as of December 1, 2022). The presentations will remain online for six months after the conclusion of the workshop (i.e., until February 5, 2022).

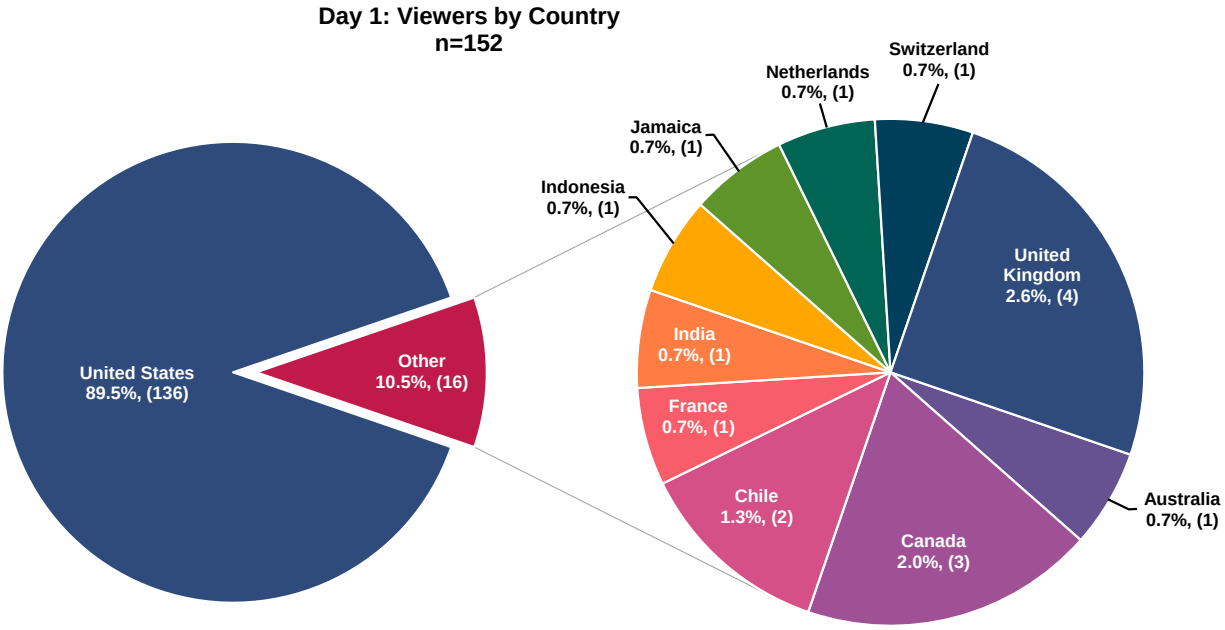

Figure 4: Global distribution of viewers during the first day of the workshop. Shown are countries from where participants logged in, which do not necessarily correspond to the primary country of residence.

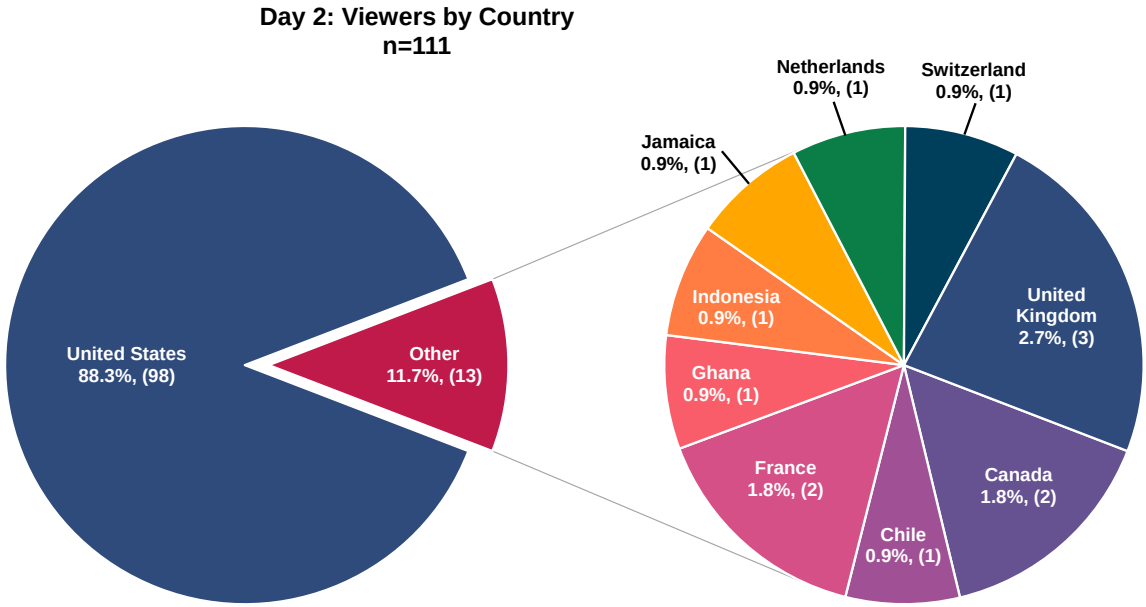

Figure 5: Global distribution of viewers during the second day of the workshop. Shown are countries from where participants logged in, which do not necessarily correspond to the primary country of residence.

APPENDIX 1: Workshop Agenda

Thursday August 4, 2022

The Critical Mineral Potential of the USA
Evaluation of existing, and exploration for new resources

11:00 – 11:05 **Opening Remarks**
Marek Locmelis, Missouri University of Science and Technology

11:05 – 11:15 **Chancellor's Welcome to Missouri S&T**
Chancellor Mohammad Dehghani, Missouri University of Science and Technology

11:15 – 12:00 **Keynote Lecture**
Jeffrey Mauk, United States Geological Survey
Critical mineral potential of the U.S.: Evaluation of known resources of aluminum, arsenic, beryllium, chromium, cobalt, fluorspar, gallium, germanium, graphite, indium, lithium, manganese, niobium, platinum-group elements, rare-earth elements, tantalum, tellurium, tin, titanium, tungsten, uranium, and vanadium

12:00 – 12:30 **Invited Talk**
Lee Ann Munk, University of Alaska
Lithium Brines and Emerging Lithium Deposits in the U.S.

12:30 – 13:00 **Invited Talk**
H. Sebnem Düzgün, Colorado School of Mines
Quantitative Approaches to Evaluation of Mineral Supply Chain Transparency and Resiliency

13:00 – 13:30 **Invited Talk**
Isabel Barton, University of Arizona
Bringing students into the minerals workforce: a University of Arizona study

13:30 – 13:45 **Q&A Discussion**
All speakers

13:45 – 14:00 **BREAK**

Mineral Processing and Recycling

Maximizing critical mineral recovery from existing production streams

14:00 – 14:45 **Keynote Lecture**
Karin Olson Hoal, Cornell University
New directions for the mineral resources industry: geomet, adaptivity, and a bigger tent

14:45 – 15:15 **Invited Talk**
Hojong Kim, Penn State University
Electrochemical Properties of Nd and Gd in Molten Salts: Challenges & Opportunities for Sustainable Rare-Earth Recovery Processes

15:15 – 15:45 **Invited Talk**
Eric Werner, University of Tampa
Development of rare earth element separation methods utilizing a tripodal CMPO ligand system

15:45 – 16:15 **Invited Talk**
Shannon Biros, Grand Valley State University
REE workforce development in the undergraduate research lab: Recruiting and training the next generation of scientists

16:15 – 16:30 **Q&A Discussion**
All Speakers

Friday August 5, 2022

Critical Mineral Policies

Toward effective and responsible governance

11:00 – 11:05 **Opening Remarks**
Marek Locmelis, Missouri University of Science and Technology

11:05 – 11:50 **Keynote Lecture**
Michelle Michot Foss, Rice University's Baker Institute for Public Policy
New Sheriffs in Town? Governing the Minerals Wild West

11:50 – 12:20 **Invited Talk**
Morgan Bazilian, Colorado School of Mines
Critical Minerals and Energy Geopolitics

12:20 – 12:50 **Invited Talk**
Mahelet Fikru, Missouri University of Science and Technology
An economic framework for producing critical minerals as joint products and lessons for policy

12:50 – 13:20 **Invited Talk**
Kristin Vekasi, University of Maine
Supply Chain Resiliency for Critical Minerals in the Indo-Pacific

13:20 – 13:35 **Q&A Discussion**
All speakers

13:35 – 13:45 **BREAK**

Resource Sustainability

Ethical and environmentally sustainable supply of critical minerals

13:45 – 14:30 **Keynote Lecture**
Debra W. Struhsacker, Women's Mining Coalition
How Policies, Legislation, and Litigation Could Reduce Domestic Mining of Critical Minerals

14:30 – 15:00 **Invited Talk**
Giovanni Andrea Blengini, Politecnico di Torino
Critical minerals and the EU Green deal: demand, circularity, footprint

15:00 – 15:30 **Invited Talk**
Brett Carlson, South Dakota School of Mines and Technology
Manganese: The Other Critical Material

15:30 – 16:00 **Invited Talk**
Samuel Kessinger, South Dakota School of Mines and Technology
Coltan Track and Trace Technologies

16:00 – 16:15 **Q&A Discussion**
All Speakers

APPENDIX 2: Speakers and Abstracts

Jeffrey Mauk, *United States Geological Survey*
Research Geologist, Geology, Geophysics, and Geochemistry Science Center

Critical mineral potential of the U.S.: Evaluation of known resources of aluminum, arsenic, beryllium, chromium, cobalt, fluorspar, gallium, germanium, graphite, indium, lithium, manganese, niobium, platinum-group elements, rare-earth elements, tantalum, tellurium, tin, titanium, tungsten, uranium, and vanadium

The U.S. Geological Survey's USMIN project is developing national-scale, geospatial databases that are the authoritative source of the most important mines, mineral deposits, and mining districts in the U.S. Since May 2017, part of our work has focused on critical minerals in the U.S., which aligns with several Executive and Congressional mandates. The 2022 final list of critical minerals for the U.S. includes 50 commodities, in part because it lists individual rare-earth (n=15) and platinum-group (n=5) elements. The critical mineral potential of the U.S. varies tremendously for different commodities. For some commodities, such as Mn, deposits in the U.S. are typically low-grade and metallurgically complex, and in a 21st century global economy are not likely to be competitive with Mn sourced elsewhere, such as South Africa, where deposits are large, high-grade, and easier to beneficiate. In other cases, such as Li, the U.S. has both conventional and unconventional deposits that, depending on technological developments and concomitant costs, may combine to provide substantially increased domestic supplies. For principal commodities that are produced as the primary products from orebodies, such as Al, Be, Cr, graphite, Li, Mn, PGEs, REEs, Sn, Ti, and W, our knowledge of where in the U.S. these commodities occur in significant deposits is relatively robust. For commodities recovered as byproducts, such as As, Ga, Ge, In, and Te, our knowledge is very limited with respect to: which deposits host significant concentrations of these elements, how much of that commodity is theoretically recoverable, and how much is actually recovered. Increased reporting of byproduct critical mineral production would greatly enhance our ability to evaluate the mineral potential of byproduct commodities in the U.S.

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.

Lee Ann Munk, *University of Alaska*
Professor, Geological Sciences

Lithium Brines and Emerging Lithium Deposits in the U.S.
As the world strives toward a realized energy transition, lithium has been placed front and center because of its key role in battery manufacturing. The U.S. has historically been underexplored for lithium and currently only has one producing lithium mine and contributes a small percentage of total lithium to the market. The geologic understanding of closed-basin continental brines is the most developed among all brine types. Potential emerging types of brines that contain elevated concentrations of lithium include geothermal and oil field brines which are typically low grade but potentially high volume. Other occurrences of lithium in the U.S. are found in pegmatites and tuffaceous lacustrine sediments. Recently, there has been a renewed interest in known pegmatite locations/mines as well as increased exploration particularly in the eastern U.S. Tuffaceous lacustrine sediment-hosted lithium deposits are abundant in the Great Basin region of the U.S. and have recently received notable exploration activities. The well-known Thacker Pass project in northern Nevada is not yet in operation but may soon come online. The Clayton Valley, NV deposit which is the only current lithium producing site in the U.S. has been reclassified as a brine-lacustrine sediment-hosted deposit with an estimated 54 Mt of lithium in the subsurface solids. New resource estimates are warranted for lithium in the U.S. and globally as increased exploration adds new information on these important deposit types.

Biography
Dr. Munk is a Professor of Geological Sciences at the University of Alaska Anchorage and a global expert on lithium resources with a focus on brines and clays. She holds a Ph.D. in Geological Sciences from The Ohio State University. Dr. Munk and her research team are global leaders in the understanding of lithium brine basins from a resource, sustainability and environment perspective. She developed the first and only ore deposit model for closed-basin lithium brines, the world's most important resource of lithium. She and her team are highly sought after by the lithium brine exploration and mining industry to help solve critical problems

and to advise on the most environmentally sustainable methods of resource exploration, extraction and production. Their team is the most published in the area of lithium brine formation, climate-driven influence on brine basins, and the understanding of water resources needed to support lithium brine mining.

H. Sebnem Düzgün, *Colorado School of Mines*
Professor, Mining Engineering
Fred Banfield Distinguished Endowed Chair

Quantitative Approaches to Evaluation of Mineral Supply Chain Transparency and Resiliency

Mineral supply chains (e.g., tantalum, lithium, gold, copper, iron, metallurgical coal, and steel) are complex sociotechnical systems including social, economic, and technical dimensions that require quantitative approaches in assessing their transparency and resiliency. This talk explains the use of systems engineering principles, specifically system dynamics modeling and supply chain analytics, to map the mineral supply chains with a focus on mining and mineral processing. The system dynamics modeling unpacks the mineral supply chain's physical (mining and beneficiation) and sociotechnical (workforce, regulatory aspects, transportation modes, and other material flows) components, providing transparency analysis. Furthermore, by applying stressors to the system dynamics models of the mineral supply chains, its resiliency can be quantitatively measured.

Moreover, explicit system models provide a quantitative assessment of alternative decarbonization strategies for the whole supply chain. The first part of the talk presents examples of system dynamics models of mineral supply chains.

The supply chain analytics provides insight into the global trade of mineral products (e.g., concentrate, metal, scrap, and other finished products). Mineral supply chains exhibit one of the most considerable discrepancies in world trade data. Moreover, the involvement of small-scale artisanal mining (ASM) in mineral supply chains increase its opacity due to illicit activities (e.g., gold and tantalum). Gold is one of the opaquest mineral supply chains due to traceability problems and the involvement of artisanal-small-scale mining (ASM). The second part of the talk provides results of machine learning algorithms applied to overall world trade data over 20 years and the position of some mineral product trades (e.g., gold, tantalum) in global trade.

Biography
Dr. H. Sebnem Düzgün is Professor and Fred Banfield Distinguished Endowed Chair in Mining Engineering at Colorado School of Mines. She also has double appointment in Computer Science. Dr. Düzgün has over 30 years of experience in research, teaching consultancy in mining engineering and information technologies in geosciences. Dr. Düzgün's expertise involve big data analytics, artificial intelligence, virtual/augmented reality, GIS, remote sensing, information fusion, systems engineering and their use in mineral supply chains, mine closure and reclamation, risk and safety analysis, mine environmental monitoring and uncertainty management in geosciences. Dr. Düzgün has authored four books, published over 15 book chapters, over 80 papers in peer-reviewed scientific journals, over 200 papers in conferences and many technical reports. She has recently included in UK`s 100 Global Inspirational Women in Mining 2020 Edition and appointed as 100 Resilience Fellows of 4TU-Federation`s Resilience Engineering Program and become Newmont STEM Equity Instructional Fellow.

Isabel Barton, *University of Arizona*
Assistant Professor, Mining and Geological Engineering

Bringing students into the minerals workforce: a University of Arizona study

Low enrollments in university mining engineering, metallurgy, and other minerals-related programs represent a future workforce challenge for supplies of critical minerals. New data from an ongoing University of Arizona study show that the principal barrier to higher recruitment is students' lack of knowledge about mining engineering as a potential career. While they have a neutral (neither positive nor negative) starting view of the mining industry, most freshman engineering students know very little about it. Relatively small amounts of information have a significant positive effect on students' knowledge about and interest in mining engineering as a major. What students find particularly attractive about mining engineering are its importance to society and technology and the opportunities it offers to work outside and travel the world. The most effective channels for communication are freshman engineering class and a robust internet presence. This talk will describe the results of the study and implications for recruiting students to the mineral resources workforce.

Biography
Isabel Barton is an Assistant Professor of Mining & Geological Engineering at the University of Arizona, where she also obtained a Ph.D. in Geosciences and an M.S. in mining engineering. Most of Isabel's research and teaching focus on geometallurgy, which integrates the mineralogy of ore deposits with extractive metallurgy to make metal production more efficient. In 2021 she received a National Science Foundation CAREER award for the geometallurgy of critical metals such as cobalt, copper, uranium, and vanadium. She works with departments across campus to

find interdisciplinary solutions to various mineral resource problems. In collaboration with the UA's Aerospace Engineering and Anthropology departments and the Lowell Institute for Mineral Resources, she recently obtained another NSF grant to study the causes of low diversity in mining and other engineering majors.

Karin Olson Hoal, *Cornell University*
Professor and Consultant, Earth and Atmospheric Sciences

New directions for the mineral resources industry: geomet, adaptivity, and a bigger tent

The need for materials in coming years is driven not only by the renewable energy transition but more importantly by the necessity of bringing billions of people out of poverty to a standard of living that includes global infrastructure development, education, healthcare and clean environments. New methods of finding and extracting elements from minerals in the Earth are therefore required so that 20th Century methods with 20th Century impacts are not simply accelerated. Three key changes to industry are required in order to build a positive, welcome, and innovative mineral resources industry for the future (and current) sustainable development of humanity. First, it is necessary to fully understand what is where in order to know how best to extract and use it. Thus, the huge capabilities of characterization and analysis of element deportment currently in use to understand ores and waste will be brought into operations through geomet applications. Second, engineering design will become highly flexible and adaptive to the data from the subsurface, so that potential challenges and impacts can be predicted and planned for years in advance. Third, a bigger tent will include scientists, engineers, computational experts, the business community and sustainability leaders who are not from traditional mining schools but who instead can design, develop, communicate, and implement novel solutions to the minerals and metals challenges of today and tomorrow.

Biography

Karin Olson Hoal is the Wold Family Professor in Environmental Balance for Human Sustainability at Cornell University, building interdisciplinary approaches across science, engineering, and business for broader engagement from diverse perspectives. A geologist by training, she has worked in the minerals industry for 30 years with metals and diamond mining companies and process development firms and as a consultant in the US, Canada, Australia, southern Africa, and Chile. She has 20 years of experience in developing the field of geomet (geometallurgy), integrating geology with better engineering practices, and prior to Cornell built and directed a major interdisciplinary research center at Colorado School of Mines for new applications development in cross-discipline characterization. She has degrees from St Lawrence University, McGill University, and the University of Massachusetts, was a Postdoctoral Fellow

at the University of Cape Town, is a Fellow of SEG, past Chair of the SME Sustainable Development Committee, and is currently active with Women in Mining (US and UK), the Women Advisory Board Doctoral Network (Europe), and the World Mining Congress Future Workforce and Education Committee (Brisbane, 2023)

Hojong Kim, *Penn State University*
Associate Professor, Materials Science and Engineering

Electrochemical Properties of Nd and Gd in Molten Salts: Challenges & Opportunities for Sustainable Rare-Earth Recovery Processes

Rare-earth materials are critical for the transition to a green, low-carbon economy because of their essential role in renewable energy technologies such as permanent magnet (NdFeB) motors for wind turbines and electric vehicles. The projected increase in demand for rare earths will outstrip primary resource supplies; however, less than 1% of the rare earths are recycled, requiring the development of efficient and environmentally-friendly recycling techniques for future deployment of clean energy technologies. This presentation will examine the state-of-the-art electrochemical processes in molten salts (e.g., LiF-NdF_3) for rare-earth production with specific focus on fundamental challenges of rare-earth electrochemistry (e.g., high reactivity and multi-valent states) that can lead to low process yield. Approaches to mitigate the high reactivity of rare-earth metals are introduced based on the electrochemical studies of Nd and Gd metals/alloys with an aim to help develop efficient rare-earth recovery and recycling processes.

Biography

Dr. Hojong Kim is an associate professor at Penn State University in Material Science and Engineering. He received a B.S. degree from Seoul National University in South Korea and Ph.D. degree at MIT in the Uhlig Corrosion Laboratory. Dr. Kim worked as a senior researcher at Samsung-Corning Precision Glass to improve the process yield for TFT-LCD glass manufacturing by engineering high-temperature materials. After five years of industrial experience, Dr. Kim returned to MIT as a post-doctoral researcher to contribute to the growing need for sustainable technology, with a research focus on molten oxide electrolysis for carbon-free iron production and liquid metal batteries for large-scale energy storage. His current research focuses on electrochemical processes for the separation of energy-critical elements and the development of corrosion-resistant materials. He received the NSF CAREER award, the new doctoral new investigator award from the American Chemical Society, and Young Leader Professional Development Award from TMS. He served as the chair (2017-2019) and vice-chair (2015-2017) of the hydrometallurgy and electrometallurgy committee at TMS.

Eric Werner, *University of Tampa*
Professor, Chemistry

Development of rare earth element separation methods utilizing a tripodal CMPO ligand system

Given the increasing relevance of the rare earth elements across many areas of emerging technologies, interest in the acquisition of these valuable metals from both natural sources and product recycling continues to grow. We have been developing ligands for lanthanide extraction and separations that utilize the carbamoylmethylphosphine oxide (CMPO) metal chelating group. Over the past several years, our group has generated a series of ligands that tether three CMPO units to central capping scaffolds of varying size and composition. This presentation will give an overview of the effect of the ligand "cap" on metal extraction, highlighting some promising selective lanthanide and actinide extraction results via a liquid-liquid protocol. Recent studies that have more closely examined extraction protocol variation (e.g., varying ligand concentration and mixing times) will be presented as well.

Biography

Eric J. Werner earned his undergraduate chemistry degree from the University of Florida (B.S., 2002). He pursued graduate studies in the group of Prof. K. N. Raymond at the University of California, Berkeley (Ph.D., 2007) with a focus on the development of hydroxypyridonate-based Gd^{3+} complexes as improved MRI contrast agents. After beginning his independent career as an Assistant Professor of Chemistry at Armstrong State University in 2007, he moved to The University of Tampa in 2010. He is now a Professor of Chemistry with an active undergraduate research program in f-element coordination chemistry. Current research aims include the development of luminescent lanthanide-based sensors and improved rare earth element separation methods.

Shannon Biros, *Grand Valley State University*
Professor, Chemistry

REE workforce development in the undergraduate research lab: Recruiting and training the next generation of scientists

This presentation will discuss research aimed toward the purification of rare earth elements using tripodal CMPO-based ligands. Also described will be the recruitment of undergraduate research students into our research groups, which provides the foundation for their future career in the area of f-element coordination chemistry. By engaging undergraduate students in a research program dedicated to f-element chemistry, this exposes students to research topics such as rare earth element separations and recycling of critical materials at a relatively early stage in their careers.

Biography
Shannon M. Biros joined the faculty of GVSU as an Assistant Professor of Organic Chemistry in the fall of 2008. She was a graduate of GVSU, receiving her B.A. in chemistry and B.S. in biomedical sciences in 2001. From there, she moved to San Diego to pursue a Ph.D. in chemistry at The Scripps Research Institute under the direction of Professor Julius Rebek, Jr. Following the completion of her thesis, Shannon spent a year at the University of California, Berkeley as a postdoctoral research associate in the laboratory of Professor Kenneth N. Raymond investigating the guest binding properties of a series of supramolecular metal-ligand clusters. She is currently in her thirteenth year as a faculty member at GVSU and maintains an active research group of undergraduate students.

Michelle Michot Foss, *Rice University's Baker Institute Fellow in Energy, Minerals and Materials*

New Sheriffs in Town? Governing the Minerals Wild West
Attention, and considerable hype, are being directed toward minerals supply chains. Growth in legacy uses and new demand are disrupting often opaque and not well understood resource markets. Consequences range from security challenges to price risk, with implications for traditional, operational, and non-traditional, financial, oversight and surveillance. The natural resource landscape stands to become vastly more complicated, with a tendency toward rigged games, given lessons from past experience with both market and government failures and resource politics.

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. She has served on the advisory committees for the UTA Jackson School of Geosciences Energy & Earth Resources graduate program and Jackson School Endowment.

She is a member of the advisory boards for Haddington Ventures LLC and Energy Intelligence Group. She is past president of the International Association for Energy Economics, past president of the U.S. Association for Energy Economics, and was named USAEE Senior Fellow for service. Michot Foss is a partner in Harvest Gas Management LLC. She created and leads a nonprofit organization, Friends of Briargrove Park Green Space LLC, to coordinate activities with Harris County Flood Control District for post-Harvey rehabilitation.

Michot Foss received her B.S. from the University of Louisiana at Lafayette, an M.S. from Colorado School of Mines, and a Ph.D. from the University of Houston.

Morgan Bazilian, *Colorado School of Mines*
Professor, Public Policy, Division of Economics and Business
Director, Payne Institute for Public Policy

Critical Minerals and Energy Geopolitics

The energy transition is changing the global geopolitical landscape. The role for critical minerals is essential to a successful move to a low-carbon economy. The environmental, security, trade, and governance issues are complex and require considerable attention.

Biography

Morgan Bazilian is the Payne Institute for Public Policy Director and a Professor at the Colorado School of Mines. Previously, he was Lead Energy Specialist at the World Bank. Dr. Bazilian holds a Ph.D. in energy systems and was a Fulbright fellow. His work has been published in Science, Nature, Foreign Affairs, Foreign Policy, and Proceedings of the National Academy of Science. Previously he was a senior diplomat at the United Nations. He was the EU's lead negotiator on technology at the UN climate negotiations. He is also a member of the Council on Foreign Relations.

Mahelet Fikru, *Missouri University of Science and Technology*
Associate Professor, Economics

An economic framework for producing critical minerals as joint products and lessons for policy

The topic of economics of critical minerals has received little attention in the literature. This study presents a two-stage optimization model to frame the economics of critical minerals production. The model examines the impact of geological, cost, and technology parameters on the extraction of a common ore to produce critical minerals with or after the production of another (main) mineral. Results from the economic model are used to evaluate trade-offs involved in production decisions and designing policies aimed at supporting the industry.

Biography

Dr. Fikru joined Missouri S&T in 2011. She holds a Ph.D. in economics from Southern Illinois University Carbondale. She is a member of the Association of Environmental and Resource Economists (AERE), the US Association for Energy Economics (USAEE), and the American Solar Energy Society (ASES).

Kristin Vekasi, *University of Maine*
Associate Professor, Political Science and School of Policy and International Affairs

Supply Chain Resiliency for Critical Minerals in the Indo-Pacific

Supply chains around the world seem increasingly vulnerable, and governments around the world are seeking strategies to make them more resilient to both political and market challenges. Critical mineral supply chains are at the forefront of many of these efforts. This talk will address the related concepts of "economic security" and "economic resiliency" in China, Japan, and the United States and apply it to rare earth minerals. The talk will compare approaches to rare earth policies across the world three largest economies and assess possible outcomes and ways forward for more resilient supply chain governance.

Biography

Kristin Vekasi is an Associate Professor in the Department of Political Science and School of Policy and International Affairs at the University of Maine. Her research focuses on trade and investment strategies in changing geopolitical environments and the political risk management of supply chains. She specializes in Northeast Asia and has spent years conducting research in China, Japan, and South Korea. Her book Risk Management Strategies of Japanese Companies in China (Routledge 2019) explores how Japanese multinational corporations mitigate political risk in China. Her current research examines how Japan, China, and the United States cooperate

and compete to manage complex supply chains in Southeast Asia, focusing on industries essential for the transition to green energy.

Vekasi received her Ph.D. in political science from the University of Wisconsin, Madison. Before joining the faculty at the University of Maine, she taught at New College of Florida, was a visiting Research Fellow at the University of Tokyo, and a Fulbright Fellow at Tohoku University. She is a member of the Mansfield Foundation's US-Japan Network for the Future and a 2019 National Asia Research Program Fellow with the National Bureau of Asian Research; she is also a nonresident fellow. From 2021 to 2022, she was an academic associate at the Harvard University US-Japan Program.

Debra W. Struhsacker
Women's Mining Coalition Co-Founder, Environmental Permitting & Government Relations Consultant

How Policies, Legislation, and Litigation Could Reduce Domestic Mining of Critical Minerals

This talk will explore the administrative policies, legislative initiatives, and a recent court ruling that will make mining on western public lands for minerals, including the critical minerals needed to build clean energy infrastructure and strengthen domestic critical mineral supply chains, more difficult. This discussion will focus on: 1) President Biden's Interagency Working Group to evaluate changes to hardrock mining regulations and the U.S. Mining Law; 2) House and Senate bills to overhaul the U.S. Mining Law; and 3) the recent U.S. Ninth Circuit Court of Appeals decision in the Rosemont litigation (Center for Biological Diversity et al. v. U.S. Fish and Wildlife Service et al.). The numerous federal environmental protection laws and financial assurance requirements for modern mines will be reviewed to demonstrate that upending the Mining Law is unnecessary to protect the environment. Suggestions for streamlining the mine permitting process will be offered.

Biography

Debra Struhsacker is a hard rock mining policy expert with over 30 years of hands-on expertise with the environmental and public land laws and regulations pertaining to mineral exploration and mine development. Since 1993, she has been an active participant in the legislative dialogue about changing the U.S. Mining Law when she and two other Reno-based geologists, Kathy Benedetto and Ruth Carraher, started the Women's Mining Coalition. Today, nearly 30 years later, the Coalition is recognized as one of the mining industry's most effective advocacy groups.

Debra has received numerous awards for her mining advocacy work including the American Exploration & Mining Association's 2021 Life Member award. She is one of 15 women featured in the National Mining Hall of Fame and Museum temporary exhibit entitled "Pioneering the Field: Women in Mining."

Debra serves on the Women's Mining Coalition's board and is an American Institute of Professional Geologists Certified Professional Geologist. She is a member of the Mining and Metallurgical Society of America; the Society for Mining, Metallurgy, and Exploration, Inc.; and the Geological Society of Nevada.

Ms. Struhsacker is a Phi Beta Kappa graduate of Wellesley College where she majored in both geology and French. She also has a Master of Science degree in geology from the University of Montana. She lives in Reno, NV.

Giovanni Andrea Blengini, *Politecnico di Torino*
Associate Professor, Environment, Land and Infrastructure Engineering

Critical minerals and the EU Green deal: demand, circularity, footprint

Starting from the EU's experience in periodically running criticality assessments and updating the list of CRMs for the EU every three years, the contribution will discuss on how sustainability of the supply chain is taken into account, directly or indirectly, in the assessment itself. The presentation will also build on how demand, circularity, carbon-footprint and sustainability aspects of the critical minerals supply chain interplay now and in the future as we transition to green energy.

Biography

Gian Andrea Blengini received an MSc in Mining Engineering from Politecnico di Torino, Italy (1994) and a Ph.D. in Earth resources from TU Lisbon, Portugal (2006).

Presently an Associate Professor at the Politecnico di Torino (TU Turin, Italy), where he leads the Life Cycle Assessment (LCA) research group and lectures on Life Cycle Assessment (LCA) and Resources & Environmental Sustainability at undergraduate, master, and postgraduate level.

He has been a senior researcher at the Joint Research Centre of the European Commission in the Land Resources Unit from October 2013 to October 2021, with the role of team coordinator in projects and activities: (1) in support of EC raw materials policies, with focus on critical raw materials and monitoring of Circular Economy, and (2) targeted to the EU Raw Materials Knowledge Base, including Life Cycle Inventory data availability, coherence, and quality.

Brett Carlson, *South Dakota School of Mines and Technology*
Assistant Professor, Materials and Metallurgical Engineering

Manganese: The Other Critical Material

Manganese (Mn) is an essential component for the steelmaking industry, with 800 thousand tons of this material consumed in the US for this purpose in 2019. Mn will also be an important component of the next-generation of electric vehicle (lithium-ion) batteries. Despite the criticality of this metal, there is no current US production. The lack of domestic Mn production has attracted attention at the highest levels, and the US executive branch has recently authorized the Defense Production Act to be used for the production of domestic production of five critical elements, including manganese. Because of its critical nature, it is necessary to consider non-traditional sources of this material, which will be the subject of this discussion.

Biography

Brett Carlson earned his undergraduate degree in Metallurgical Engineering from South Dakota Mines, and a Ph.D. in Materials and Metallurgical Engineering from the Colorado School of Mines, where he specialized in extractive metallurgy. He has worked in several industries, most recently as a Technology Transfer Fellow at the Steel and Metals Institute at Swansea University in the UK before joining the faculty at South Dakota Mines in the Materials and Metallurgical Engineering Department. Brett Carlson's research interests include recycling critical materials, bioleaching, and processing non-traditional feedstocks.

Samuel Kessinger, *South Dakota School of Mines and Technology*
PhD Student

Coltan Track and Trace Technologies

Following the enactment of the Dodd-Frank Act in 2010 (section 1502) US companies have been required to report utilization of conflict minerals from the Democratic Republic of Congo (DRC). The conflict mineral coltan, an ore consisting of elements tantalum and niobium, is central to Dodd-Frank legislation. Thus, track-and-trace methodologies are necessary to define the provenance of such conflict minerals. In the current research effort XRF (X-Ray Fluorescence) spectroscopy and LIBS (Laser Induced Breakdown Spectroscopy) have been used in tandem to identify elemental fingerprints of coltan samples with known provenances. Individual mineral spectra were used in conjunction with multiclass machine learning algorithms. It was demonstrated that the algorithms were able to classify samples,

using each sample's individual spectra, culminating in the determination of a sample's provenance.

Biography

Samuel Kessinger was born in Idaho and raised in South Carolina prior to heading west for higher education. Samuel attended The University of Wyoming for two years before completing a bachelor's degree in Metallurgical Engineering from the South Dakota School of Mines and Technology. He is currently completing a graduate degree in Materials Engineering from South Dakota Mines. His research interests include mineral processing and recycling, critical mineral supply chains, and track & trace technologies as applied to conflict minerals.

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