Testimony before the U.S. House of Representatives
Committee on Science, Space, and Technology

The Role of Federal Research in Establishing a Robust U.S. Supply Chain of Critical Minerals and Materials

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November 30, 2023

Chairman Lucas, Ranking Member Lofgren, and members of the committee, thank you for this opportunity to testify today.

Summary. A secure and resilient national supply of critical minerals and materials cannot be achieved without new domestic discoveries of critical mineral deposits. Benchmark Minerals (Benchmark Minerals, 2022) has estimated that about 300 new mines will be needed during the next decade alone. Most of these mines require new discoveries. Worldwide, more than $10 trillion (Kobold Metals, 2023) in new discoveries are needed by 2050, for batteries alone, to meet the goals set forward for the energy transition away from fossil fuels. My testimony documents that funding for research and development of critical mineral exploration by government agencies is presently insignificant. A secure, resilient and environmentally responsible critical mineral supply cannot be achieved in the United States with the current funding approach. Moreover, leaving exploration and mining to countries with lax environmental standards and unfair labor regulation is a global environmental justice concern, a responsibility we should not abdicate. Finally, I will provide recommendations on how this alarming situation can be addressed.

What is happening in critical minerals research in the United States now?

The United States, and its allies are strategically disadvantaged in developing a secure and resilient supply chain for its energy transition, in particular, for the upstream and midstream components, namely: discovery, mining & refining. In the past year, the White House has called for a serious rethink on how to achieve the needed supply (Bloomberg, 2023). Currently funding in research and development of mineral exploration by the NSF and the DOE does not provide the foundation for success in creating critical mineral supply chains. I will document the most important funding opportunities over last 3 years:

- The NSF announced, September 2023, awards for an ambitious new program: the NSF Global Centers. These centers are funded by large awards (up to $10 million), to collaborate with US allies, Australia, Canada and the UK across three main areas: critical minerals, energy & climate. A total of $76.4 million dollars in funding was announced. Almost all funding went to Energy and Climate projects; a single critical mineral supply award in Chile was funded at the level of $250,000. At the same time, the funded energy projects in green hydrogen, upgrading the electrical grid, and renewable energy require vast amounts of critical minerals. For example, efficient green hydrogen relies on metals of the platinum group elements, which today are sourced mostly from Russia and South Africa. The latter country has failed to condemn the invasion of Russia in the Ukraine. Building a resilient electrical grid will require large amounts of copper. The United States is mining an ever decreasing copper grade, now at 0.39% (for every ton of material displaced, we get only 15 ounces of copper; compare that with Zambia that gets close to 150 ounces). The last major copper discovery in the US was in 1995, almost 30 years ago.

- The Department of Energy funds multi-billion dollar projects in mining and battery manufacturing, but does not have programs dedicated to mineral exploration or characterization of the ores that are being mined and processed. I will provide three examples:

    - The DOE funded 17 projects in the MINER (Mining Innovations for Negative Emissions Resources) program. Innovation in mining is much needed and this program is an excellent start. However, the program focuses significantly on negative emissions, locking CO_2 in mining waste. First, tier 1 and 2 CO_2 emissions of the mining industry are less than 1% of the oil & gas industry. Secondly, prioritizing carbon dioxide removal research is a missed opportunity in the more urgent business of preventing CO_2 emission, much of which will rely on critical mineral discoveries.

    - The Critical Materials Innovation Hub is a U.S. DOE Energy Innovation Hub led by Ames National Laboratory that seeks to accelerate innovative scientific and technological solutions to develop resilient and secure supply chains for rare-earth metals and other materials critical to the success of clean energy technologies. Since CMI's inception, its researchers have published more than 580 scientific papers in scholarly journals. None of these papers focus on critical mineral exploration, while many on recycling. According to most experts, recycling technologies, for example for batteries, will not be needed until 2040.

- The DOE webpage last September where “the Biden-Harris Administration Announces $150 Million to Strengthen Domestic Critical Material Supply Chains”, does not include exploration or mentions exploration, new discoveries. The energy security mentioned cannot be achieved without more discoveries.

What does federal law say about research & development in critical minerals?

I’d like now to juxtapose the above with legislation passed by Congress: the CHIPS & Science Act & Energy Policy Act of 2020.

- Consulting the Chips act: sec. 10359. Critical minerals mining research and development, one will find that four out of the eight bullet points call for research and development of new ways of mineral exploration, including the use of artificial intelligence & machine learning, the study of ore forming processes (economic geology), geochemistry as well as providing training and research opportunities to undergraduate and graduate students. The FY24 appropriations process for the CHIPS & Science act is still ongoing. The Senate’s committee report for the Commerce, Justice, Science bill (which includes all funding for NSF) includes the following language: *the Committee encourages NSF to consider supporting critical minerals mining research and development activities as authorized under section 10359 of Public Law 117-167. In particular, NSF is encouraged to support, on a competitive basis, institutions of higher education or nonprofit organizations to provide training and research opportunities to undergraduate and graduate students to prepare the next generation of mining engineers and researchers.*

- Energy Policy Act of 2020. “The Energy Act represents the first modernization of our nation’s energy policies in well over a decade. This bipartisan package will foster innovation across the board on a range of technologies that are critical to our energy and national security, our long-term economic competitiveness, and the protection of our environment.” (Sen. Lisa Murkowski). “This bill incorporates much of the high-priority legislative work done by our Republican committee members in this Congress. Importantly, it recognizes that the most effective way to improve energy efficiency, reduce greenhouse gasses, and maintain U.S. energy independence is through technological innovations, which we can support by investing in basic and early-stage research.” Rep. Frank Lucas. Reading the portion on critical minerals, section 7002, one will find that Congress tasks the The Secretary of Energy (acting through the Assistant Secretary for Fossil Energy) with the “resource assessments for each critical mineral such that critical minerals considered to be most critical” and to “facilitate the availability, development, and environmentally responsible production of domestic resources to meet national material or critical mineral needs”, and “for actions to be taken to avoid supply shortages, mitigate price volatility, and prepare for demand growth", "workforce training for exploration and development of critical mineral resources".

It is clear that federal law on the matter calls for research and development of domestic supply, which can only be produced with new discoveries.

Debunking arguments against funding mineral exploration research

Several arguments are routinely offered countering the need for an increase in domestic mineral exploration and mining, and funding such activities.

- *We have enough critical minerals*. Media articles as well as government announcements often make it appear as if enough reserves are present in the US. A typical example is lithium. CBS 60 minutes reported that a bonanza of lithium is just for grabs in our backyard, the Salton Sea in California. However, a resource is not a reserve, the latter requires economic considerations. Lithium in Salton Sea geothermal brines is at a concentration of ~200 parts per million (ppm; compare that with Chilean brines of ~1400 ppm). Extracting lithium from such brines is termed Direct Lithium Extraction (DLE) and is part of projects funded by the DOE. This technology however has never made it beyond the pilot-scale stage, as dealing with large volumes of brines, containing many impurities remains challenging and a risky investment, relative to hard rock mining. Most research on extraction & processing techniques ignore the complexity and variability of real ore deposits, which is a geoscientific problem, needed to be quantified with in-situ data. Lithium is also extracted from clays, in the US most famously at the Thacker Pass project of Lithium Americas which recently broke ground with funding from the US government. However the Thacker Pass will only produce lithium for ~600,000 EVs per year, hardly making a dent in meeting the targeted future production of EVs in the US.

- *Friendshoring*. Australia and Canada are prolific producers of many of the important critical minerals. For example, Australia produces 55% of the world supply of Lithium, from hard rock lithium. However, the world's largest hard rock lithium mine, the Greenbushes is majority owned (51%) by the Chengdu Tianqui Industry Group of China. Australia exports all of its lithium ore to China for processing, only for it to be shipped back for further manufacturing. I participated in a roundtable discussion on batteries hosted by the Australian Trade Commission during the last APEC in San Francisco. Australia currently does not know or have plans to fund processing plants near its own mines. Compare that to

White House announcement earlier this year: “Prime Minister Albanese reiterated his support for President Biden’s request of Congress to add Australia as a “domestic source” within the meaning of Title III of the U.S. Defense Production Act, which would streamline technological and industrial base collaboration and build new opportunities for United States investment in the production and purchase of Australian critical minerals, critical technologies, and other strategic sectors.” If more than half of the world’s largest lithium mine, located in Australia, is owned by China, it could hardly be called a domestic resource.

- *Mining in the US is too destructive to the environment*. Mining indeed leaves a significant footprint to the local landscape as well as uses large amounts of water in areas affected by drought. However, not all mining is the same. High grade deposits can be mined using underground mining techniques, and the innovations in mining funded by the MINER program can be used to mine out only what is needed, using the latest robotics innovations. The main driver for environmental destruction today is the low grade at which deposits are mined, which requires large-scale open pit mining. The single most effective way to address this problem is the discovery of high grade deposits. Finally, leaving mineral exploration and mining to countries without any environmental or labor regulations will be destructive to the planet as a whole. Should the US export its responsibility to the Democratic Republic of the Congo, China or Russia?

- *No social license to operate in the US*. Local opposition and delay in permitting are key factors in the decline of domestic mining operations. Unfortunately local community engagement starts only at the construction of a mine, when it is too late to engage. Including social community engagement at the mineral exploration phase will help in determining whether local community consent can be obtained, and work with such communities is a collaborative fashion. Exploration should not just be geological, it should be social and environmental as well. Our Australian friends at the CSIRO (Australian NSF/DOE) have a long tradition of such engagement holding data from surveys of citizens and community members, as well as publicly available data to support automated stakeholder analysis, such as concept mapping, theme identification and topic framing of issues related to social acceptability of various activities across the critical mineral supply chain. Friendshoring the intelligence of local community engagement will be beneficial.

- *Replacement solutions*. A large amount of funding in the United States goes to research that aims at mitigating the critical mineral problem by replacing critical materials using more abundant minerals and materials. This is indeed important research, but not all materials can easily be replaced or on a time-scale that matters. Basic research in replacement materials takes several decades to make it into actual working products. The lithium-ion battery itself is a replacement for older technology such as lead-zinc batteries. It took 40 years for its discovery to make it to the mass market. Research published in Nature Energy (Gent et al. 2022) has shown that lithium in the right combination with nickel and cobalt provides, theoretically, the largest energy density combined with the best thermal stability. Theoretically here means according to the elements available in the "Table of Elements". God has given us a Table to work with; there are no other magical elements available that will do better than lithium, the third lightest elements in the Universe, according to the stated criteria. Sodium for example is touted as a replacement, yet, it is heavier and has much less thermal stability than lithium. The lithium-ion battery for light duty vehicles is here to stay for the next foreseeable future, any short term improvement in performance will come from better manufacturing. New materials ultimately only matter when they work in devices, such as cars, hence the ability to mass manufacture them is a critical point in the supply chain.

- *Recycling solves the supply problem*. Recycling is an absolute must to achieve a greener metal supply chain. Metals beat fossil fuels in this regard, as the waste of burning fossil fuel is put in the air. In the case of batteries, recycling is an important but not urgent matter, as car batteries will make their way in second and third lifes, for example in stationary energy storage. The lithium battery in a car may well be used for up to 20 years.

The United States is funding technological innovation in mining, processing, refining and manufacturing while it has not identified future domestic sources of critical metals. The government is funding dozens of recipes to make bread, but does not fund efforts to produce flour, yeast, sugar, and salt. Similarly, it provides farmers with new technologies, but no land for actual farming!

Environmental justice

According to the EPA environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. From an environmental justice perspective, a gap in understanding the ethical components of ramping up extractive enterprises that have disproportionate impacts on Indigenous peoples and their territories.

Technology to extract critical minerals from waste streams or from recycling, in combination with efforts to build out public transportation, or more efficient vehicles will aid in reducing the effects on indigenous and other affected communities. An environmental perspective is complementary to technology-focused research because it asks for researchers to engage directly with those who are most impacted on the production side. The recent DOE announcement mentioned above requires applicants to "explain how projects are expected to deliver economic and environmental benefits and mitigate impacts; conduct community and stakeholder engagement; incorporate diversity, equity, inclusion, and accessibility; and promote workforce development and quality jobs. Projects selected under this opportunity will be required to develop and implement strategies to ensure strong community and worker benefits, and report on such activities and outcomes."

Since the landscape of any future mining is not well known, federal research should focus on spatial planning (e.g. mapping) work with community-based organizations as partners in identifying and animating the conflicts over land-uses, water stress, and cumulative environmental hazard that deserve to be known transparently before a new extraction project proceeds. Targeting exploration to high grade deposits will also help in this regard.

Mineral-X and Kobold Metals

I now turn to what I believe are key needs to overcome the lack of investment in mineral exploration and make some recommendations. Mineral-X is a new program in critical mineral exploration and supply chains in the Stanford Doerr School of Sustainability. I founded this program less than a year ago. Mineral-X is now the only US research program in mineral exploration with committed funding in the millions of dollars. These dollars do not come from NSF or DOE funding. In fact all of our proposals have been declined by US government agencies, which makes sense as none have mineral discovery as a priority focus. As a consequence, our program is 90% funded by foreign venture companies, foreign mining companies, foreign geophysical exploration companies as well as a large foreign conglomerate corporation. But we are only getting started. During APEC, I was invited by Indonesians to personally present Mineral-X to the president of Indonesia, Joko Widodo. In collaboration with a large Indonesian mining conglomerate as well as the ministries in Indonesia, Mineral-X is starting conversations to use Mineral-X research for mineral exploration, mining and processing with a country that has the largest reserves of Nickel in the world as well as 40% of the world geothermal energy. Mineral-X collaborates with Xcalibur Multiphysics, a key player in the mineral exploration world that performs country scale geophysical imaging to assess mineral and other natural resources. It recently made deals with countries such as the Congo and Kazakhstan, all rich in minerals. Through our partner Bidra, we are starting collaboration with Morocco, producing 50% of the world's phosphorus, a key fertilizer without which there would not be enough food in the world, to optimize and clean up the mining and processing to produce phosphorus. We collaborate with Ideon, a Canadian start-up that has made breakthrough technology in harnessing solar rays (muons) to sense ore-bodies in three dimensions when they are not outcropping at the surface. The technology behind this, muon scattering tomography was first proposed by Chris Morris and his group at Los Alamos National Laboratory, but currently not employed in the US..

What has attracted the world's attention to the new Mineral-X program? To understand this, I'd like to go back to 2019, when I joined Kobold Metals as an unpaid external advisor, a small start-up company with an even smaller WeWork office in Berkeley, California. Kobold Metals became in 2022, the largest US mineral exploration company working on three continents and more than 60 assets, including obtaining a mining license in Zambia to develop its first copper mine (WSJ, 2022). That resource will be mined at 3.5% copper grade with an underground mine, a marked difference from the 0.39% in the US. Kobold Metals and Mineral-X have built technology that is founded on rigorous data science and (Vanity Fair, 2022; MIT Technology Review, 2021) comprehensive Artificial Intelligence (AI), turning a small start-up into a billion dollar company in less than four years. None of that technology today is used in the United States.

Artificial Intelligence will be the defining technology of the first half of this century. Artificial intelligence can broadly be seen as technology that uses computers to mimic problem-solving and decision-making capabilities of the human mind, and moreover, improve on it and perform the same tasks in milliseconds instead of months or years. Artificial Intelligence is fundamental to mineral exploration, not just a tool to enhance it. With Kobold Metals, Mineral-X is redefining mineral exploration as a science, combining elements of the geosciences, information science, decision science and AI to create computational methods that can accelerate critical mineral discovery. Kobold is drilling exploration holes and performing geological field work supported by AI, faster than any other company in the world. At the foundation lies the automated ingestion of vast amounts of data, with the goal of creating the google map of the Earth's crust. To weave these seemingly disconnected fields together, we use existing and develop entirely new AI algorithms & theory to solve mineral exploration problems. Our approaches require the development of fundamental science as well as practical algorithms that can be used by exploration and mining companies. While the White House has asked Congress and government agencies for a "rethink" in developing a resilient and secure domestic mineral supply chain, AI can bring revolutionary thinking along the entire critical mineral value chain and solve problems expert humans can't.

Recommendations

I hope to have provided convincing arguments that the NSF and DOE efforts in mineral exploration are lacking and that this may lead to a declining national security and energy independence in the long term. I have also provided evidence that mineral exploration is a hot interdisciplinary area of science that has attracted many foreign investors. Finally, I'd like to provide recommendations on how we can move ahead as a country to address the situation we find ourselves in today.

<u>A National Program to set the US up for success in critical mineral discovery & resulting supply</u>

National programs such as the Manhattan Project are successful because they bring the best scientists and engineers together to work on a single goal and with a single metric of success. Successful mineral exploration relies on a vertical integration of disparate disciplines into a single unified program. Kobold metals hires the best of Silicon Valley in data science & artificial intelligence as well as the world's best geologist in critical minerals, many with a +30 year track record of making major discoveries. The NSF and DOE funding models (for example the MINER program) spreads funding laterally over dozens of groups of Principal Investigators (PIs) without combining the work done in an individual project into a vertically integrated solution. The way some of US government funding works is the opposite of how the technology and business world is evolving. Agencies focus on a horizontal distribution of funding awards with individualized metrics of success, while the real world is accelerating towards vertical integration, often aided by AI, focusing on a unified outcome: better and faster than yesterday.

More specifically, I propose the following

- For Congress to fully fund the critical minerals mining research and development program authorized in the CHIPS & Science act, and to encourage partnerships with allied nations, Canada and Australia in a national program similar to the NSF Global Centers at the level of $25 million. This funding is likely to be supplemented by funding of the Australian and Canadian governments similar to what is an NSF Global Center.

- For NSF and DOE to create an interagency committee to oversee federal research and development on critical minerals exploration and mineral resource characterization research. This agency is already part of the critical minerals mining research and development provision in the CHIPS & Science act. Such an agency should be tasked to engage and consult with academic, industry, and environmental justice leaders. The interagency will be encouraged to include leaders from the environmental justice community in the US Government

- Research in this new program should focus on

- Building collaborations in mineral exploration between the USGS, state geological surveys and those universities who offer both a strong geosciences and computer science research program.

- Building collaborations in mineral exploration between the USGS and equivalent organizations in Australia and Canada, including those focusing on the environment.

- Fund interdisciplinary research that combines any of the following disciplines: geology, geophysics, data science, decision science and artificial intelligence in the advancement of discoveries on US soil.

- Fund research that integrates mineral resource characterization and uncertainty quantification into mining and mineral processing operations, with the purpose of reducing waste.

- Fund research and field work on the social license to operate as well as environmental justice concerns of mining, with a focus of starting such research at the mineral exploration phase.

- Develop educational programs, undergraduate and graduate that provide interdisciplinary courses on mineral exploration, next to fundamental courses in economic geology and geophysics.

- Develop environmental justice programs and field work where those working on critical mineral technology experience the impact of their technology on the environment and communities.

- Fund a computational and software infrastructure for data science and artificial intelligence algorithms to enable the generation of mineral resource evaluation, making mineral exploration in the US readily attractive to investors.

The Bipartisan Infrastructure Law provided a $510.7 million investment to the USGS to advance scientific innovation and map critical minerals, including through USGS's Earth Mapping Resources Initiative (MRI), a partnership between the USGS and state geological surveys to modernize our understanding of the nation's fundamental geologic framework and improve knowledge of domestic critical mineral resources both in the ground and in mine waste. Earth MRI is investing $74 million per year, of which $64 million comes from the Bipartisan Infrastructure Law. I have spoken with many members of the USGS over last year. The USGS has some of the world's best geologists, but the organization is not in position to comprehensively use data science and AI to achieve the vertical integration such as done in Kobold Metals. Scientists have shared that the USGS plans to hire data scientists and work with 3rd party software vendors, but such endeavor is likely not successful because it lacks the vertical integration required to make mineral discovery a success. It is also questionable that the USGS can compete with major tech companies in hiring the best talent in the field. My overall impression is that staff at the USGS is overwhelmed by a task that covers 50 states and more than 50 critical minerals.

Instead, it makes much more sense to enlist major geosciences & artificial intelligence programs within United States colleges and universities. Like at Stanford, geology students can collaborate with computer scientists at individual universities with PIs from both the geosciences/mining & AI. These efforts can be vertically integrated into a national effort covering many of the critical minerals as well as all of the 50 states. Alaska could be the initial focus, as a mining state it is rich in critical minerals such Cobalt, Copper and REE. The USGS has had a significant focus recently there via the Alaska Science Center, and the EarthMRI project is well underway in that state. In this way, we will make the US more attractive to mineral exploration and mining companies as high-quality data will become readily available and ingestible to do business with. At the same time it educates students in computer science/engineering about critical minerals, creating the future workforce in a sector that desperately needs one.

Education is one area where a change in mentality about mining will happen. Over the last year, I have met many computer science graduates who have become disillusioned with AI jobs that focus on consuming, toxic social media, computer games or even online gambling. Many of today's young graduates are looking to make meaningful contributions to the world that are cool, and make a living. Mining has a poor reputation, but the message of accelerating the mineral supply chain with AI is very attractive to them, when accompanied with a strong environmental justice footprint. The transformation of the mineral supply chain into a fully digital, automated and AI-assisted enterprise is likely to attract workers that would initially not have considered being part of it. Unfortunately, our proposal to provide education to the USGS using AI and data science in mineral exploration in the United States has been declined by the NSF, despite the fact that Mineral-X has written the book on data science for mineral exploration (Wang et al., 2023). Instead, next year, with the support of the State Department, I will travel to Zambia and teach AI and data science for mineral exploration to Zambian and Congolese government agencies and universities. Similar countrywide courses can be developed in the US and attract college students not in the geosciences/mining to this challenge. Critical minerals discovery is the 21st century challenge that is dying to meet the world best 21st century opportunity: artificial intelligence.

Jef Caers, San Francisco, CA, November 27, 2023

I'd like to thank Rod Ewing, Sibyl Diver, Holmes Hummel, Megan Artleth and Russel Wald of Stanford University for the valuable advice in writing this testimony.

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Jef Caers received both an MSc ('93) in mining engineering / geophysics and a PhD ('97) in mining engineering from the Katholieke Universiteit Leuven, Belgium. Currently, he is Professor of Earth and Planetary at Stanford University, California, USA, previously (1998-2015), a Professor of Petroleum Engineering. Jef Caers' research interests are decision making under uncertainty in developing the critical mineral supply as well as geothermal energy. Jef Caers is founder of Stanford Mineral-X, a community building effort to strengthen stewardship for a prosperous future for all, powered by Earth's minerals. From 1998 to 2022, Dr. Caers was Director of the Stanford Center for Earth Resources Forecasting, a period where he collaborated with 35+ oil/gas companies to advance quantitative decision making in the Exploration & Production.

Jef Caers has published in a diverse range of journals covering Mathematics, Statistics, Earth Sciences, Engineering and Computer Science. Jef Caers authored or co-authored five books entitled "Petroleum Geostatistics" (SPE, 2005) "Modeling Uncertainty in the Earth Sciences" (Wiley-Blackwell, 2011), "Multiple-point Geostatistics: stochastic modeling with training images" (Wiley-Blackwell, 2015), "Quantifying Uncertainty in Subsurface Systems (Wiley-Blackwell, 2018), "Data Science for the Geosciences" (Cambridge UP, 2023). He was awarded the Krumbein Medal of the IAMG for his career achievement.