THE ROLE OF FEDERAL RESEARCH IN ESTABLISHING A ROBUST U.S. SUPPLY CHAIN OF CRITICAL MINERALS AND MATERIALS

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

OF THE

HOUSE OF REPRESENTATIVES

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C O N T E N T S

November 30, 2023

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THE ROLE OF FEDERAL RESEARCH IN ESTABLISHING A ROBUST U.S. SUPPLY CHAIN OF CRITICAL MINERALS AND MATERIALS

THURSDAY, NOVEMBER 30, 2023

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Committee met, pursuant to notice, at 10:08 a.m., in room 2318 of the Rayburn House Office Building, Hon. Frank Lucas [Chairman of the Committee] presiding.

FULL COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HEARING CHARTER

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

Thursday, November 30, 2023
10:00 a.m.
2318 Rayburn House Office Building

Purpose

This hearing will explore the role that Federal research agencies can play in strengthening U.S. supply chains of the minerals and materials that are essential for U.S. energy independence and international competitiveness. This hearing will specifically examine relevant research, development, demonstration, and commercial application activities carried out by key research agencies like the U.S. Department of Energy and the National Science Foundation, among others. This hearing will provide members an opportunity to review the implementation status of critical minerals R&D provisions recently authorized in the Energy Act of 2020 and the CHIPS and Science Act of 2022.

Witnesses

- **Mr. Ryan Peay**, Deputy Assistant Secretary for the Office of Resource Sustainability, Office of Fossil Energy and Carbon Management, U.S. Department of Energy
- **Dr. Jef Caers**, Professor of Earth & Planetary Science and Director of Stanford Mineral-X, Stanford University
- **Mr. Drew Horn**, Chief Executive Officer, GreenMet
- **Dr. Dustin Mulvaney**, Professor of Environmental Studies, San Jose State University
- **Mr. Thomas E. Baroody**, President & Chief Executive Officer, K-Technologies, Inc.

Overarching Questions

- What are some fundamental and early-stage research and development challenges associated with extracting, recovering, and recycling of critical minerals and materials?
- How has recently enacted R&D legislation such as the Energy Act of 2020 and CHIPS and Science Act impacted the U.S.' ability to complete in the critical minerals and materials supply chain?

- When it comes to the future of U.S. critical mineral and materials security, what areas of research should Congress prioritize?
- How will emerging technology areas like artificial intelligence and machine learning impact our mineral security?

BACKGROUND

Critical minerals are non-fuel minerals like lithium, graphite, and cobalt, or materials that are essential to U.S. energy independence, national security, or economic growth, and which have a supply chain vulnerable to disruption.[1] With applications in healthcare, defense systems, smartphones, laptops, energy storage, and renewable energy technologies, these resources are essential to our modern way of life.

Despite substantial domestic reserves, a large proportion of the critical minerals used in the U.S. are sourced abroad. In fact, the U.S. is net import-reliant for approximately 31 of the 50 mineral commodities designated as critical by the U.S. Department of the Interior and relies completely on imports to supply 12 of these minerals.[2] This heavy dependence on foreign supply chains, including those of adversarial nations, creates alarming strategic vulnerabilities. Through years of investment and strategic partnerships, China now controls over 60% of worldwide production and 85% of processing capacity of critical minerals.[3] As a result, the U.S. has a 50% net import reliance on China for about 26 mineral commodities.[4]

Ensuring a stable U.S. supply of critical minerals and materials starts with encouraging responsible critical minerals production and use here at home. Federal research agencies like the U.S. Department of Energy (DOE) and the National Science Foundation (NSF) have a central role to play in reducing U.S. dependence on foreign sources of critical minerals by supporting domestic mineral development and innovation.

U.S. Department of Energy:

DOE stewards robust cross-cutting activities in critical minerals and materials research and development, which prioritize the creation of a circular supply chain through recycling, development of new alternatives through material sciences, and formation of new mineral resources through extraction. These activities are carried out through various offices including the Office of Fossil Energy and Carbon Management (FECM), the Office of Science (SC), the Office of Energy Efficiency and Renewable Energy (EERE), the Advanced Research Projects Agency (ARPA-E), and the Office of Manufacturing and Energy Supply Chains (MESC).

[1] "H.R.133 - 116th Congress (2019-2020): Consolidated Appropriations Act, 2021." *Congress.gov*, Library of Congress, 27 December 2020, https://www.congress.gov/bill/116th-congress/house-bill/133.

[2] "U.S. Reaches Highest Recorded Mineral Import Reliance." National Mining Association, 31 January 2023, https://nma.org/2023/01/31/u-s-reaches-highest-recorded-mineral-import-reliance/#:~:text=Of%20the%2050%20mineral%20commodities%20identified%20in%20the,import%20reliance%20greater%20than%2050%25%20of%20apparent%20consumption.

[3] Glaser, Bonnie S., and Abigail Wulf. "China's Role in Critical Mineral Supply Chains." *GMFUS*, German Marshall Fund, 2 Aug. 2023, www.gmfus.org/news/chinas-role-critical-mineral-supply-chains.

[4] U.S. Geological Survey, 2023, Mineral commodity summaries 2023: U.S. Geological Survey, 210 p., https://doi.org/10.3133/mcs2023.

Within FECM, DOE's Office of Resource Sustainability manages its critical minerals and rare earth element (REE) programs. This office prioritizes the development of new sources of critical minerals using unconventional feedstocks and legacy waste. In addition, the Office of Resource Sustainability advances the creation of novel technologies, which improve extraction and processing of critical minerals. Largely carried out by DOE's National Energy Technology Laboratory (NETL), FECM also supports R&D into the extraction, separation, and recovery of rare earth elements from coal.[5] Over the last ten years, NETL has progressed from its feasibility studies and partnered with universities such as the University of North Dakota, University of Kentucky, and West Virginia University to host pilot scale projects. These projects have demonstrated the use of coal-based materials to secure rare earth elements. Recently, DOE selected University of North Dakota and West Virginia University to host the Rare Earth Element Demonstration Facility, which will develop a first of its kind rare earth and critical minerals extraction and separation facility.[6]

Through EERE, DOE hosts the Critical Materials Institute (CMI) Energy Innovation Hub at Ames National Laboratory. CMI brings together industry, universities, and the national laboratories – including Oak Ridge, Lawrence Livermore, and Idaho National Laboratory – to address fundamental critical materials science challenges. Through the CMI, DOE supports crosscutting research in four key areas, including critical material reuse and recycling, the development of novel material substitutes, the creation of new research tools, and broadening of the supply chain.[7] Moreover, CMI strives to transfer innovations and technological breakthroughs from the lab to the market. In addition, EERE supports related R&D activities in vehicle technologies, renewable energy technologies, and advanced materials and manufacturing technologies. For instance, the Office of Geothermal Technologies advances R&D activities involving the extraction of critical minerals from geothermal brines.[8]

MESC manages programs relating to the critical minerals and materials supply chain. Authorized and appropriated in the Infrastructure, Investment, and Jobs Act (IIJA), MESC manages the Battery Manufacturing and Recycling Grants, Battery Materials Processing Grants, and Battery and Critical Mineral Recycling programs. These programs support the development of a domestic battery ecosystem in the United States and the recycling of these materials as well. For example, the Battery and Critical Mineral Recycling program advances the extraction or recovery of critical minerals from batteries, which creates a closed loop supply chain.[9]

Similarly, other DOE offices like SC and ARPA-E play an important role in DOE's critical materials R&D activities. SC's Basic Energy Sciences program has expertise in material sciences, chemical sciences, geosciences, and biosciences, which is essential to understanding these materials and their properties. SC's National Laboratories and their user facilities prioritize

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[5] "Report on Rare Earth Elements from Coal and Coal Byproducts." *Energy.Gov*, 2 Feb. 2017, www.energy.gov/fecm/articles/rare-earth-elements-report-congress.

[6] "Funding Notice: Bipartisan Infrastructure Law: Rare Earth Element Demonstration Facility." Energy.Gov, 4 Apr. 2023, www.energy.gov/fecm/funding-notice-bipartisan-infrastructure-law-rare-earth-element-demonstration-facility.

[7] "About the Critical Materials Innovation Hub." *Ameslab.gov*, https://www.ameslab.gov/cmi/about-critical-materials-institute

[8] "U.S. Department of Energy Awards $2 Million for Innovations to Source Domestic Lithium From Geothermal Brines." *Energy.gov*, 19 September 2023, https://www.energy.gov/eere/articles/us-department-energy-awards-2-million-innovations-source-domestic-lithium-geothermal

[9] "Biden-Harris Administration Announces $192 Million to Advance Battery Recycling Technology" *Energy.gov*, 12 June 2023, https://www.energy.gov/articles/biden-harris-administration-announces-192-million-advance-battery-recycling-technology

basic research along with the creation of new technologies and processes. Meanwhile, ARPA-E has one main program dedicated to advancing mineral production. Known as MINER, the Mining Innovations for Negative Emissions Resources program seeks to increase mineral yields through reprocessing while reducing carbon emissions. To date, ARPA-E has awarded over $39 million to 16 projects, which include universities, national laboratories, and companies.[10]

National Science Foundation:

The National Science Foundation has regularly funded proposals on fundamental research to facilitate the discovery, characterization, extraction, and separation of critical minerals. This research is key to ensuring the availability of essential metals and rare earth elements required to achieve a clean-energy future. The CHIPS and Science Act of 2022 directed NSF to fund basic research that will accelerate innovation and advance critical mineral mining strategies and technologies to support supply chain resilience by increasing the efficient use of domestic resources. In addition to funding research proposals, NSF also supports the education and workforce training necessary to prepare the next generation of mining engineers and researchers. However, the industry has seen a 39% drop in graduations from domestic degree-granting programs. In 1982, there were 25 mining and mineral engineering programs in the United States. In 2023, there are only 14 accredited mining engineering schools. These remaining institutions will be crucial to filling the estimated 221,000 jobs needed by 2029.[11]

Recent Legislation:

In the Energy Act of 2020, Congress authorized many of DOE's research and development activities in this space, including the research and development of alternatives to, recycling of, and efficient production and use of critical materials (activities which may be carried out by DOE's critical materials Energy Innovation Hub.) Importantly, the law requires the executive branch to designate a list of critical minerals and update that list every three years.. In addition, the Energy Act of 2020 directs the National Science Foundation to develop curriculum for institutions of higher education to build a strong critical minerals workforce.[12]

In 2021, the IIJA expanded on Energy Act of 2020 critical minerals authorizations while appropriating over $800 million for these programs and activities like the DOE Rare Earth Element Demonstration Facility. In addition, the IIJA gave DOE's Loan Program Office new authority to provide financing to critical mineral projects involving production, processing, manufacturing, recycling, and fabrication of mineral alternatives. In January of 2023, DOE awarded Ioneer a $700 million loan for a lithium carbonate plant in Nevada.[13]

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[10] "Press Release: U.S. Department of Energy Announces $39 Million for Technology to Grow the Domestic Critical Minerals Supply Chain and Strengthen National Security." *Arpa e*, 27 Oct. 2022, arpa-e.energy.gov/news-and-media/press-releases/us-department-energy-announces-39-million-technology-grow-domestic.

[11] Hale, Thomas. "The United States Needs More than Mining Engineers to solve Its Critical Mineral Challenges." *Center for Strategic and International Studies*, 8 May 2023, https://www.csis.org/analysis/united-states-needs-more-mining-engineers-solve-its-critical-mineral-challenges#:~:text=The%20workforce%20and%20talent%20gap,2029%20(roughly%20221%2C000%20workers).

[12] "H.R.133 - 116th Congress (2019-2020): Consolidated Appropriations Act, 2021." *Congress.gov*, Library of Congress, 27 December 2020, https://www.congress.gov/bill/116th-congress/house-bill/133.

[13] Shah, Jigar. "LPO Announces Conditional Commitment to Ioneer Rhyolite Ridge to Advance Domestic Production of Lithium and Boron, Boost U.S. Battery Supply Chain." *Energy.Gov*, 13 Jan. 2023, www.energy.gov/lpo/articles/lpo-announces-conditional-commitment-ioneer-rhyolite-ridge-advance-domestic-production#:~:text=The%20U.S.%20Department%20of%20Energy's,Project%20(Rhyolite%20Ridge)%20in%20Esmeralda.

In the CHIPS and Science Act of 2022, Congress authorized the Carbon Materials Science Initiative: it directs the Office of Science to coordinate research activities with the Office of Fossil Energy and Carbon Management pertaining to the extraction and processing of coal and carbon-based compounds. This partnership will accelerate FECM's current research and development activities as it secures critical minerals from untraditional feedstocks. In addition, CHIPS and Science created a Critical Materials Interagency Subcommittee housed under the National Science and Technology Council. Its goal is to coordinate between various agencies to ensure a reliable critical minerals supply chain and provide recommendations for future programs and activities. Also, the law authorized two NSF programs: Critical Minerals Mining Research and Development program, and Carbon Materials Research Centers. The former will provide grants to universities to fund basic research involving critical minerals and examine the use of artificial intelligence and machine learning in this space. Likewise, the Director of NSF will establish two Carbon Materials Research Centers, which will support early-stage research and development activities.[14]

[14] "H.R. 4346 – 117th Congress (2021-2022): CHIPS and Science Act." *Congress.gov*, Library of Congress, 9 August 2022, https://www.congress.gov/bill/117th-congress/house-bill/4346?q=%7B%22search%22%3A%22chips+and+science+act+hr+4346%22%7D&s=4&r=1

Chairman LUCAS. The Committee will come to order. Without objection, the Chair is authorized to declare recess of the Committee at any time.

Welcome to today's hearing entitled "The Role of Federal Research in Establishing a Robust U.S. Supply Chain of Critical Minerals and Materials." And I recognize myself for an opening statement.

Good morning. Today, the Science Committee will examine the role that the Federal research agencies can play in developing a robust domestic supply chain of critical minerals and materials. Critical minerals like lithium, graphite, cobalt are essential to our Nation's, our country's energy independence, national security, and economic growth. With applications in healthcare, defense systems, smartphones, and advanced energy technologies, these resources are essential to our modern way of life and our clean energy future.

Despite substantial domestic reserves, an alarming majority of the critical minerals used in the United States are sourced abroad. In fact, the United States has a net import reliance of over 50 percent of 31 of the 50 mineral commodities designated as critical by the U.S. Department of Interior and relies completely on imports to supply a dozen of these commodities. This heavy dependence on foreign supply chains, including those of adversarial nations, puts the United States and its allies at risk.

Today, China controls 60 percent of worldwide production and 85 percent of the processing capacity of critical minerals. As a result, the United States has a 50 percent net import reliance on China for about 26 mineral commodities. As more advanced technologies enter the marketplace, we can only expect the global demand for critical minerals to increase. It's never been more important to protect ourselves by developing sustainable supply chains for these critical resources both domestically and with like-minded allies. Ensuring a stable U.S. supply of critical minerals and materials starts with encouraging responsible production and the use here at home.

Federal research agencies like the U.S. Department of Energy (DOE) and the National Science Foundation (NSF) have a central role in reducing U.S. dependence on foreign resources of critical minerals by supporting domestic mineral development and innovation. Just as DOE lead the way to the shale revolution through innovation and advanced technologies, the Department stewards important research in critical minerals and materials research and development (R&D). DOE prioritizes the development of new mineral alternatives through innovation in material sciences, the creation of a circular supply chain through recycling, and the identification of new mineral resources through advanced extraction approaches. These cross-cutting activities are carried out through various offices within the Office of Fossil Energy and Carbon Management, the Office of Science, and the Office of Energy Efficiency and Renewable Energy, just to name a few.

In 2013, the Department created the Critical Minerals Institute of Ames National Laboratory to accelerate solutions to the supply chains of critical minerals. This consortium of industry, academia, and National Labs allows for their individual expertise to come together to tackle the most difficult challenges facing this sector.

Recently, the Department has also started a Mine of the Future program, looking into major technology gaps in the Federal Government's supply chain of these materials and how to address them. I look forward to hearing from our DOE witness on how this initiative is progressing.

Similarly, the National Science Foundation funds basic research and STEM (science, technology, engineering, and mathematics) education initiatives to advance critical mineral mining technologies and strategies to better utilize existing domestic resources. However, the United States is facing a workforce gap that will hamper our goals of securing our domestic supply chains. It is imperative that we continue to support and nurture talent in every community across the country.

The ongoing activities at NSF are an important part of the whole-of-government approach to securing the domestic supply chain of critical minerals and materials. The Committee has prioritized Federal critical minerals R&D in recent years by providing updated guidance to both DOE and NSF through the *Energy Act of 2020* and the *CHIPS and Science Act of 2022.* I look forward to hearing from my colleagues on both sides of the aisle as we continue to review the Administration's implementation of these important laws.

A robust domestic supply chain of critical minerals is important not only for U.S. national security and economic growth, but for global environmental stewardship and humanitarian efforts. Through innovation in advanced critical materials technologies, we can increase domestic production of critical minerals and materials, while minimizing our need to outsource this work to other countries that do not share our core values or standards.

I'm looking forward to speaking with our panel of experts on how we in Congress can ensure that the United States regains its footing in this field, and I want to thank our witnesses for their testimony, and I look forward to a very productive discussion.

[The prepared statement of Chairman Lucas follows:]

Good morning. Today, the Science Committee will examine the role that Federal research agencies can play in developing a robust domestic supply chain of critical minerals and materials.

Critical minerals like lithium, graphite, and cobalt are essential to our country's energy independence, national security, and economic growth. With applications in healthcare, defense systems, smartphones, and advanced energy technologies, these resources are essential to our modern way of life and our clean energy future.

Despite substantial domestic reserves, an alarming majority of the critical minerals used in the U.S. are sourced abroad. In fact, the U.S. has a net import-reliance of over 50 percent for 31 of the 50 mineral commodities designated as critical by the U.S. Department of Interior and relies completely on imports to supply a dozen of these commodities.

This heavy dependence on foreign supply chains, including those of adversarial nations, puts the United States and its allies at risk. Today, China controls over 60 percent of worldwide production and 85 percent of the processing capacity of critical minerals. As a result, the U.S. has a 50 percent net import reliance on China for about 26 mineral commodities.

As more advanced technologies enter the marketplace, we can only expect the global demand for critical minerals to increase. It has never been more important to protect ourselves by developing sustainable supply chains for these crucial resources both domestically and with like-minded allies.

Ensuring a stable U.S. supply of critical minerals and materials starts with encouraging responsible production and use here at home. Federal research agencies like the U.S. Department of Energy (DOE) and the National Science Foundation

(NSF) have a central role to play in reducing U.S. dependence on foreign sources of critical minerals by supporting domestic mineral development and innovation.

Just as DOE led the way to the shale gas revolution through innovation in advanced technologies, the Department stewards important research in critical minerals and materials research and development. DOE prioritizes the development of new mineral alternatives through innovation in material sciences, the creation of a circular supply chain through recycling, and the identification of new mineral resources through advanced extraction approaches.

These cross-cutting activities are carried out through various offices including the Office of Fossil Energy and Carbon Management, the Office of Science, and the Office of Energy Efficiency and Renewable Energy, just to name a few.

In 2013, the Department created the Critical Materials Institute at Ames National Laboratory to accelerate solutions to the supply chains of critical materials. This consortium of industry, academia, and the National Labs allows for all their individual expertise to come together and tackle the most difficult challenges facing the sector.

Recently, the Department has also started a “Mine of the Future” program looking into the major technology gaps in the federal government’s supply chain of these materials and how to address them. I look forward to hearing from our DOE witness on how that initiative is progressing.

Similarly, the National Science Foundation funds basic research and STEM education initiatives to advance critical minerals mining strategies and technologies to better utilize existing domestic resources.

However, the United States is facing a workforce gap that will hamper our goals of securing our domestic supply chains. It is imperative that we continue to support and nurture talent in every community across the country.

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A robust domestic supply chain of critical minerals is important not only for U.S. national security and economic growth, but also for global environmental stewardship and humanitarian efforts.

Through innovation in advanced critical minerals technologies, we can increase domestic production of critical minerals and materials while minimizing our need to outsource this work to other countries that do not share our core values and standards.

I’m looking forward to speaking with our panel of experts about how we in Congress can ensure that the United States regains its footing in this field.

I want to thank our witnesses for their testimony today, I look forward to a productive discussion.

Chairman LUCAS. I now recognize the Ranking Member, the gentlewoman from California, Ms. Lofgren, for an opening statement.

Ms. LOFGREN. Well, thank you, Mr. Chairman, and good morning to all of our witnesses. This is an important hearing, and I want to take a moment of personal privilege to, among all these great experts, note that Dr. Mulvaney is right from San Jose State University in my district. He’s one of the Nation’s foremost experts on energy technologies supply chains, has published extensively on those subjects. And I know that it’s a hassle to get here from San Jose, so I certainly appreciate your being here, along with the other excellent witnesses.

As we know, this Science, Space, and Technology Committee has played a leading role in addressing our needs for a sustainable supply of critical materials through contributions to the *CHIPS and Science Act* and, in particular, the *Energy Act of 2020,* which guided most of the funding for these activities provided in the *Infrastructure Investment and Jobs Act.*

As a nation, we’re moving quickly, as quickly as we possibly can, to reach our goal of net zero emissions to address the climate crisis.

But to do that, we need to rapidly scale a broad suite of clean energy technologies that include, for example, the hydrogen electrolyzers supporting the regional hydrogen hub network, which I'm happy to say will include California, and the batteries used in many electric vehicles (EVs). However, several of these technologies are currently dependent on critical materials from nations that unfortunately, are not our friends.

Thanks in no small part to our recent bipartisan legislative efforts, we started on the path to addressing the climate crisis and our clean energy future, but that future is threatened and our progress may well be halted if we do not have a sustainable supply of critical materials to build these technologies.

To that end, I'm encouraged by the progress that the Department of Energy has made to identify the specific materials threatening our clean energy supply chains, and I'm particularly happy to see the Department's promotion of research into innovative solutions to improve manufacturing efficiency, recycling, and the use of more abundant alternatives that can save significantly reduce our need for these materials going forward. These efforts show that we can protect the environment and strengthen our economy at the same time, and there's no good reason for our Nation to make a false choice here.

I also applaud recent announcements from the national labs that have been hard at work researching domestic sources of critical minerals. Just last week, an analysis conducted by Lawrence Berkeley National Lab just up the road from my district found that the California Salton Sea has a significant potential as a domestic source of lithium with enough of this critical material to support 375 million batteries for electric vehicles. That discovery may prove to be critical as we move forward to our efforts to wean ourselves from a fossil fuel world.

The bottom line is that we have to continue to work toward securing a sustainable supply of the materials we'll need to tackle the climate crisis head on. But at the same time, all of the communities that we deserve, certainly—we serve certainly deserve to live in a safe and healthy environment, and I think this hearing is a good step toward striking that balance. We—as we move forward to develop domestic supplies, we need to be mindful of the impact on communities and how those impacts can be reduced or eliminated.

I look forward to today's conversation, and again, Mr. Chairman, I thank you and the witnesses for what I am sure will be an enlightening morning. And I yield back.

[The prepared statement of Ms. Lofgren follows:]

Good morning and thank you, Chairman Lucas, for holding this very important hearing. I thank the witnesses for being here today, including my very own district's Dr. Mulvaney. As you know, the Science, Space, and Technology Committee has played a leading role in addressing our needs for a sustainable supply of critical materials through contributions to the *CHIPS and Science Act,* and in particular through the *Energy Act of 2020*—which guided much of the funding for these activities provided in the *Infrastructure Investment and Jobs Act.*

As a nation, we are moving as quickly as possible to reach our goal of net-zero emissions to address the climate crisis. But to do that, we need to rapidly scale a broad suite of clean energy technologies that include, for example, the hydrogen electrolyzers supporting the regional hydrogen hub network, and the batteries used in many electric vehicles. However, several of these technologies are currently dependent on critical materials from nations that, unfortunately, are not always our friends.

Thanks in no small part to our recent bipartisan legislative efforts, we've started on the path to addressing the climate crisis and enabling our clean energy future. But that future is threatened, and our progress may well be halted if we do not have a sustainable supply of critical materials to build these technologies. To that end, I am encouraged by the progress that the Department of Energy has made to identify the specific materials threatening our clean energy supply chains.

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The bottom line is that we must continue to work diligently towards securing a sustainable supply of the materials we'll need to tackle the climate crisis head-on. But at the same time, all of the communities that we serve certainly deserve to live in safe and healthy environments, and this hearing is a good step towards striking that balance. As we move forward to develop domestic supplies, we need to be mindful of the impact on communities and how those impacts can be reduced or eliminated.

I look forward to today's conversation, and thank the witnesses again for being here today. I yield back.

Chairman LUCAS. The gentlelady yields back. And, as always, I appreciate her comments.

Let me introduce our witnesses for today's hearing. Our first witness today is Mr. Ryan Peay. Mr. Peay is the Deputy Assistant Secretary for the Office of Resource Sustainability at the Department of Energy's Office of Fossil Fuel and Carbon Management.

Our second witness witnesses Mr. Jef Caers. Mr. Caers, he is a Professor of Earth and Planetary Science, as well as the Director of the Stanford Mineral-X at Stanford University.

Our third witness is Mr. Drew Horn, the CEO (Chief Executive Officer) of GreenMet.

Our fourth witness is Mr. Dustin Mulvaney, a Professor of Environmental Studies at San Jose State University.

And I'd now like to recognize the gentleman from Florida to introduce our final witness.

Mr. FRANKLIN. Thank you, Mr. Chairman. I'm pleased to introduce our next witness, Mr. Thomas Baroody, the President and CEO of K-Technologies also known as K-Tech. With his engineering background, he's held numerous leadership roles in mining and chemical processing companies before starting his own business. K-Tech is based in Lakeland, Florida, which is in my home district, and is a shining example of the innovation that comes from the private sector to strengthen our critical mineral supply chain.

Under Mr. Baroody's leadership, his team has been focusing on processing techniques such as continuous ion exchange and continuous ion chromatography to extract rare earth elements (REEs) and minerals. And, as Members of this Committee know, the United States is in a race against our adversaries to secure the minerals and processing technology in this sector. Critical minerals are essential for advancing our domestic production of semiconductors, weapons systems, and new technologies.

For those who don't know, Florida plays a significant role in feeding our Nation, not only with agricultural products, but also by producing fertilizer. There are some challenges, though, with the storage and the management of the byproducts from the mining that produces that. But through these new extraction technologies, these byproducts from the mining can be harnessed instead of importing these minerals from overseas.

I look forward to hearing from Mr. Baroody about the role of small businesses in unleashing domestic minerals to support our economy and our national security.

Thank you, Mr. Chairman. I yield back.

Chairman LUCAS. I thank the gentleman for that introduction.

I now recognize Mr. Peay for five minutes to present his testimony. You may proceed, sir.

TESTIMONY OF MR. RYAN PEAY, DEPUTY ASSISTANT SECRETARY FOR THE OFFICE OF RESOURCE SUSTAINABILITY, OFFICE OF FOSSIL ENERGY AND CARBON MANAGEMENT, U.S. DEPARTMENT OF ENERGY

Mr. PEAY. Good morning, Chairman Lucas, Ranking Member Lofgren, and esteemed Members of the Committee. Thank you for the opportunity to testify before you today and discuss DOE's work on critical minerals and materials.

Demand for new clean energy technologies, aerospace and defense technologies, and consumer electronics, to name a few, will continue to put pressure on the supply chain for critical minerals, materials, and rare earth elements. China maintains a dominant position in the midstream processing capabilities for several different critical materials. Dependence on a single source for these materials leaves the United States and our allies vulnerable. We must ensure sufficient worldwide supplies of critical materials from responsible sources to protect U.S. national security and enable a clean energy and industrial economy.

However, that alone will not be sufficient to establish resilient supply chains. A lack of processing and refining capabilities often poses a greater risk to supply than the sources themselves. This provides both a challenge and an opportunity for the United States to diversify supply chains, improve labor and environmental standards, and create new technologies that can be deployed domestically. DOE's Critical Materials Research, Development, Demonstration, and Deployment Program is meeting this challenge with a strategy consisting of five pillars: diversify and expand supply, develop alternatives, materials and manufacturing efficiency, circular economy, and enabling activities.

To implement this strategy across the Department, we have created the Critical Materials Collaborative to integrate applied RDD&D (research, development, demonstration, and deployment) to accelerate the development of transformational technologies that will be foundational to domestic critical material supply chains.

There are four main methods to diversify supplies of critical materials: recycling, recovery from secondary and unconventional feedstocks, responsible domestic mining, and assessing a broader range of international sources. Two areas I want to focus in on are unconventional feedstocks and the future of mining.

Secondary and unconventional feedstocks encompass many potential sources, such as coal and coal byproducts, coal waste, hard rock mine tailings, and acid mine drainage. There are billions of tons of coal waste and coal ash that had been generated over the past two centuries and remain in waste piles and impoundments. These feedstocks represent a significant opportunity to diversify the supply of resources, while remediating longstanding environmental impacts and creating jobs in mining and energy communities.

There is also a real need for new and innovative approaches to the future of domestic mining. That is why DOE is evaluating the potential for research to advance technological solutions and revolutionize mining that uses a more surgical approach to extract minerals in a manner that minimizes surface and environmental impacts and improves public confidence in responsible mining techniques.

Technology development areas for a Mine of the Future program would include advanced drilling technologies, novel geophysics, digital subsurface applications, and situ mineral extraction, novel processing and tailings management. Analytical support activities, including data collection and developing a traceability capability are also critical.

Mr. Chairman, critical minerals and materials are crucial to the way we live our lives every day. They are required in a wide range of strategic industries. U.S. reliance on foreign sources for these materials is neither sustainable, nor secure. Further investments and efforts to diversify domestic supply chains, develop the Mine of the Future, and other research will help the U.S. meet our domestic and global supply and security needs and protect U.S. consumers in the competitiveness of domestic industry and manufacturing.

I appreciate the Committee for its bipartisan support of our critical materials research over many years, and I look forward to your questions.

[The prepared statement of Mr. Peay follows:]

Testimony of Ryan Peay

Deputy Assistant Secretary for Resource Sustainability

Office of Fossil Energy and Carbon Management

U.S. Department of Energy

before the

House Committee on Science, Space, and Technology

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

November 30, 2023

Chairman Lucas, Ranking Member Lofgren, and esteemed Members of the Committee, thank you for the opportunity to testify before you today. My name is Ryan Peay, and I am the Deputy Assistant Secretary for Resource Sustainability in the Office of Fossil Energy and Carbon Management (FECM) at the Department of Energy (DOE). I appreciate the opportunity to be here today and discuss with you DOE's work to advance technologies and approaches to ensure secure domestic critical minerals and materials (CMM) supply chains.

The U.S. Geological Survey (USGS) has identified 50 critical minerals for multiple economic sectors.[1] Critical minerals are defined in the Energy Act of 2020 as "any mineral, element, substance, or material designated as critical by the Secretary [of the Interior]."[2] Under the Act, critical minerals are essential to U.S. economic or national security; vulnerable to supply chain disruptions; and serve an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economic or national security of the United States.[3] Congress specifically excluded "fuel minerals" from the definition of critical minerals.[4] For 31 of these critical minerals, the U.S. relies on other countries for more than 50 percent of our requirements, and we rely entirely on foreign sources for more than a dozen of these minerals.[5] Our current reliance on foreign sources for critical minerals is made more challenging as the world transitions to a clean energy and industrial economy.

In response to these challenges, President Biden signed Executive Order 14017, *America's Supply Chains*, on February 24, 2021, directing each department in the administration to assess potential supply-chain risks within their jurisdiction and develop strategies to mitigate and

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[1] U.S. Geological Survey. 2022 Final List of Critical Minerals. Federal Register. February 24, 2022. Available at https://www.federalregister.gov/documents/2022/02/24/2022-04027/2022-final-list-of-critical-minerals
[2] 30 U.S.C. 1606(a)(3)(A).
[3] 30 U.S.C. 1606(c)(4)(A).
[4] 30 U.S.C. 1606(a)(3)(B)(i).
[5] U.S. Geological Survey. Mineral Commodity Summaries 2023. 2023. Available at https://pubs.usgs.gov/publication/mcs2023

overcome these deficiencies.[6] This Executive Order expands work previously directed in EO 13953, *Addressing the Threat to the Domestic Supply Chain from Reliance on Critical Minerals from Foreign Adversaries and Supporting the Domestic Mining and Processing Industries* from September 30, 2020.[7] In addition, in October of 2022, President Biden announced the new American Battery Materials Initiative. The ABMI is a DOE-coordinated interagency effort to secure the minerals and materials needed for everything from batteries to defense systems. It works to coordinate federal investment across the interagency to meet the Administration's short- and long-term critical minerals goals; support policies and solutions to solve the biggest critical mineral supply chain chokepoint—minerals processing; and align responsible mining and processing standards.

In February of 2022, DOE released a report titled *America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition*, followed by a Critical Materials Assessment in July of this year.[8] DOE designated our Critical Materials List based on the definition in the Energy Act of 2020 and the results of the Assessment, which determined criticality based on the potential for supply risk and importance to energy supply chains in the short (2020-2025) and medium (2025-2035) terms. The Critical Materials List includes all of the critical minerals on the 2020 USGS list and because of differences in mandate and methodology, includes four additional critical materials that were identified based on projected future needs for energy applications. These additional materials include copper, electrical steel, silicon, and silicon carbide. It is expected that DOE's list will be updated every few years, as well as the USGS list which will be updated every three years, as requirements for critical minerals and materials are inherently dynamic.

To meet the projected demand for CMMs, the U.S. must develop multiple sources (upstream) for critical materials. However, that alone will not be sufficient to establish resilient supply chains. A lack of processing and refining capabilities (midstream), as well as manufacturing (downstream), often poses a greater risk to supply chain robustness than the sources themselves. For example, the U.S. mines the largest amount of rare earth elements (REEs) of any country other than the People's Republic of China (PRC), but we ship much of our REE concentrate to the PRC for future processing and refining.[9] For most critical materials, midstream processing represents the greatest U.S. challenge.

The PRC maintains a dominant position in the midstream processing capabilities for several different critical materials, including REEs, graphite, and cobalt. By intervening in each stage of the supply chain for over three decades, PRC non-market policies and practices and resulting market distortions have made it very difficult for midstream processing capabilities to be built in the U.S. or other countries. Dependence on a single source for these materials leaves the U.S.

[6] Executive Order on America's Supply Chain. February 24, 2021. Available at https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains/

[7] https://www.govinfo.gov/content/pkg/FR-2020-10-05/pdf/2020-22064.pdf

[8] https://www.energy.gov/policy/articles/americas-strategy-secure-supply-chain-robust-clean-energy-transition; https://www.energy.gov/sites/default/files/2023-05/2023-critical-materials-assessment.pdf

[9] https://pubs.usgs.gov/periodicals/mcs2023/mcs2023.pdf; https://mpmaterials.com/articles/mp-materials-reports-second-quarter-2023-results/

and our allies vulnerable. Therefore, we must ensure sufficient worldwide supplies of critical materials from responsible sources to protect U.S. national security and enable a clean energy and industrial economy.

With expected demand growth for critical materials to increase by four to six times over the next three decades, no single country will be able to satisfy global demand. This situation provides both a challenge and an opportunity to diversify critical material supply chains, improve labor and environmental standards worldwide, and create new technologies that can be deployed domestically. For the U.S. to be globally competitive, we should lead on innovation to develop sustainable approaches to our domestic critical material supply chains across the entire innovation pipeline, increasing efficiency and circularity while driving down environmental and health impacts.

DOE's Critical Materials Research, Development, Demonstration, and Deployment (RDD&D) program seeks to develop reliable, resilient, affordable, diverse, sustainable, and secure domestic critical mineral and material supply chains with a strategy consisting of five pillars: (1) diversify and expand supply; (2) develop alternatives; (3) materials and manufacturing efficiency; (4) circular economy; and (5) enabling activities.

- Diversify and expand supply: Identifying new feedstocks for CMMs, including secondary sources such as wastes from coal and hard rock mining and industrial processes, as well as expanding traditional sources from existing mining and international partners.
- Develop alternatives: Developing new materials, components and systems as replacements that can reduce or eliminate dependence on critical materials.
- Material and manufacturing efficiency: Designing mining, processing, refining, and manufacturing technologies that require less energy, water, heat, and chemical inputs; produce fewer environmental impacts; and generate little to no waste containing critical materials.
- Circular economy: Reducing the need for new CMM supply by enabling reuse and recycling of materials and extending their lifetime when in use.
- Enabling activities: Continued and accelerated interagency efforts to solidify the impact of our work are key to DOE's strategy. These efforts include the development of strong international environmental and labor standards for critical material supply chains, robust life cycle and technoeconomic analyses, advanced modeling and machine learning capabilities, and mineral source traceability and verification capabilities.

To better collaborate across DOE offices and ensure effective interagency coordination, the DOE has created an institutionalized structure, the Critical Materials Collaborative (CMC).[10] The CMC was established in September 2023, from direction in the Energy Act of 2020 and the Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL). The mission of the CMC is to accelerate DOE's critical materials applied RDD&D to achieve domestic clean energy manufacturing, climate, and national security goals by building a robust innovation ecosystem; training the critical materials workforce across multiple sectors; enabling

[10] https://www.energy.gov/cmm/critical-materials-collaborative

industry adoption of novel, cutting-edge technology; and laying the scientific and technological groundwork needed to address emerging challenges.

The CMC serves to help better plan critical minerals and materials RDD&D efforts and ensure DOE's larger interagency coordination through the NSTC Critical Minerals Subcommittee. FECM's Office of Resource Sustainability and the Office of Energy Efficiency and Renewable Energy's (EERE) Advanced Materials & Manufacturing Technologies Office are co-leading the CMC, while all DOE offices involved in critical minerals and materials RDD&D form a CMC Executive Committee. The aim of the CMC is to integrate critical minerals and materials applied RDD&D across DOE and improve coordination with the rest of the federal government to accelerate the development of transformational technologies that will be foundational to securing critical material supply chains. The CMC will work closely with the interagency to expand project performers' access to the Department's world-class expertise, capabilities, and facilities.

As part of its coordination and planning efforts, the CMC is engaging with its members to develop a research roadmap, share up-to-date information, support NSTC coordination, and share resources. The Collaborative will be a focal point for developing an innovation ecosystem around critical minerals and materials to include other agencies, laboratories, academia, industry, and others.

There are four main methods to diversify supplies of critical materials: recycling, recovery from secondary and unconventional feedstocks, responsible domestic mining, and accessing a broader range of international sources.

Recycling from end-of-life systems like electric vehicles and offshore wind turbines could eventually be able to produce a significant percentage of the Nation's critical material requirement. DOE's review of large-capacity batteries indicated that 20 percent to 40 percent of nickel and cobalt needs for new batteries could be met with cobalt recovered from recycling batteries as soon as 2030.[11] Recycling can dramatically decrease the cost, energy and water use compared to conventional mining. One ton of battery-grade cobalt can be recovered from 5 to 15 tons of spent lithium-ion batteries, which requires the equivalent of 300 tons of ore.[12] RDD&D can enable competitive recycling technology in the future. In the near term, sourcing 10 percent of material needs from recycling can support stressed supply chains and reduce the threat of supply shocks.

EERE is advancing technologies to recover critical materials from components at end-of-life, including through the Critical Materials Innovation Hub (CMI Hub), led by Ames National Laboratory, and the ReCell Center, led by Argonne National Laboratory. EERE's Wind Energy Technologies Office also launched the BIL-funded Wind Turbine Materials Recycling Prize this year, which will develop cost-effective and sustainable recycling industry for two material categories, including rare earth elements. EERE's Solar Energy Technologies Office announced the partially BIL-funded Materials, Operation, and Recycling of Photovoltaics (MORE PV)

[11] https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf
[12] https://www.energy.gov/sites/default/files/2021-06/FCAB%20National%20Blueprint%20Lithium%20Batteries%200621_0.pdf

funding opportunity, which will optimize critical material requirements in PV systems and develop advanced low-cost pathways for PV recycling.[13]

Secondary and unconventional feedstocks encompass many potential sources, including coal and coal byproducts, coal wastes, produced water from oil and gas production, ionic clays, hard rock mine tailings, acid mine drainage, bauxite residue, and phosphate sludge. Together, these sources have the theoretical potential to provide enough REEs to meet the nation's needs for decades, as well as significant quantities of other CMM resources.[14] For most secondary and unconventional resources, there is an opportunity for remediating the environmental impacts and reducing the waste from mining and other extraction activities. RDD&D in this area is geared toward commercial scale development, with a BIL funded DOE REE demonstration facility being built this decade.

FECM's Carbon Ore, Rare Earth, and Critical Minerals (CORE-CM) Initiative supports regional coalitions of academia, industry, States, NGOs, and Tribal entities, that assess the potential for developing domestic supply chains using secondary and unconventional feedstocks. Billions of tons of coal waste and coal ash have been generated over the past two centuries and remain in waste piles or impoundments.[15] These and similar feedstocks represent a significant opportunity to diversify the supply of CMM resources while remediating longstanding environmental degradation and creating good jobs in mining and energy communities.

Current conventional mining practices use large amounts of energy, water, and other resources, and produce substantial greenhouse gas (GHG) emissions. Additionally, the success rate for finding new mines is very low (1000:1), taking almost a decade or more and hundreds of millions of dollars to identify and prove a resource.[16] The Administration's Interagency Working Group on Mining Laws, Regulations, and Permitting led by the Department of the Interior recently produced a report that outlined the need for mining organizations to build more robust engagements with local communities, as well as potential methods to improve the permitting process for mineral development, especially on Federal lands.[17] Ultimately, new and innovative approaches would help extract resources in a responsible and sustainable manner.

To that end, DOE is evaluating the potential for additional RDD&D investments to advance technological solutions and revolutionize mining into a more targeted enterprise that uses

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[13] https://www.ameslab.gov/cmi;
https://recellcenter.org/;
https://americanmadechallenges.org/challenges/wind-turbine-materials-recycling;
https://www.energy.gov/eere/solar/articles/funding-notice-materials-operation-and-recycling-photovoltaics-more-pv

[14] Report to Congress on Recovery of Rare Earth Elements and Critical Minerals from Coal and Coal By-Products. Available at https://www.energy.gov/sites/default/files/2022-05/Report%20to%20Congress%20on%20Recovery%20of%20Rare%20Earth%20Elements%20and%20Critical%20Minerals%20from%20Coal%20and%20Coal%20By-Products.pdf

[15] "Domestic Wastes and Byproducts: A Resource for Critical Material Supply Chains." Evan J. Granite, Grant Bromhal, Jennifer Wilcox, and Mary Anne Alvin, National Academy of Engineering, The Bridge, 53(3), 59-66, Fall 2023.

[16] "Geological data for mineral exploration." Eldosouky, et al. Geospatial Analysis Applied to Mineral Exploration. 2023. Available at https://www.sciencedirect.com/science/article/abs/pii/B9780323956086000068

[17] https://www.doi.gov/sites/doi.gov/files/mriwg-report-final-508.pdf

"surgical" approaches to extract minerals from ever deeper sources, minimize surface and environmental impacts, and improve public confidence in responsible mining techniques. Technology development areas for future mining research would likely include advanced drilling technologies, digital subsurface applications (autonomous operations, robotics, real-time extraction), *in situ* mineral extraction, novel processing, and tailings management. Data collection and management capabilities will also be critical in such an effort, as well as the building of a traceability capability with verification for all major critical materials.

This effort would build on and incorporate work initiated by the Advanced Research Projects Agency-Energy's (ARPA-E) Mining Innovations for Negative Emissions Resources (MINER) program which seeks to identify novel technologies that can substantially reduce waste, resource use, and GHG emissions from new mining.

In the meantime, domestic sources are not sufficient in the near-term to satisfy the Nation's critical material needs. Even in the long-term, it is important to develop a diverse critical materials supply network to maintain supplies needed by our allies and keep market prices for critical materials affordable in international and domestic markets. Therefore, U.S. collaboration with other countries could expand the sources and quantities of responsible supplies of critical materials. As part of this process, it is important to build capabilities for tracing and verifying the mineral origin for advanced batteries, magnets, and other manufactured products. Currently, countries such as the PRC that hold monopolies on the midstream and downstream processing of these critical minerals are investing heavily internationally to ensure a diverse feedstock that will feed their supply chains for years to come.

The Department is proactively engaging with our international partners. This includes the G7 and the International Energy Agency, where we are working with allies to promote secure and diversified supplies, market transparency, and responsible practices across the supply chain. The Department is also working closely with Australia through the recently signed Australia-United States Climate, Critical Minerals, and Clean Energy Transformation Compact. Canada, Japan, the UK, and the European Union are also key partners in advancing resilient critical material supply chains.

The Department has identified a tiered approach to help build new domestic commercial infrastructure in the near-term and bring new technologies to market in the next decade. This approach has allowed the Department to coordinate efforts across various technology readiness levels and exploit the exceptional expertise that resides across multiple DOE offices. These three technology development tracks are: (1) demonstration and commercial application; (2) advanced technology development; and (3) transformational technology development. The first track focuses on getting current or near-ready technologies to the marketplace to help stand up critical pieces of domestic supply chains as soon as possible. The second track is focused on technologies that advance the current state of the art in terms of cost, equitable social and environmental performance, but which remain three to ten years away from commercialization. The third track includes potentially transformational technologies that have the potential to revolutionize the critical materials industry in terms of environmental and equitable social performance as well as cost, but which are probably at least a decade from commercialization.

All of these development pipelines are important to accelerate the deployment of robust domestic supply chains for critical materials.

It is urgent to get new commercial midstream technology in place in the U.S. to establish domestic supply chains this decade. With funding from the BIL and the Inflation Reduction Act (IRA), the Department's Office of Manufacturing and Energy Supply Chains (MESC) and the Loan Programs Office (LPO) are leading these efforts, with LPO committing more than $3 billion for several critical materials production and recycling project, and MESC targeting over $6 billion in BIL funding to support battery materials processing, manufacturing, and recycling.[18]

MESC works to strengthen and secure energy supply chains and manufacturing to modernize U.S. energy infrastructure and support the clean energy transition. To this end, MESC is implementing provisions in the BIL, the Defense Production Act, and the IRA. Two important efforts include the Battery Materials Processing and Battery Manufacturing Recycling Supply Chain Facilities to separate and process critical battery materials and the Rare Earth Element Demonstration Facilities that will extract from unconventional feedstock materials, such as lignite coal and acid mine drainage.

At the same time, FECM, EERE, and other DOE applied research offices are working to develop technologies that improve on the current commercially available state of the art technologies that have reduced costs and adverse impacts while demonstrating optimal performance through their lifecycles. As these technologies are shown to be effective at lower Technology Readiness Levels, DOE's applied science and technology offices will work to advance them toward commercialization.

FECM is also advancing an RDD&D portfolio geared toward increasing the domestic production of critical materials in the United States. Research is focused on extracting, separating, and recovering rare earth elements and critical materials from unconventional and secondary sources. We have had success in this area, including the design, construction, and operation of five first-of-a-kind bench and small pilot-scale facilities that are producing high-purity mixed rare earth oxides/salts from coal-based resources using conventional beneficiation and separation processes. FECM has released several BIL-related FOAs this year to help accelerate these efforts.[19][20][21] We are also developing more energy efficient synthetic graphite, graphene and carbon anode materials from coal, coal waste, and coal byproducts.

[18] https://www.energy.gov/lpo/portfolio-projects;
https://www.energy.gov/mesc/battery-materials-processing-grants;
https://www.energy.gov/mesc/battery-manufacturing-and-recycling-grants

[19] September 6, 2023 Funding Opportunity Announcement: https://www.energy.gov/fecm/funding-notice-critical-materials-innovation-efficiency-and-alternatives
[20] August 21, 2023 Funding Opportunity Announcement: https://www.energy.gov/fecm/funding-notice-bipartisan-infrastructure-law-advanced-processing-critical-minerals-and
[21] July 13, 2023 Funding Opportunity Announcement: https://www.energy.gov/fecm/funding-notice-bipartisan-infrastructure-law-front-end-engineering-and-design-feed-studies

EERE is working to establish sustainable supply chains for the critical materials needed to support clean energy technologies. EERE's Advanced Materials and Manufacturing Technologies Office manages an applied RDD&D portfolio that addresses high-impact opportunities and challenges across the life cycle of critical minerals and materials for clean energy. This includes the CMI Hub, a public-private consortium of national laboratories, universities, and industry focused on technologies that make better use of materials and eliminate the need for materials that are subject to supply disruptions. Since its inception in 2013, CMI research has been awarded forty-seven U.S. patents, licensed twenty technologies, and received five Federal Laboratory Consortium awards, twelve R&D 100 Awards, and over $80 million in follow-on funding. Funding from BIL has accelerated the commercialization of CMI-developed technology to recycle critical materials from lithium-ion batteries.

Through prize competitions, EERE's Geothermal Technologies Office is incentivizing innovators to de-risk and increase market viability for direct lithium extraction from geothermal brines, while the Vehicle Technologies Office is spurring innovative solutions to collect, sort, store, and transport spent and discarded lithium-ion batteries for eventual recycling and materials recovery. The Hydrogen and Fuel Cell Technologies Office (HFTO) is advancing research on substitutes for and reducing the amount of platinum and iridium in electrolyzers needed for clean hydrogen production, as well as addressing critical material recovery and recycling, with a target for increasing the efficiency and cost effectiveness of raw materials for hydrogen technologies by 2028. The Vehicle Technologies Office continues to drive research and development on next-generation battery chemistries as alternatives to commercial lithium-ion batteries and the critical materials like cobalt, nickel, graphite, manganese, and lithium that they currently contain.

Additionally, several DOE offices help to identify discoveries and inventions that show promise at very low Technology Readiness Levels and work on advancing technologies toward commercial deployment. ARPA-E and the Office of Science are investing in game changing breakthroughs that can lead to transformational technologies that will be part of a next generation of critical minerals and materials supply chains. ARPA-E's MINER program seeks to increase U.S. domestic supplies of copper, nickel, lithium, cobalt, and other rare earth elements. And the Office of Science supports foundational science on understanding the role of rare earth elements, platinum group elements, other critical elements to determine the properties of materials and molecules and science that will enhance the extraction and chemical processing of these elements, including engaging in the Material Genome Initiative.[22]

DOE has over $8 billion in funding dedicated to critical materials and minerals advancement. Additionally, the IRA provides 48C tax credits to re-equip, expand, or establish industrial facilities for the processing, refining, or recycling of CMM.

Mr. Chairman, critical minerals and materials are crucial to the way we live our lives every day. They are required in a wide range of strategic industries, including aerospace, medicine, and defense. They are also indispensable components in clean energy technologies, such as batteries, electric vehicles, wind turbines, and solar panels.

[22] The Materials Genome Initiative (MGI) is a U.S. Federal government multi-stakeholder initiative to develop an infrastructure to accelerate and sustain domestic materials discovery and deployment in the United States

U.S. reliance on foreign sources for these materials is neither sustainable nor secure. That is why the DOE is taking robust and wide-ranging actions to address this challenge and secure domestic and allied supply chains for critical minerals and materials.

For over a decade, DOE has invested in basic and applied research and development related to critical minerals and materials to address the scientific and technological challenges that underpin supply chain vulnerabilities as demand for CMMs increase worldwide. RDD&D has the potential to help create the transformational technologies to ensure that the U.S. has the material resources needed for economic, energy and national security.

DOE appreciates the Committee on Science, Space, and Technology for its bipartisan support of critical materials research, development, and demonstration over many years, and we look forward to continuing our work with the Committee on additional critical materials policy going forward.

Ryan Peay

Ryan Peay is the Deputy Assistant Secretary for Resource Sustainability in the Office of Fossil Energy and Carbon Management. He sets the strategic direction for the Office of Resource Sustainability and administers the programs, including fossil energy research and development, engagement, analysis, budget, and natural gas regulation. Previously, Ryan was the Director of Planning and Administration for the Office of Oil and Natural Gas and was responsible for strategic planning as well as coordinating and integrating daily activities across the Office.

Prior to joining DOE, Ryan was a manager at a major consulting firm, focused on strategic planning, financial programming, and budgeting activities. From 2002 to 2007, Ryan served on active duty in the U.S. Army as a Field Artillery Officer in the 101st Airborne Division.

Ryan holds an MBA from the Darden School of Business at the University of Virginia and is a graduate of the Virginia Military Institute with a B.A. in International Studies and Political Science.

Chairman LUCAS. Thank you. The Chair now recognizes Dr. Caers for five minutes to present his testimony.

TESTIMONY OF DR. JEF CAERS, PROFESSOR OF EARTH & PLANETARY SCIENCE AND DIRECTOR OF STANFORD MINERAL-X, STANFORD UNIVERSITY

Dr. CAERS. Chairman Lucas, Ranking Member Lofgren, and Members of the Committee, thank you for this opportunity to testify today. My testimony will document that a secure and resilient national supply of critical minerals and materials cannot be achieved without new domestic discoveries of critical mineral deposits.

Benchmark Minerals has estimated that about 300 new mines will be needed during the next decade alone. Most of these mines require new discoveries. Currently, the NSF and DOE do not fund innovation in mineral exploration. Two months ago, the NSF announced inaugural awards for an ambitious program, the NSF Global Centers, large awards up to $10 million, aimed to foster collaboration with U.S. allies Australia, Canada, and the United Kingdom across three main areas: critical minerals, energy, and climate. Critical minerals projects received $250,000 in funding, while energy and climate projects received $76 million.

Yet at the same time, the funded energy projects in green hydrogen, upgrading the electrical grid, and renewable energy require vast amounts of critical minerals. Some of these would today be sourced from Russia and processed in China. The DOE announced last September $150 million to strengthen the domestic critical mineral supply with no mention of exploration or the need of making new domestic discoveries.

Legislation passed by Congress, the *CHIPS and Science Act* and the *Energy Policy Act of 2020,* call for research and development of new ways of mineral exploration, including the use of artificial intelligence (AI) and machine learning, and the study of ore forming processes to have a mentally responsible production of domestic resources, as well as workforce training for exploration of critical mineral resources.

In my written testimony, I cover six misconceptions that are routinely offered countering the need for increase in domestic exploration and funding such activities. One misconception is that we just need to find replacement materials. This is indeed important research, but why bet on a single horse? Not all materials can easily be replaced or, more importantly, at a timescale we find ourselves today in the energy transition.

Recent research published in Nature has shown that lithium in the right combination with nickel and cobalt provides the largest energy density, combined with the best thermal stability. There is no replacements in the table of elements between nickel and cobalt, and lithium is the third largest—lightest element in the entire universe.

My overall assessment is that United States is funding technological innovation in all parts of the circle of critical materials economy except any innovation to discover where in the United States these minerals actually are. As an analogy, the government's funding new technology in farming, but has no good soil to farm on. While the USGS (United States Geological Survey) is tasked to assess 50 critical minerals in 50 States by 2029, without innovation in mineral exploration, this will never happen.

Less than a year ago, I founded Stanford Mineral-X, a new program in critical mineral exploration. Mineral-X is now the only U.S. research program in mineral exploration with committed funding in the millions of dollars. All of our proposals to innovate the critical mineral supply chain in the United States have been declined by NSF and DOE. As a consequence, it is mostly now funded by foreign companies.

During the last APEC (Asia-Pacific Economic Cooperation) in San Francisco, I personally presented Mineral-X to the President of Indonesia, Joko Widodo, resulting in the planning of Mineral-X research to be developed to use—be used to develop a more sustainable supply chain in Indonesia. Why this interest? Together with Coble Metals, a startup company in Silicon Valley, Mineral-X has built technology that is founded on rigorous data science and comprehensive artificial intelligence to accelerate critical mineral exploration now actively employed in 60 assets over three continents. That technology today is not used in the United States.

Finally, I'd like to provide recommendations on how we can address this alarming situation. I propose for Congress to fully fund the Critical Minerals Mining Research and Development Program authorized in the *CHIPS and Science Act,* and to encourage partnerships with allied nations, Canada, Australia in a national program similar to the NSF Global Centers at the level of $25 million. Artificial intelligence, geosciences, and environmental justice are foundational to such a program, and my written testimony has detailed proposals on how to achieve this. If finding critical minerals is one of the defining challenges of this century, its most revolutionary technology—AI—may well hold the key to unlocking them. Let's start using that in this country as well.

Again, many thanks for the opportunity today, and I'll be happy to answer any questions.

[The prepared statement of Dr. Caers follows:]

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

Jef Caers, Ph.D, Professor of Earth & Planetary Science and
Director of Stanford Mineral-X, Stanford University

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 CO2 in mining waste. First, tier 1 and 2 CO2 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 CO2 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.

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

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

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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.

Chairman LUCAS. Thank you. I now recognize Mr. Horn for five minutes to present his testimony.

TESTIMONY OF MR. DREW HORN, CHIEF EXECUTIVE OFFICER, GREENMET

Mr. HORN. Thank you, Chairman. Chairman Lucas, Ranking Member Lofgren, Members of the Committee, thank you for the opportunity to testify today on this important topic of leveraging Federal research dollars to achieve a robust American supply chain for critical minerals. My name is Drew Horn, and I am the founder, President, and CEO of GreenMet. We are a private company working to develop American critical mineral and clean energy supply chains. Our efforts serve to reduce U.S. overreliance on imports of critical minerals and metals, particularly from adversaries, thereby strengthening U.S. national security. In other words, Mr. Chairman, America's critical mineral security is national security.

As the new American conduit between private capital and critical mineral innovation, GreenMet has unique privilege of representing the complete private sector policy interests that support and sustain reliable and uninterruptible U.S. supply chains of critical minerals from mine through manufacturing. It is from that lens that I address the Committee today.

Public-private partnerships are the most effective way to harness Federal research dollars and incubate, accelerate, and scale innovations in all segments of the mineral supply chains from mining to manufacturing. In the context of the critical mineral supply chain, not all minerals or elements are of equal priority to our national agenda. Federal research dollars must be allocated toward those projects that achieve our economic, energy, and national security needs.

For example, we absolutely need the rare earth neodymium to produce rare earth magnets. However, only magnets containing added dysprosium and terbium can resist extreme temperatures required for critical military and civilian uses to include electric vehicle supply chains and motor services. Our adversaries in China and Russia recognize this and restrict access to these heavy rare earths wherever and whenever they can.

By directing applied research funds further upstream, the United States can continue to bolster its capabilities in mining, processing, refining, and metallurgy, all steps that lead to true domestic manufacturing. I urge the Committee to fully consider that we can develop our own superior U.S. capabilities in this sector and that we can do more than simply re-shore from adversaries to options that provide only a slight decrease in vulnerability.

A good recent example of prioritizing upstream funding is the *DPA (Defense Production Act)* Title III language in the *IRA (Inflation Reduction Act)* that is intended to fund critical domestic projects based off the latest R&D. Two projects well-suited for this type of funding are the Wyoming-based Bear Lodge Rare Earth Project and Missouri-based Caldera tailings reclamation project at Pea Ridge, between which we can meet all domestic heavy rare earth demand without looking outside our own borders.

GreenMet is proud to support both as they would seek to provide the U.S. Government with the most cost-effective and practical path to secure an uninterruptible supply chain for heavy rare earths from mine to separated rare earth oxides. These oxides are vital for high-strength permanent magnets required for defense, offshore wind turbines, and electric vehicles, and innumerable uses in clean energy. We must ensure our R&D efforts and national labs are focused on meeting our national priorities.

These efforts must be matched with large-scale investors and commercial leaders and manufacturing so that this research serves as a true catalyst and enabler for commercial large-scale U.S. growth, successful research grants to facilitate breakthrough developments and incubate those new methods to the point of a viable commercial handoff. Just yesterday, our partner Caldera announced they will be licensing Oak Ridge National Lab's advanced extraction technique to separate rare earth elements in mined ore. Their Pea Ridge mine has high amounts of the key rare earth element dysprosium, and now, through federally developed technology, they will be able to separate that and other critical elements and minerals in a more efficient and environmentally friendly manner.

We have another partner that is leading the world in vapor metallurgy technology and is looking to use this technology to cleanly and efficiently transform mineral waste piles, also known as tailings, into metals essential to our energy and national security applications.

For minerals in American mines to their end products in American manufacturing plants, our industries benefit most from federally funded R&D that goes beyond laboratory and demonstration products such that we can achieve full commercialization as rapidly as possible. To that end, projects developed through Federal R&D dollars must automatically qualify for fast tracking of any follow-on permitting required to commercialize.

The time for bold bipartisan congressional action is now. In summary, we need Congress to ensure we are investing our Federal research dollars across the entire mineral supply chain to enable America to be more secure and self-sufficient. Furthermore, when allocating these precious taxpayer dollars, we must be expeditious in meeting—in moving innovations through the complete project development lifestyle. By doing so, we can establish the United States as the world leader in responsible, clean, ethical, and cost-efficient production of minerals.

Mr. Chairman, I thank you again, and I look forward to taking any questions from the Committee.

[The prepared statement of Mr. Horn follows:]

GreenMet

WRITTEN TESTIMONY BEFORE THE
HOUSE SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENATATIVES

FULL COMMITTEE HEARING ON
"THE ROLE OF FEDERAL RESEARCH IN ESTABLISHING A ROBUST U.S. SUPPLY CHAIN OF CRITICAL MINERALS AND MATERIALS"

DREW HORN
FOUNDER, PRESIDENT & CEO
GREENMET

November 30, 2023

Chairman Lucas, Ranking Member Lofgren, Members of the Committee: Thank you for the opportunity to testify today on this important topic of leveraging Federal research dollars to achieve a robust American supply chain for critical minerals.

My name is Drew Horn, and I am founder, president and CEO of GreenMet - a private company working to develop American critical mineral and green energy supply chains. Our efforts serve to reduce U.S. over-reliance on foreign imports of critical minerals and metals - particularly from our adversaries - thereby strengthening U.S. national security. In other words, Mr. Chairman, **America's critical mineral security *is* our national security**.

I am also a former U.S. Army Special Forces officer and a Marine officer who served this country for over 10 years in uniform. During my time as an officer, I successfully completed three combat deployments to Afghanistan as a Green Beret, and one to Iraq as a Marine. After my military service I had the privilege to serve as a senior policy executive at the Departments of Defense and Energy, the Office of the Vice President, and the Office of the Director of National Intelligence.

Our GreenMet team is made up of decorated veterans, former public servants, and industry experts. GreenMet was founded in 2021 to build U.S.-based technical solutions to mining, processing, and metallurgy for critical minerals that are more cost-efficient and environmentally responsible than those practiced in the same trade space that is dominated by U.S. adversaries. As the conduit between private capital and critical mineral innovation, GreenMet has the unique privilege of representing the complete private sector policy interests that support and sustain reliable and uninterruptable U.S. supply chains for critical minerals from mine through manufacturing.

GreenMet is currently involved in multiple mineral resource projects that will strengthen domestic critical mineral supply chains. GreenMet is focused on developing the required infrastructure for sustainable and uninterruptable critical mineral supply chains which can meet U.S. and North American energy and technological needs. Our approach is predicated on the belief that good, comprehensive critical mineral policy begins with good public-private partnership to tackle much needed innovative research and development in the minerals resource arena. This approach helps incubate, accelerate, and scale innovations in all segments of the mineral supply chains from mining to manufacturing.

Our GreenMet team works to demonstrate that the U.S. can produce domestic energy in a cleaner and more technologically superior way than the current status quo practiced by our foreign adversaries. Our nation's 21st century mining and metalmaking practices are governed by the world's highest and best standards. Hence, as the U.S. unleashes its domestic energy production according to these high standards, sustainable and uninterruptable supplies will result.

As the U.S. rebuilds its mineral supply chains, we need to place the greatest emphasis on minerals and metals that that make our energy independence possible, including our energy systems and especially our energy grid. Not all minerals or elements are of equal priority to our national agenda.

For example, we absolutely need the rare earth metal *neodymium* to produce rare earth magnets. However, only magnets containing added *dysprosium* and *terbium* can resist extreme temperatures required for essential military and civilian uses. Magnets without heavy rare earth *dysprosium* and *terbium* are only useful for low-temperature application as in commercial electronics, appliances, and toys. Our adversaries in China and Russia recognize this and restrict access to heavy rare earths wherever and whenever they can as our trade history with them has demonstrated in the last 15 years.

While the CHIPS Act touches fabrication and other supply chain links, Federal research funding needs to directly support (i.e. "applied research") those identified innovative methods and technologies needed to successfully re-shore U.S. capabilities in mining, mineral processing, metal and alloy refining (metallurgy), and manufacturing. Given the interdependent nature of our economic and national security priorities, we believe the inclusion of funding for these mineral projects will propel the advancement of a domestic supply chain and meet our current and future defense needs.

The Inflation Reduction Act and its advanced manufacturing tax credits that include critical minerals was a step in the right direction. However, to facilitate the hand off from Federally supported R&D to commercial viability, future funding must be targeted further upstream in the critical mineral supply chain. We cannot build the house from the roof down, nor can we only incent a single step in the supply chain. If we do, then all our efforts are for naught, and we are still relying on China for the rest.

The first crucial step in the complex challenge of fortifying U.S. critical mineral supply chains will require Federal applied research funding tailored to prioritize advancements in technology resulting in better environmental standards while enabling robust U.S. competition in the global market, especially against countries that don't subscribe to our economic and environmental standards and rules. By directing applied research funds further upstream, the U.S. can continue to bolster its capabilities in mining, processing, refining, and metallurgy – all the steps that lead to TRUE domestic manufacturing.

A good recent example of prioritizing upstream funding is The Defense Production Act Title III in the Inflation Reduction Act (Public Law 117-169) that is intended to fund critical domestic projects based on the latest R&D. Two projects well suited for this type of funding are the Wyoming-based "Bear Lodge Rare Earth Project," and the Missouri-based Caldera tailings reclamation project at Pea Ridge, between which we can meet all domestic heavy rare earth demand without looking outside our borders. GreenMet is proud to support both as they seek to provide the U.S. government with the most cost-effective and practical path to a secure an uninterruptable supply chain for heavy rare earths, from mine to separated rare earth oxides or "REOs." These REOs are critically necessary to produce high-strength permanent magnets required for defense, offshore wind turbines, and electric vehicles, and innumerable uses in clean technology.

To help ensure R&D efforts and national labs are pursuing and advancing innovations that meet our national priorities, the U.S. also needs increased centralized oversight by the White House and at the headquarters-level of appropriate agencies. The most effective way to ensure proper and coordinated funding and policy oversight for the critical mineral sector is to establish an interagency taskforce under the Executive Office of the President.

To reiterate, mineral security is national security. The window of opportunity is fleeting, and delay increases our already severe mineral vulnerabilities. By fast-tracking the deployment of projects arising from federal research projects, we can accelerate them towards commercialization. Conflicts in Ukraine have drawn down our nation's munitions. Our National Defense Stockpile of critical minerals is at an all-time low, only about 4% of what it used to be at its peak. America is vulnerable, but we have begun to tackle the challenge. You, the esteemed members of this committee, can help us change course by investing federal research dollars into all levels of the mineral supply chain, especially the ones most dominated by our adversaries such as mineral extraction, refining, and processing.

Successful research grants should both facilitate break-through developments and incubate those new methods to the point of a viable commercial hand off. From minerals in American mines to their end products in American manufacturing plants, our industries really benefit from Federally funded R&D that goes beyond laboratory and demonstration projects, with an eye toward achieving full commercialization as rapidly as possible.

To that end, projects developed through Federal R&D dollars must automatically qualify for fast-tracking of any follow-on permitting required to commercialize. Expedited permitting for critical mineral projects here at home will bring us closer to a carbon neutral economy, decrease our dependence on China, and increase our energy and national security.

Mr. Chairman, inaction regarding the utilization of America's mineral wealth to sustain our national security and protect our economic stability is far beyond extremely serious, it is dangerous given our wild over-reliance on critical mineral imports from China and other adversaries. America is behind the curve reshoring our mineral supply chains.

Our country is blessed with mineral deposits beyond belief and geologists are still far from completing mapping of the U.S. Now we desperately need the national will to leverage our mineral wealth. This can be achieved through successful public-private partnerships with our great mining and metallurgical industries, and the elimination of the permitting labyrinth and frivolous lawsuits that stymy our progress toward mineral independence.

The time for bold, transformative bi-partisan Congressional action is now. In summary, we need your support for investing federal research dollars across the entire mineral supply chain to enable America to be secure and self-reliant. Furthermore, when allocating those precious tax-payer dollars, we must be expeditious in moving innovations through the entire project development lifecycle.

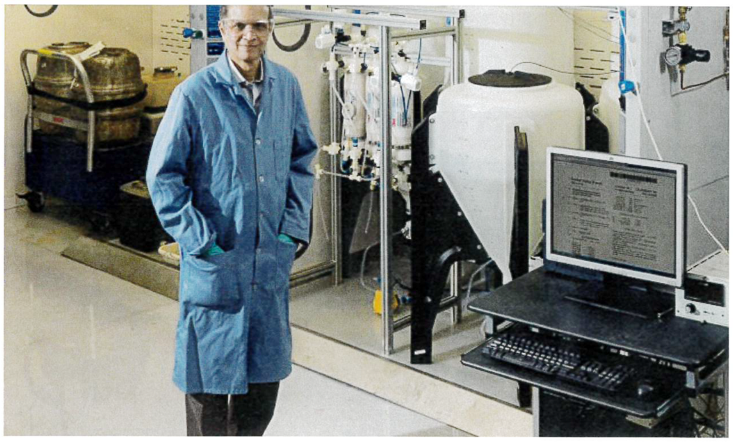
Mr. Chairman, I thank you for permitting me to testify today regarding the importance of fueling American ingenuity to fully realize the potential of our domestic mineral wealth.

News

Owner of US heavy rare earth mine licenses ORNL separation technology

November 28, 2023

Topic: Materials



Ramesh Bhave, pictured in his chemical sciences laboratory at ORNL, has been refining a membrane solvent extraction technique for critical materials for more than a decade. The technology was recently licensed to Caldera Holding for research into its application for domestically mined ores. Credit: Carlos Jones/ORNL, U.S. Dept. of Energy

- Caldera Holding has licensed ORNL's membrane solvent extraction technique to separate rare earth elements in mined ore.
- The company also owns the Pea Ridge iron mine in Missouri.
- The Pea Ridge mine is among the first in America shown to have relatively high amounts of dysprosium, a critical element for permanent magnets.

Caldera Holding, the owner and developer of Missouri's Pea Ridge iron mine, has entered a nonexclusive research and development licensing agreement with Oak Ridge National Laboratory to apply a membrane solvent extraction technique, or MSX, developed by ORNL researchers to mined ores. MSX provides a scalable, efficient way to separate rare earth elements, or REEs, from mixed mineral ores.

The MSX technology was pioneered at ORNL by researchers in the Department of Energy's **Critical Materials Innovation Hub**, or CMI, led by Ames National Laboratory. The inventors, Ramesh Bhave and Syed Islam of ORNL's Chemical Sciences Division are named in 26 inventions and five active licenses related to the recovery of REEs.

REEs are a group of 17 lanthanide elements used in several technologies critical to global economic competitiveness such as electronic devices, wind turbines, electric vehicle motors, medical imaging, optics and advanced defense systems. Separated REEs are essential constituents of the neodymium-based magnets — also known as NdFeB — used in permanent magnets that operate in extreme conditions. Heavy REEs including terbium, dysprosium and holmium are required for electric vehicle motors and advanced defense systems but currently must be procured from foreign suppliers.

"Developing a domestic supply of these elements is critical to a range of clean energy and national security technologies," said Cynthia Jenks, associate laboratory director for physical sciences. "ORNL is focused on expanding supply through the development of innovative technologies."

Compared with other traditional separation methods such as hydrometallurgy and chemical separation, the MSX process is more efficient, using much less energy, labor and chemical solvents and can be applied to a variety of critical material recovery efforts. The MSX system contains porous hollow fibers with a neutral extractant that function as a chemical "traffic cop" of sorts; creating a selective barrier and letting only REEs pass through. The REE-rich solution collected can then be further processed to yield rare earth oxides with purities exceeding 99.5%.

"The Pea Ridge iron ore mine is the only fully permitted domestic source for heavy REEs critical for high operating temperature, high value neodymium magnets," said Jim Kennedy, president of Caldera. "The Caldera mine has three distinct rare earth deposits, open at depth, containing 700,000 tons of REEs and significant levels of praseodymium, neodymium, terbium, dysprosium, holmium and other heavy REEs.

"Caldera seeks to integrate ORNL's technology into a domestic, vertically integrated value chain, to produce neodymium magnets," Kennedy said.

The MSX technology can separate REEs from other mineral deposits but can also separate light and heavy elements. Islam noted that the Pea Ridge mine is among the first in America shown to have dysprosium and in a relatively high amount within the ore's composition.

For Bhave and Islam, the license to Caldera provides a long-sought opportunity.

Syed Islam co-invented a process to recover rare earth elements from scrap magnets. Under a new licensing agreement, Islam and colleague Ramesh Bhave will apply their technology to mined ores. Credit: Carlos Jones/ORNL, U.S. Dept. of Energy

"We've been looking for this for a long time, since we started working in the critical materials and rare earth space more than 10 years ago," Bhave said. "We've always wanted to test our method on a mining source."

Islam said, "For me, as a young staff scientist, this kind of impact supersedes publication — seeing that what we do can make a difference in the scientific community to make the world a better, cleaner and safer place for ourselves and for the next generation."

The team is planning for a continued research relationship, which includes a demonstration of the technology.

Jennifer Caldwell, ORNL technology transfer director, negotiated the terms of the license. **Learn more about ORNL's intellectual property in chemistry**. For more information, **email the ORNL Partnerships Office** or call 865-574-1051.

The Critical Materials Innovation Hub 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.

UT-Battelle manages ORNL for DOE's Office of Science, the single largest supporter of basic research in the physical sciences in the United States. DOE's Office of Science is working to address some of the most pressing challenges of our time. For more information, visit **energy.gov/science**.

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RESEARCHERS

Ramesh R Bhave

Syed Z Islam

Organizations

Partnerships

Technology Transfer

Physical Sciences Directorate

Chemical Sciences Division

Separations and Polymer Chemistry Section

Soft Matter Group

Related News

Chemical Sciences
Critical Materials

Drew Horn

Drew Horn is a trailblazer in securing critical minerals supply chain resources to serve business and national security needs. With this vision in mind, he founded GreenMet, the world's primary project finance company dedicated to building and facilitating responsible and economically-sound growth in the United States renewable energy and critical minerals supply chain. GreenMet specializes in matching public and private capital to build advanced materials growth in a manner that supports the energy and technological needs of the future.

Mr. Horn's time in the federal government, private sector, and active-duty military service gave him extensive leadership experience in business management and national security. During his time in the US federal government, he led US government efforts in minerals supply chain development. He served as a senior policy executive at the Departments of Defense and Energy, Offices of the Vice President, and the Director of National Intelligence. Mr. Horn led government-wide efforts in economic security and intelligence. This entailed creating and implementing a new US strategy for building the national critical minerals supply chain, as well as a new international energy plan focused on optimization of renewable energy efforts worldwide. These efforts culminated in his work to optimize related national intelligence operations and accelerate the establishment of public-private partnerships between government and business leaders in the energy, commercial, and manufacturing security space.

Prior to his federal service, Mr. Horn worked as a strategic management consultant at one of the Big Four consulting firms. There he managed teams that provided intelligence and risk analysis for clients in the national security space. Mr. Horn also spent ten years in uniform as a commissioned officer in the US military, first as a United States Marine and then as a Special Forces Officer in the United States Army. He has extensive combat experience in Afghanistan as a commander of a direct-action commando team and successfully completed three combat deployments to Afghanistan, and one to Iraq as a Marine.

Mr. Horn is originally from Northern Virginia and has a Master of Business Administration from the University of Virginia's Darden School of Business, and an undergraduate degree in Political Science and History from the University of Wisconsin. He currently resides in Northern Virginia and West Virginia.

<u>DREW HORN</u>

PROFESSIONAL EXPERIENCE

GREENMET, Washington, DC.
April 2021 – Present
Founder, President, and Chief Executive Officer

- Founder of GreenMet, the world's premier green energy supply chain company.
- Priorities are matching unparalleled preferred public and private funding options by leveraging the links between national security interests and green energy development needs, utilizing our unique knowledge and expertise of US government and private industry leaders.
- Built the company from conception to full operational status, including building a full management team, incorporating as a C Corporation with a top-level Board of Directors, Board of Advisors, Steering Committee, and solidified deal flow with a valuation more than two billion dollars.

Safeguarding America's Future Energy (SAFE), Washington, DC.
September 2021 – Present
Senior Fellow

- Provides senior level industry and government leadership perspective to a critical think tank that helps provide energy policy guidance to key global leaders.
- SAFE enhances the nation's energy security and supports our economic resurgence and resiliency, by advancing transformative transportation and mobility technologies and ensuring that the United States secures key aspects of the technology supply chain to achieve and maintain our strategic advantage.
- Primary points of focus include recommendations on policy goals, strategic planning, fund-raising, and period Op-Eds raising public awareness on critical materials.

GREENTECH MINERALS ADVISORY GROUP, Alexandria, Virginia.
February 2021 – October 2021
Founding Partner

- Founder and leader of a boutique consulting firm dedicated to green and renewable energy supply chain development.
- Core company principles included integration of proven economic principles and responsible and efficient critical minerals processing advancement.
- Dedicated to matching public and private capital for the purposes of building advanced materials growth in a manner that supports the energy and technological development and needs of the future.

DEPARTMENT OF ENERGY, Washington, DC.
November 2020 – January 2021
Senior Advisor to the Secretary of Energy

- Advised the Secretary of Energy, the White House, and Congressional leadership on national security priorities and all U.S. energy policy.
- Served as one of several key U.S. government leaders on all U.S. critical mineral supply chain and renewable energy policy.
- Led U.S. government efforts on energy security policy, critical minerals supply chain development, advanced nuclear technology, renewable energy innovation, and other strategic energy security issues.

DREW HORN

OFFICE OF THE DIRECTOR OF NATIONAL INTELLIGENCE, McLean, VA.
March 2020 – November 2020
Senior Advisor to the Director of National Intelligence

- Advised and guided the Director on national security priorities and served in a deputy capacity in Intelligence Community enterprise engagement with the White House, U.S. private sector leadership, Congressional leadership, and leaders of the international community.
- Led Intelligence Community efforts in an acting Deputy capacity, with a primary focus on national energy, business intelligence, defense security, and technological advancement and integration policy issues, and facilitated the transition of roles and responsibilities from the Acting Director of National Intelligence to the new Director of National Intelligence.
- Regularly coordinated with the White House and interagency and represented the Office of the Director of National Intelligence at the deputy and senior director level in engagement with the National Security Council, National Economic Council, and Domestic Security Council.

OFFICE OF THE VICE PRESIDENT, THE WHITE HOUSE, Washington, DC.
August 2019 – March 2020
Associate Director of Policy for the Vice President

- Advised the Vice President on U.S. policy development and implementation.
- Led Executive Branch policy development at the deputy and senior director level in the energy, interior, trade, commerce, space commerce, law enforcement, national defense, defense industrial, immigration, and critical minerals areas of focus.
- Led Policy Coordination Committee (PCC) meetings that coordinated the actions of each federal agency on the Administration's policy priorities.

DEPARTMENT OF ENERGY, Washington, DC.
December 2018 – August 2019
Principal Deputy Assistant Secretary (Acting) for the Office of International Affairs

- Led the Office of International Affairs at the Department of Energy, the office responsible for all international energy policy for the Department and served as the alter ego and Acting Assistant Secretary in the Senate-confirmed Assistant Secretary's absence.
- Represented the Department of Energy in key engagement with the National Security Council on energy-related national security matters and represents U.S. interests through interaction with international counterparts.
- Successfully developed and implemented five regional energy strategies that globally increased U.S. energy-related involvement in strategic areas of interest.

DEPARTMENT OF ENERGY, Washington, DC.
December 2018 – August 2019
Chief of Staff for the Office of International Affairs

- Managed five Deputy Assistant Secretaries, their offices, and staff.
- Managed the budget and appropriations process for the office to include continual Congressional engagement.
- Designed and implemented a major office re-organization that grew the office by forty personnel and three additional Deputy Assistant Secretaries, and their respective sub-offices.

DREW HORN

OFFICE OF THE UNDER SECRETARY OF DEFENSE FOR POLICY, OFFICE OF THE SECRETARY OF DEFENSE, Arlington, VA.
July 2017 – December 2018
Country Director for Afghanistan

- Lead as the senior presidentially appointed policy director for U.S. defense policy in Afghanistan.
- Contributed to interagency policy initiatives through regular engagement and collaborative work with multiple federal agencies and the National Security Council, primarily with the South and Central Asia, Transnational Threats, and Middle East directorates.
- Served as the Afghan defense policy representative to interagency Afghan Security, Counter Terror, Middle East-Afghan relations, Counter Narcotics, Defeat-ISIS, Russian-Afghan Relations, Counter Threat Finance working groups, and the DoD Defeat-ISIS Task Force.

DELOITTE CONSULTING LLP, FEDERAL PRACTICE, Arlington, VA.
January 2016 – July 2017
Senior Consultant

- Coordinated intelligence analysis within the intelligence community and the interagency that supported Department of Homeland Security priorities.
- Managed five teams that conducted all levels of intelligence analysis into adversary trends and preferences through strategic qualitative and quantitative analyses and performed risk modeling through coordinated work with the Department of Energy's National Laboratories, sub-agencies within the Department of Homeland Security, and multiple intelligence agencies.
- Conducted analysis and made recommendations to agency executives on risk assessments on populations of the traveling public and conducted research to develop potential answers to specific questions about adversary characteristics and preferences, adversary preference simulation and modeling, and other analysis.

1ST BATTALION, 3RD SPECIAL FORCES GROUP, U.S. ARMY SPECIAL OPERATIONS COMMAND, Fort Bragg, NC, and Eastern Afghanistan
January 2013 – January 2016
Special Forces Officer

- Served as a Direct Action/Counter Terrorism focused Operational Detachment – Alpha Team (A-Team) Commander, Company Executive Officer, Assistant Battalion Operations Officer, and Afghan National Army Special Operations Command Special Operations Advisor.
- Commanded the Battalion's primary Direct-Action Special Forces A-Team in both training and intense, close combat, conducting pre-deployment, deployment, and post-deployment operations, achieving all goals with zero U.S. combat losses. Led a 200-man combined US and Afghan Special Forces force in continuous combat operations, credited with significantly reducing the insurgent presence in the Kapisa, Kabul, Parwan, and Logar Area of Operations.
- Served as an advisor to national strategic-level Afghan security operations, and served in the position billeted for a Major, a rank above the level designated, due to superior performance. Completed three combat deployments to Afghanistan as part of Operation Enduring Freedom, and Operation Resolute Support Mission/Operation Freedom's Sentinel.

U.S. ARMY SPECIAL WARFARE CENTER AND SCHOOL/U.S. ARMY MANEUVER CAPTAINS CAREER COURSE/U.S. ARMY AIRBORNE SCHOOL, Fort Bragg, NC, and Fort Benning, GA

DREW HORN

November 2009 – January 2013
Infantry Officer/Special Forces Officer Candidate

- Successfully graduated as a Special Forces Officer, as a leader in a class of 205 Soldiers, from the US Army's Special Forces Accessions/Qualification Course, a program with a 15 percent graduation rate.
- Trained to high proficiency in the Pashto language, Direct Action Combat, Unconventional Warfare, Close Quarters Combat, Special Forces Martial Arts, Counterinsurgency, and Intelligence Operations tactics and methods.
- Conducted interagency training with the nation's premier intelligence and counter-insurgency agencies.

U.S. MARINE CORPS, Quantico, VA, Twenty-Nine Palms, CA, and Al Anbar Province, Iraq
October 2005 – November 2009
Marine Officer

- Trained as an Infantry Officer, Human Resources Officer, Legal Officer, Marine Corps Martial Arts Program Instructor, and Marine Corps Combat Swimmer.
- Commanded a Human Resources section of ten Marines and was responsible for the human resources support for the entire Battalion and served as the Headquarters and Service Company Commander and commanded 150 Marines and Sailors in Logistical Support Operations.
- Completed one combat deployment to Iraq as part of Operation Iraqi Freedom and provided Convoy Security and Logistical Support to Marines and Sailors throughout Al Anbar Province.

FLORIDA DEPARTMENT OF FINANCIAL SERVICES, Tallahassee, FL
February 2005 – September 2005
Accountant II

- Operated as an accountant in the insurance claim support department of the Florida Department of Financial Services.
- Processed millions of dollars of insurance payments to Florida businesses and citizens.
- Delivered insurance claim support to citizens recovering from Hurricane Katrina.

Chairman LUCAS. Thank you. I now recognize Dr. Mulvaney for five minutes to present his testimony.

TESTIMONY OF DR. DUSTIN MULVANEY, PROFESSOR OF ENVIRONMENTAL STUDIES, SAN JOSE STATE UNIVERSITY

Dr. MULVANEY. Good morning, Chairman Lucas, Ranking Member Lofgren, and other Members. Thank you for the invitation today.

Experts widely agree that there are serious risks posed by weak and fragile critical mineral and material supply chains to national security, domestic industries, and critical infrastructure sectors. I would like to emphasize continued and further support in several areas of research and regulation that would make critical mineral and materials supply chains more resilient and improve social and environmental outcomes.

Federal investments in research and development for critical minerals and materials will be greatly enhanced with comprehensive and enforceable standards. This includes policies that require extended producer responsibility, green design, and setting high benchmarks for recycled content in new materials, helping foster emerging domestic markets in recycled and recovered materials. These efforts in tandem with investments in research and development and setting comprehensive rules and standards will enhance critical material and mineral supplies and strengthen domestic supply chains. This will further reduce the need for primary extraction in mining activities and reduce the burden on local landfills, material recovery facilities, and the communities that they're located in.

The new battery regulation in the European Union released is a good starting point that could be replicated here for other products that contain critical minerals and materials. These rules require battery producers meet specified social and environmental standards across the entire lifecycle of the product, including an end-of-life management plan. Today, only 10 to 15 percent of lithium-ion batteries are collected in the United States. Recycling efforts could recover cobalt, nickel, manganese, lithium, graphite, aluminum, copper that would bring environmental benefits as well. Recycling can augment critical mineral and materials supplies. Some estimates suggest that recycled supplies could satisfy up to 25 percent of lithium, 35 percent For cobalt and nickel, and 55 percent for copper by 2040.

The reason these materials go uncollected is a lack of rules and regulations that require recovery and collection. According to the GAO (Government Accountability Office), most critical minerals such as rare earths are not collected for recycling on a large scale in part because of variations in recycling programs. U.S. recycling collection infrastructure is also outdated. Germanium and gallium are two critical minerals that are representative of challenges posed by a lack of extended producer responsibility. We do very little recycling of LEDs (light-emitting diodes), scrap materials, and everyday devices and appliances containing germanium and gallium-based semiconductors including microwaves, Blu-ray players, and other electronic products. No gallium is recycled in the

United States, and only small amounts of germanium are recovered and exported for recycling. The United States should develop regulations and invest in more efforts like the recently developed Defense Logistics Agency Program for recycling optical-grade germanium. That will result in supplying up to 10 percent of the materials needed for the next generation of equipment in a few years.

Finally, avoiding toxic materials in electronic products and devices are also critical to adjust an equitable circular economy. Effective public policy that reduces toxic exposures can help ensure workers and communities where recycling and recovery facilities are located will not be harmed by the operations of these infrastructures. Utilizing the purchasing power of the Federal Government could also be used to set some of these standards through procurement.

Waste is also an important resource for critical metals. Policies and practices that encourage waste and tailings use at mine sites is another strategy to augment critical mineral supplies. Recovering from mine waste could be pursued alongside environmental remediation where work to process materials may be underway for cleanup already.

Material recovery in mining and downstream processing in the market is optimized for profitability, not maximizing materials or byproducts. More incentive to develop byproducts, recover materials at smelters, or increase recovery rates could help drive up the recycling of these materials. Smelters in the United States, for example, are not designed to recover many critical minerals. For example, there are no domestic smelters that can recover cobalt.

We can increase the resource efficiency of many of the materials we use today as well. A photovoltaic module today, thanks to increased resource efficiency, uses about five times less silver than a module 10 years ago. Similarly, semiconductor wafers for the same technology are two to three times thinner than just a decade so we could avoid using polysilicon. This is translated to lower energy inputs and silicon feedstocks needed for the solar industry.

Some critical materials—minerals are used dissipatively in lower concentrations than found in ores, and these should be avoided. Some screenings of critical minerals have found that most have dissipated use rates over 50 percent, which is consistently much higher than other metals.

The social and environmental benefits of developing a circular economy for critical minerals and materials supplies are manyfold. Other implications of expanded recycling collection systems for materials include job creation, infrastructure investment, and workforce development.

I appreciate the opportunity to speak before you and look forward to any questions you might have.

[The prepared statement of Dr. Mulvaney follows:]

Testimony of Dustin Mulvaney, Professor,
Environmental Studies, San José State University,
House Committee on Science, Space, and Technology
The Role of Federal Research in Establishing a Robust U.S. Supply Chain of Critical Minerals and Materials
Thursday, November 30, 2023

Introduction

Good morning, Chairman Lucas, and Ranking Member Lofgren, thank you for the opportunity to testify before this committee.

My name is Dustin Mulvaney and I am a Professor in the Environmental Studies Department at San José State University, and a Fellow at the Payne Institute for Public Policy at the Colorado School of Mines. This testimony reflects my views and expertise on the subjects of critical minerals and materials, supply chains, and circular economy.

Whether it is "critical minerals" or "strategic and critical materials," experts widely agree that there are serious risks posed by weak and fragile critical mineral and material supply chains to national security, domestic industries, and critical infrastructure sectors. The United States in 1973 was the top producer of non-fuel minerals, and that position 50 years later has been ceded largely overseas, making the United States import dependent on many critical minerals and materials. The very existence of national strategic stockpiles reflects these dynamics and the consequences of supply chain disruptions to national defense or disaster response.

Lawmakers in the United States have recognized this in a series of public policies—including the 2020 Energy Act and 2021 Infrastructure Investment and Job Act (IIJA), as well as other executive actions intended to strengthen the resilience of supply chains, which will have the added benefits of geographic diversification, reduced environmental impact, and spurring innovation.

I would like to emphasize continued and further support in several areas of research and regulation that would make critical mineral and material supply chains more resilient and improve social and environmental outcomes.

1. **Promote more circular economy approaches to the critical minerals and materials management**

To promote more circular approaches to critical mineral and materials use, we need both carrots and sticks. We need investments in research and development in everything from basic science to pilot production facilities. But at the same time, there are enormous gaps in the critical mineral and materials loop before we realize a circular economy that warrant attention. Recovering and reusing critical minerals and materials from waste flows will help close these gaps.

Federal investments in research and development for critical minerals and materials will be greatly enhanced with comprehensive and enforceable standards. This includes policies that require (1) extended producer responsibility—holding producers responsible for the safe disposal of products they make, (2) green design—requiring products be made of safer materials that are easier to recycle, and (3) setting high benchmarks for recycled content in new materials, helping foster emerging domestic markets in recycled and recovered materials.

These efforts in tandem—investments in research and development, and setting comprehensive rules and standards—will enhance critical mineral and material supplies and strengthen domestic supply chains. This will further reduce the need for primary extraction and mining activities and reduce the burden on local landfills, materials recovery facilities, and the communities they are located.

The new battery regulation in the European Union released in August 2023 is a good starting point for a circular economy approach to managing lithium-ion batteries that could be replicated here and for other products that contain critical minerals and materials. The rules require that battery producers meet specified social and environmental standards across the entire life cycle of the product including a product end-of-life management plan.

2. **Require extended producer responsibility, take back and collection systems, and avoid toxic materials in products**

A similar take back program for lithium batteries as Europe has would close an important gap as only 10% to 15% of lithium ion batteries are currently collected in the United States. Recycling efforts could recover cobalt, nickel, manganese, lithium, graphite, aluminum and copper, and would bring environmental benefits as well. Recycling can significantly augment critical minerals and materials supplies. Some estimates suggest that recycled supplies could satisfy up to 25% for lithium, 35% for cobalt and nickel and 55% for copper, based on projected demand and technology adoption scenarios. According to the Copper Alliance, less than 40% of global copper is currently recycled. According to research from Fraunhofer Institute for Systems and Innovation, 2/3rds of end-of-life copper are sent to landfills annually. Recycling some critical minerals and materials can avoid up to 90% of the energy used to produce them from natural resources.

The reason these materials go uncollected is the lack of rules and regulations that require their recovery and collection. According to a 2022 GAO report, “DOE officials stated that most critical minerals, such as rare earth elements (REE), are not collected for recycling on a large scale, in part because of variations in recycling programs” (p 16, GAO 2022). Where recycling infrastructure is in place, “according to a US EPA report, U.S. recyclable collection infrastructure is outdated.” (p. 17, GAO, 2022).

Germanium and gallium are two critical minerals and materials that representative of challenges posed by a lack of extended producer responsibility. They were in the news last August (2023) as critical minerals that would be restricted from export by China. Yet we do very little recycling of LEDs, scrap materials, and everyday devices and appliances containing germanium- and gallium-based semiconductors including microwaves, blue ray players, and other electronic products that are often landfilled today. No gallium is recycled in the United States and China produces 98% of that global supply. Only small amounts of germanium are recovered and exported for recycling. Germanium and gallium often are alloyed in a way that complicates recovery. Use of critical minerals in low concentrations in alloys like this is another area where research into substitutes could allow more minerals to be available for green infrastructures.

The U.S. should develop regulations and invest in more efforts like the recently developed Defense Logistics Agency program for recycling optical-grade germanium used in military weapons systems that will result in supplying up to 10% of the materials needed for next generation equipment in a few years.

Finally, avoiding toxic materials in electronic products and devices are also critical to a just and equitable circular economy. Effective public policy—much like Europe's Restriction on Hazardous Substances—that reduce toxic exposures can help ensure that workers and communities where recycling and recovery facilities are located will not be harmed by the operations of these infrastructures.

Utilizing the purchasing power of the federal government could be used to set some of these standards through procurement. The US EPA encourages the use of the EPEAT standard for federal purchases and this standard could be utilized to encourage emerging markets in recovered critical minerals and materials by, for example, requiring certain percentages of recycled content in federal purchases, avoid materials of concern in product, or that producers have a take back and collection program. This would send market signals to would be recyclers. However, private certifications like these are sometime the only option absent regulation; comprehensive extended producer responsibility is still the most effective path to recovering end-of-life critical minerals and materials.

3. **Recover more critical minerals and materials from waste at industrial sites and increase resource efficiency**

Waste is an important resource for critical metals. With over 400,000 to 500,000 abandoned mines in the United States, according the several estimates, policies and practices that encourage waste and tailings use at mine sites is another strategy to augment critical mineral supplies. There are also opportunities to recover these materials from coal ash, red mud, slag piles, mine tailings, and other wastes. Critical minerals and materials recovery from mine waste could be pursued alongside environmental remediation, where work to process materials may be underway anyways for cleanup.

To help encourage more critical minerals and materials from waste flows, lawmakers should augment IIJA investments in recycling processes. Product materials are complex and require experimentation with different technique from chemical processing to materials science. More innovative methods and techniques for critical materials recycling should continue to get support to clean up legacy mine sites and procure more critical minerals and materials from waste.

Materials recovery in mining and downstream processing in the market is optimized for profitability not maximizing materials or biproducts. More incentives to develop biproducts, recover materials at smelters, or increase recovery rates could help drive up recycling of materials. Smelters in the United States are not designed to recover many critical minerals; for example, there are no domestic smelters that can recover cobalt.

We can increase the resource efficiency of many of the materials we use today. There are excellent examples of resource efficiency avoiding significant amounts of critical minerals and materials. A photovoltaic module today, thanks to increased resource efficiencies, uses about five times less silver than a photovoltaic module yesterday. Similar, semiconductor wafers in the same technology are two to three times thinner than just a decade ago, avoiding polysilicon. This has translated to lower energy inputs and silicon feedstocks needed for the solar industry. We could recover even more with better take-back and collection programs.

There are other ways to increase resource efficiency across society as well. In a recent report from the Climate and Community Project they found up to 90% of lithium demand can be reduced by encouraging public transportation and more lightweight electric vehicles and other modes of transportation.

4. **Avoid dissipative uses of critical minerals and materials and increase input substitution.**

Some critical minerals and materials are used dissipatively, in lower concentrations than found in ores. Steel for example uses very low quantities of tellurium and aluminum and recovering such low concentrations requires correspondingly more energy. Innovations in materials science to replace materials used dissipatively which if substituted can be found can augment critical minerals supplies. Some screenings of critical minerals have found that most have dissipative use rates over 50%, which is consistently much higher than other metals.

Research that develops substitutes and alternatives to critical minerals and materials as sustainable ways to secure domestic supplies. This would help mitigate extensive impacts from extractive industries, which can be poorly regulated and environmentally-damaging. The critical mineral of concern a few years ago for lithium-ion batteries was cobalt. In a few short years, projections for use of cobalt—75% of which according to Benchmark Minerals currently goes to making lithium-ion batteries—has fallen dramatically with lowering of cobalt content and advances non-cobalt batteries. Companies concerned about bottlenecks and reputational risks have begun to eschew cobalt supply chains. We are already seeing companies move away from nickel and manganese as well in next generation in lithium iron phosphate batteries.

These shifts in technology are sometimes beyond the horizon. We do not necessarily know the battery chemistries and composition of tomorrow's lithium-ion batteries, how do we know which materials to prioritize for development today? The next generation batteries may have no lithium at all. We are also seeing the development of non-lithium batteries. One of the largest battery makers in the world BYD announced in August 2023 a partnership to build sodium-ion batteries and has plans to put in a popular and inexpensive electric vehicle. It is not clear how widespread this technology will eventually be, but it is a perfect of example of how materials demand can change in a short time. Not far off in the future, we are likely to see batteries that altogether avoid graphite, currently used as the anode in 95% of lithium-ion batteries today, as well.

5. **Conclusions**

The social and economic benefits of developing a circular economy for critical minerals and materials supplies are manyfold. Other implications of expanded recycling and collection systems for materials include job creation, infrastructure investments, and workforce development. Developing a value chain for various critical metals here in the United States can help buffer supplies that might be vulnerable to disruption. Developing leadership in this space could result in valuable industry as the value of battery recycling alone is poised to be over $95 billion per year by 2040 (McKinsey 2023).

I appreciate this opportunity to speak with you and look forward to any questions you might have. I will add supporting documentation for the points I've raised to the record. Thank you for your time and attention.

Dustin Mulvaney is a Professor in the Environmental Studies Department at San José State University (SJSU) and a Fellow with the Payne Institute for Public Policy at the Colorado School of Mines. His areas of expertise and research are on land use change, life cycle analysis, recycling & waste, and the environmental justice impacts of energy technologies, supply chains, and infrastructures. He has published research on numerous energy technologies with extensive emphasis on the life cycle impacts of solar photovoltaics and lithium-ion batteries, and has a Ph.D. in Environmental Studies from the University of California, Santa Cruz, a Master's of Science degree in Environmental Policy Studies, and a Bachelor's of Science degree in Chemical Engineering, from the New Jersey Institute of Technology. Professor Mulvaney's professional private sector experience includes work in chemical manufacturing, environmental remediation, and environmental consulting. He has been an expert witness at the California Public Utilities Commission for 13 years, and has participated in the development of waste, land use, and energy policy with California legislators, and state and county agencies over the past decade. Professor Mulvaney serves on the Technical Advisory Committee to the Recycling and Waste Reduction Commission of Santa Clara County, the Technical Committee for an Ultra-Low Carbon Solar Standard for photovoltaics recently developed by the Green Electronics Council, and is part of the Lithium Valley Equity Technical Advisory Group advising Comite Civico del Valle on issues related to the development of geothermal and lithium near the Salton Sea in Imperial County, California.

Chairman LUCAS. Thank you. I now recognize Mr. Baroody for five minutes to present his testimony.

TESTIMONY OF MR. THOMAS E. BAROODY,

PRESIDENT & CHIEF EXECUTIVE OFFICER,

K-TECHNOLOGIES, INC.

Mr. BAROODY. Good morning, Chairman Lucas, Ranking Member Lofgren, and Members of the Committee. I want to thank you for the invitation to be on this excellent panel today.

As one of the representatives of the private sector, it is my hope that I can provide information and perspective as you consider the vital topics of Federal research and prudent taxpayer spending married with the private sector initiatives and risk-taking in critical minerals. Time is of the essence, and the task is urgent. Rare earth elements are available from multiple sources such as high-grade mineral ores, low-grade ionic clays, waste materials like phosphogypsum, coal mining, tailings, and end-of-life magnets.

Each source requires different methods to liberate the valuable rare earths. For practical economic purposes, these initial processes must be undertaken at the source location. Intermediate products from the source location are exported primarily to China as a mineral concentrate. These intermediate products are then processed to produce the purified rare earth oxides which feed the metal and alloy manufacturers, who in turn supply the magnet manufacturers. Presently, the final stage of REE processing is performed by an environmentally unfriendly solvent extraction process, which is independent of the rare earth source. China is a heavy and dominant player on this end of the business.

I would like to talk today about some of the successful projects K-Tech is engaged in and what we're doing to advance the goal of bringing critical minerals into the United States. K-Tech has specialized in developing and bringing to market chemical processing applications to extract desirable commercial-grade elements and other materials. We have been researching and developing our CIX/CIC technology for application to rare earth separation and purification for several years and are seeing excellent results. The CIX/CIC process has numerous advantages over the conventional solvent extraction route in terms of economic safety, environmental impact, and size of the production plant, with much lower capital and operating costs.

Rainbow Rare Earths is an innovator in bringing rare earths to market. They have focused on permanent magnet rare earth elements neodymium, praseodymium, dysprosium, and terbium. These elements are categorized by the U.S. Government as being vital in both the short term and the medium term. Rainbow, which is traded on the London Stock Exchange, desires to have its products processed and used in the United States, North America, and allied European markets. Their corporate strategy meshes well with the Department of Energy's July 2023 critical minerals assessment. That strategy document focuses on diversifying and expanding U.S. suppliers, developing alternative manufacturing processes, enhancing manufacturing efficiency to reduce waste, and international engagements that benefit the United States.

Rainbow is developing its Phalaborwa project in South Africa to recover rare earths from phosphogypsum and has opted for K-Tech's CIX/CIC process for the separation and purification of the rare earths. The South African project, along with a future one in Brazil, present a unique opportunity for K-Tech to utilize its process, allowing separated rare earth oxides to be produced independently from China for sale to the United States and allowing development of a U.S. supply chain. If Rainbow is successful in developing a Brazilian operation like it plans in South Africa, the back end of the process facility—that's K-Tech's system—could be logically located in the United States. I understand that Rainbow has started the project—the process to consider potential sites for a commercial plant in the United States. This would greatly benefit U.S. production of critical rare earth materials.

K-Tech is currently concluding bench-scale testing on the Phalaborwa material from South Africa and has assembled a pilot plant for Rainbow South African material at its Florida facility. The process in Florida will allow production of separated rare earth battery metal oxides on a commercial basis in the United States. That represents a major step forward in bringing this type of supply to the United States.

I would also like to stress we are doing something else that makes the United States unique, developing significant intellectual property that ensures our Nation is the technical logical leader for decades to come. My colleague Wes Berry, the company, and I hold eight patents, soon to be nine, and K-Tech and Rainbow are jointly progressing a patent application for our process in the United States.

K-Tech is highly supportive of the Federal Government's effort to support domestic and foreign sourcing, processing, research, and funding. The Departments of Energy, Defense, Commerce, and the U.S. Development Finance Corporation (DFC) are playing a key role in unlocking capital to promote opportunities in critical minerals. Rainbow has entered into an option agreement whereby TechMet has the right to invest $50 million to fund a substantial part of the equity component of Rainbow's project in South Africa. The DFC is an important shareholder in TechMet.

In conclusion, the United States has always led the world in the field of science. At K-Tech, we are devoted to further science that leads to better and practical outcomes in the area of critical minerals. I would like to thank the Committee for the opportunity to provide you with testimony today. Thank you.

[The prepared statement of Mr. Baroody follows:]

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

U.S. House of Representatives

Committee on Science, Space and Technology

November 30, 2023

Testimony of Thomas E. Baroody

President and Chief Executive Officer

K-Technologies, Inc.

Lakeland, Florida

INTRODUCTION

Good morning, Chairman Lucas, Ranking Member Lofgren, and members of the Committee. I want to thank you for the invitation to be on this excellent panel today. As one of the representatives of the private sector today, it is my hope that I can provide you all with information and perspective as you consider the vital topic of federal research and prudent taxpayer spending married with private sector initiatives and risk-taking. Taken together, I believe we are building a more robust and diverse U.S. supply chain of critical minerals and materials. Time is of the essence and the task is urgent.

RARE EARTH ELEMENTS AND THE HISTORIC CHALLENGE OF PROCESSING

Rare Earth Elements (REE) are available from multiple sources such as mineral ores (generally higher grade), ionic clays (generally lower grade, bulk tonnage) and waste materials (phosphogypsum (PG), phosphoric acid sludges, coal mining tailings, end-of-life magnets). Each of these sources require different methods to liberate the contained REE, such as gravity concentration, flotation, hydrometallurgical, and pyrometallurgical processes.

For practical and economic purposes these initial processes must be undertaken at the source location. Intermediate products are then exported (predominantly to China) as a mineral concentrate, typically 40% to 60% contained Rare Earth Oxides (REO) or as a precipitate such as Mixed Rare Earths Carbonate (MREC). These concentrates and MREC intermediate products are then processed to produce separated and purified REO which feed the metal and alloy manufacturers who in turn supply the magnet manufacturers.

Historically, and presently, the final stage of separating and purifying the REE is performed by a highly inefficient, and environmentally unfriendly, Solvent Extraction (SX) process which is independent of the REE source. This SX process requires hundreds of mixer-settlers and virtually all of the world's REE are produced this way in China.

K-TECH AND THE COMMERICAL INDUSTRIAL PROCESS

I would like to talk today about some of the successful business projects K-Tech is engaged in and what we are doing to advance the goal of bringing critical minerals into the U.S.

Over the past 15 years, K-Tech has specialized in developing and bringing-to-market chemical and processing applications to extract desirable, commercial grade elements and other materials. Several alternative technologies to SX are being researched and developed in the West and by K-Tech. The most prospective of these technologies, for early adoption, is Continuous Ion Exchange and Continuous Ion Chromatography (CIX/CIC). This technology has been applied in production facilities for a variety of industries around the world for decades and has been the focus for technology development at K-Tech since 1987, including for REE.

K-Tech has been researching and developing CIX/CIC for application to REE separation and purification for several years and has demonstrated the ability to separate REE with its CIX/CIC process as a result of this research.

The CIX/CIC process has numerous advantages over the conventional SX route in terms of economics, safety, environmental impact, and size of plant, with much lower capital and operating cost intensity.

Over the past several years the REE markets and supply chain have seen some rather dramatic movements, and the global market now realizes that REE from other sources, both from a feedstock (i.e.; mining, waste tailing stacks, or recycled scrap) and geographical standpoint, are needed. As such, there has been a significant increase in REE sourcing assessments and evaluation of alternate feedstock sources.

It is worth emphasizing that often we are utilizing ore from waste by-products of other mining or processing projects from years ago. By using mining waste as a feedstock, we are in a win-win situation whereby critical minerals are being extracted at a lower, commercially viable cost at a benefit to the environment.

It is well known that many phosphate rock sources contain some level of REE, but the concentrations tend to be low, i.e., in the parts/million to hundreds of parts/million. It is also known that during the phosphate rock digestion process to produce phosphoric acid, the majority of the REE is not dissolved, but remains in the phosphogypsum waste. However, some percentage of available REE does dissolve into phosphoric acid and this is where K-Tech had initially focused its recovery efforts.

As an example, in the production of wet process phosphoric acid, elements such as uranium, rare earths, yttrium, vanadium, cadmium, fluorides, and silica are usually present in small quantities. K-Tech's extraction technologies can treat large volumes of intermediate process streams like phosphoric acid in a continuous manner, and isolate and recover certain desired target elements in a highly concentrated low volume solution. This solution in turn can then be treated separately to produce one or more target elements as marketable products.

THE EXAMPLE OF RAINBOW RARE EARTHS

Rainbow Rare Earths Limited (Rainbow) is in the business of establishing an independent and ethical supply chain of the rare earth elements that are driving the green energy transition and the most advanced defense articles and systems. They have a focus on the permanent magnet rare earth elements neodymium, praseodymium, dysprosium and terbium. All four of these elements are categorized by the U.S. Government as being vital in both the short term and medium term.

I note that Rainbow, traded on the London Stock Exchange, desires to have its products processed and used in the U.S., North America, or allied European markets.

Their corporate strategy meshes well with the Department of Energy's critical mineral strategy detailed in the department's July 2023 "Critical Materials Assessment". That strategy document focuses on diversifying and expanding U.S. supplies, developing alternative manufacturing processes, enhancing material and manufacturing efficiency to reduce waste, and assisting in stockpiling and international engagements to benefit the U.S. (https://www.energy.gov/sites/default/files/2023-07/doe-critical-material-assessment_07312023.pdf)

Rainbow is developing its Phalaborwa REE project in South Africa to recover REE from phosphogypsum and has opted for the CIX/CIC process with K-Tech for the separation and purification of the REE to produce the selected REO products. This presents a unique opportunity for K-Tech to utilize its process allowing separated REO to be produced, independently from China, for sale to the U.S. and allowing development of a U.S. down-stream supply-chain including specialist alloy, REE permanent magnets, drive trains, and ultimately EV/wind turbine manufacture. From a national defense standpoint, magnets are a driving force behind continuous innovation in defense technology such as precision-guided munitions, tank navigation systems, and electronic countermeasures equipment. Without guaranteed independent supply these investments could not be made in the US.

The Rainbow process to produce rare earths from historic industrial waste, cleans up legacy environmental issues and delivers a true circular economy benefit – not just producing REE from waste, also allowing the cleaned gypsum residue to be sold for agricultural/construction purposes.

Rainbow is also focusing on other global opportunities, including recovery of REE from PG waste from Mosaic Fertilizantes' Uberaba operation in Brazil owned by The Mosaic Company, a New York Stock Exchange listed U.S. multinational. That project is at an earlier stage of development, but the Brazilian undertaking is currently operating and would involve processing a great deal more PG over a much longer life than in South Africa.

The overall process is split into two major parts:

1) Front-end - production of a mixed REE carbonate from the PG, along with restacking of the cleaned-up benign PG into the new lined stack for sale;
2) Back-end - processing of the REE carbonate through K-Tech's propriety CIX/CIC system to produce the four target REE oxides.

If Rainbow is successful in developing a Brazilian operation like it plans in South Africa, the back-end of the processing facility (K-Tech's CIX/CIC system) could logically be located in the U.S. I understand that Rainbow is starting the process to consider potential sites for a commercial plant in the U.S. If so, this would greatly benefit U.S. production of critical rare earth materials.

K-Tech is currently concluding a bench scale test program on the Phalaborwa material and has assembled a CIX/CIC pilot plant for Rainbow at its Lakeland, Florida facility. This pilot plant will commence operation shortly on samples of MREC shipped from Rainbow's pilot plant operation in South Africa, to demonstrate the production of on-specification separated REO for the alloy and magnet industry. The process in Lakeland will, for the first time, allow for the production of separated REE battery metal oxides on a commercial basis in the U.S. That represents a major step forward in bringing this type of supply into the U.S.

I would also like to stress that by both public financing, private capital, and U.S. research we are doing something else that makes the U.S. unique—developing significant intellectual property that ensures our nation is the technological leader for decades to come. At K-Tech, my colleague Wes Berry (CTO of K-Tech), the company, and I hold eight patents (soon to be nine as one is scheduled to be issued in December 2023), of which three have been sold to a third party. Also, our CTO was the inventor of the CIX/CIC process, and holds some thirty other patents. The Rainbow and K-Tech process teams have developed an innovative process to recover REE from PG which has the potential to unlock the vast resource of this material worldwide with a significant environmental benefit for these polluted sites. Rainbow and K-Tech are jointly progressing a patent application for the process to be lodged in the U.S.

ROLE OF FEDERAL GOVERNMENT

K-Tech is highly supportive of the federal government's efforts to support domestic and foreign sourcing and processing, research, and project funding to diversify a secure and sustainable supply chain for minerals that are vital to our national defense and the global economy. Programs undertaken by the Departments of Energy, Defense, and Commerce and the U.S. International Development Finance Corporation (DFC) are playing a key role in unlocking capital to fund promising opportunities in mining and processing of REEs and other critical minerals.

I understand that Rainbow has entered into an option agreement whereby TechMet has the right to invest US$50 million to fund a substantial part of the equity component for Rainbow's project in South Africa. The DFC is an important shareholder in TechMet.

At the state government level, we work closely with the Florida Industrial and Phosphate Research Institute (FIPR) affiliated with the Florida Polytechnic University. K-Tech, FIPR, and Pacific Northwest National Laboratory (PNNL) are currently cooperating on a joint submission to DOE for funding to examine the extraction of REE from phosphoric acid sludges. Also, in 2014-15, K-Tech worked with Texas Mineral Resources Corp. (TMRC) on a DOE grant to successfully recover several targeted high purity REE from TMRC's Round Top rhyolite orebody in West Texas. K-Tech also participated with TMRC, and two other entities, in recovering REE from coal fly ash waste from a Pennsylvania coal mine under a DOE grant in 2017-18.

CONCLUSION

Science at its essence is about trial and error—experimentation based on systematic methodology based on evidence. The U.S. has always led the world in the field of science. At K-Tech we are devoted to furthering science that leads to better and practical outcomes in the area of critical minerals.

I would like to thank the Committee for the opportunity to provide you with testimony today. This Committee and all the other Congressional committees with jurisdiction over the federal government's role in shaping policy on science and technology, national security, foreign relations, and appropriations must continue to be well-versed on the rapidly changing environment on critical minerals.

Thomas E. Baroody
Biography

My name is Thomas E. (Tom) Baroody. I was born in Richmond, VA, and lived there through my elementary school days and one year of high school. Then I moved to Geneva, NY, where I graduated from high school, and where I played football, basketball, and baseball. After that I attended Rensselaer Polytechnic Institute, graduating in 1967 with a BCE degree. I played football and baseball for RPI during my time there. I then attended the University of Missouri-Columbia, getting an MSCE degree in 1969.

After college I started working as a staff engineer for AMAX Inc., which was a large mining company with diversified operations around the world. While at AMAX, I progressively worked my way up to a VP of their chemical division, having lived in New York City, Stamford, CT, and then Lakeland, FL., where I have resided since 1980. During my career, I have traveled to some 50 countries in the world mostly on business related to iron ore mining and processing, and later to phosphate and potash mining and processing.

After leaving AMAX in 1986, I started my own consulting business TEBCO Associates LLC, and K-Technologies, Inc. with a partner, both in 1987. As TEBCO, I have undertaken many technical, marketing, and economic studies for a number of private companies and several government agencies. At K-Tech, we got our start by providing a new technology (CIX) for a U.S. based company to build a potassium carbonate production facility, and later expand into a separate plant that produced technical grades of certain phosphate products.

After that, we expanded K-Tech's private shareholding to 15, and have worked with a number of companies around the world in providing our CIX/CIC technologies for use in various industries. These include the extraction, separation, and purification of materials such as uranium, rare earths, fluorides and silica, and certain deleterious elements from phosphoric acid. We can also do the same thing from leach solutions of various mineral ores, and from waste materials like phosphogypsum, acid mine drainage and sludges, and scrap. The company has also undertaken separations of organic materials like tocopherol/sterol mixtures leading to production of Vitamin E, as well as target proteins from plant-based feed stocks, leading to production of various meat and dairy products. We have been granted 8 U.S. patents with one more being issued in December.

During the 1996-2000 period I was a senior VP at Mulberry Corporation, a privately held company which owned and operated a phosphate mine and two phosphate chemical plants in Central Florida. I was in charge of successfully revitalizing one of their chemical plants and restarting and expanding their phosphate rock mine.

During the 2003-2006 period, I worked as COO for an entrepreneur who started a company to develop a large ammonia/UAN project that would be built in Trinidad.

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November 28, 2023

Chairman LUCAS. Thank you, and I want to thank the witnesses for their testimony.

The Chair recognizes himself for five minutes.

Establishing secure and abundant supply chains of critical minerals and materials is a global grand challenge. Now, I'd like to hear from each of you, if the United States continues to rely on foreign nations to supply and process these resources, what kinds of vulnerabilities are we exposing ourselves to in the terms of national security, economic expansion, clean energy potential? The floor is yours, gentlemen.

Mr. BAROODY. I'll answer that from a rare earths perspective and some of the other critical metals. China is a big producer of rare earths, both intermediate products and the finished products. They account for anywhere from 80 to 90 percent of the rare earths produced and used in the world today. I think we need to bring the chain over here to the United States and have the United States be the producer of record that can carry forward and offset this tremendous dependence on China.

Chairman LUCAS. Please, Doctor.

Dr. CAERS. Yes, I'd like to talk about two elements, lithium and copper. Lithium, as you perhaps know, half of the world's lithium is mined in Australia. The biggest mine is called the Greenbushes mine, and the majority ownership in that mine is China. So even though we think about Australia as a friendly country, lots of mining and processing is actually done by China.

The Salton Sea component, I don't share the optimism of my colleagues in the lab, and so do many experts internationally on lithium, and the reason for that is that about—the lithium concentration in Salton Sea is very low, about 200 ppm (parts per million). I compare that with, for example, Chile has a 1400 ppm lithium. One of the big problems with lithium extraction or called direct lithium extraction (DLE) is the many impurities, as well as other elements that are existing in these brines such as calcium and magnesium. Now, battery-grade lithium is about 99 percent pure lithium, so to go from a dirty brine so to speak into a 99 percent—7 percent lithium is something that has not been shown to be at scale. Only pilot plants have been shown to work but not large manufacturing.

In terms of copper, I'd like to note that the United States is actually mining copper at a decreasing concentration, now at 0.39 percent. Just to give you an idea of what that means, it means that if you excavate 1 ton of copper, you get 14 and—1 ton of material, you get 14 ounces of copper. If you do this in Zambia, what you are doing with Coble Metals, you get about 200 ounces of copper. That means that we in this country have to move 10 to 20 times more material into—on the earth to do that. So that means that if we continue mining this way, it's just not responsible. We have to discover deposits with high-grade copper. These are just harder to find, and that's also why my testimony was more around discovery, but particularly discovery of high-grade material and not constantly mining this very low-grade copper deposits.

Chairman LUCAS. Anyone else wish to touch that? Yes, Mr. Horn.

Mr. HORN. Mr. Chairman, I think that what you're referring to talks about vulnerability from not just a national security perspective, but from an economic security perspective and even environmental. You know, my background is in some ways not as distinguished as my fellow witnesses here. I'm just a former, you know, Green Beret with an MBA, so I kind of have a tendency to state things bluntly, maybe too bluntly at times.

But I would say, you know, right now, if we don't take corrective action, the situation is dire. We are in an existential crisis right now where two of our largest adversaries control everything that we need to conduct any sort of strategic engagement with them, should it come to that. And while we hope that that won't happen, we've seen what's happened in Ukraine. We've seen some of the events in Gaza. We've seen some of the events that are building in the South Pacific. We simply cannot allow vital materials to be dependent upon the interest of our adversaries who have in the past shown they will leverage that position much to their favor and to our disadvantage.

So I would say we have the materials here in the United States. We used to control this industry. I think we can, again, should we take the necessary corrective action. We have the best technology. We have the highest standards of oversight, environmental and social protection. Bear in mind that folks driving Teslas sadly need to be aware of where some of those materials are sourced from.

And I will say that some of the material sourced as a part of the electrification are simply coming from child slave labor run by the PRC (People's Republic of China) on the other side of the planet. We cannot allow our electrification and our technology transfer to be dependent upon such deplorable techniques, tactics, and practices. We have the ability and the need to own this again in the United States.

Chairman LUCAS. Thank you. My time has expired. I now recognize the Ranking Member, Ms. Lofgren, for her questions.

Ms. LOFGREN. Well, thank you, Mr. Chairman, and thanks to the entire panel for very instructive testimony.

You know, I was talking to some of my constituents not too long ago, and they were talking about rare earth as if it was so rare, it couldn't be found. And that's—actually, that's not the definition of rare earth. So it's really unfortunate in a way that that's the title, and it's really a matter of identifying and exploiting this opportunity for our benefit.

But I wanted to turn to the situation of the Salton Sea and lithium. Dr. Caers, your recent answer was depressing. I chair the California Democratic Delegation. We had—you know, we meet every week, and one of the topics was the lithium in the Salton Sea. And some of the information we were receiving was really more optimistic than what you have just described. Obviously, the concentration level is low, but also, it doesn't need to be mined. I mean, it's—it needs to be extracted from liquid, which is a whole different implication. What do you see—and I want to ask Dr. Mulvaney and others here—that—is there an opportunity to apply our science community to methods that might make this resource more accessible to us in your judgment?

Dr. CAERS. Yes, so to make it more accessible, we have to understand the entire system better. So the Salton Sea is a geothermal brine, so these are fluids or—that sit in the subsurface. So one of the things that's actually not quite understood is how are these fluids moving in the subsurface? How is this affecting the groundwater system? Because once you start pumping material out, you know, the earth starts to react by—in various ways, so that is not very well understood. So I think more funding needs to go in understanding the entire system.

The other thing we have to understand also better is the environmental consequences of the direct lithium extraction. If indeed the direct lithium extraction is not as good as it should be, then we still need to use freshwater and evaporation. So we need to—and that, of course, in the Salton Sea is a big issue.

The other thing is that in the Salton Sea—and my colleague will talk more about that—is the environmental justice concerns. I have a student Sergio Lopez who was the first person to go knock on people's door in the Salton Sea and actually talk to the community. People who do environmental science, people who work in industry, I think, you know, it will be also great for them to get more involved with those communities and see what their needs are. So see it more as a system approach, and I think that will help us better understand what the consequences are of extraction.

Ms. LOFGREN. Thank you for that. You know, the Salton Sea actually was a mistake was its origin. It's not—and now, of course, it's an environmental hazard with the winds. And what was described to us yesterday was extraction but then recharge to avoid the subsidence issue that is of concern.

Dr. Mulvaney, do you have any comments on this? Is this going to be an important resource to us or not?

Dr. MULVANEY. I think it depends. I think there's a lot to—that still has to play out there. I am working with an environmental justice group in the area. I'm on the Lithium Valley Equity Technical Advisory Group, so I don't have the technical background that my colleague to my right here has. But there are issues with water use and things like that that still need to be sorted out and evaluated. But I'm not sure we know the full answer. There are three current developments in progress right now where they're working on this. One is just doing straight-up lithium extraction, one's doing it with geothermal, and then there's an existing geothermal plant that's also working on lithium development.

I think a lot of this is also dictated by the price for lithium. If people have been following the market, the price of lithium has fallen pretty significantly, so that might dictate whether or not the Salton Sea is economically viable mining, and obviously, it's very—commodities with their prices bouncing around makes things a bit more challenging. But I don't know if we have the answer yet.

Ms. LOFGREN. Right. My time is almost up, but I'm hoping that after this, you can describe more of the recapture of lithium because, obviously, if we're only recycling 10 to 15 percent, we're wasting a lot of a resource. How much of it is in consumer goods? How much in commercial goods because that would lead to different endeavors in terms of recoveries.

My time has expired, Mr. Chairman. I yield back.

Chairman LUCAS. The gentlelady's time has expired.

The gentleman from Florida, Mr. Posey, is recognized for five minutes for his questions.

Mr. POSEY. Thank you, Mr. Chairman.

Mr. Horn, what has been your experience of converting federally funded R&D projects into full commercialization? Mr. Horn?

Mr. HORN. Federal funding is key to unlocking private capital and to moving projects forward. I've seen multiple examples of successful deployment across the spectrum from battery materials such as the lithium that's been described, to rare earths. Referencing several projects in California from the previous conversation, there's several that have been supported in various capacities by Federal research and development dollars, and I think that it's brought about the right kind of development that you're looking for.

I think there needs to be more. I speak representing the investor base that's looking to pour private capital into the right projects here, and I can tell you that the appetite for their deployment is entirely enabled and encouraged by deployment of these Federal funds. So I'd say that they're critical, and I hope that that answers the question to the degree you're looking.

Mr. POSEY. Yes, it does. Thank you very much.

What could Congress do to encourage it?

Mr. HORN. I think proper oversight and allocation of funding to state the obvious. The biggest thing needed would be to ensure that public capital is directed toward projects that, you know, simply put, are winners. You know, as I stated in my testimony, we've got multiple projects our partners are working on that would essentially provide the entire U.S. demand for heavy rare earths that go into every single EV, phone, commodity, you name it. So that is within our fingertips' reach, should we be able to provide additional funding capital and commonsense permitting to allow us to bring this to full commercialization. It's very close.

Mr. POSEY. As another witness mentioned previously, China announced export restrictions on germanium and gallium and recently included natural and synthetic graphite. You know, will these export restrictions harm our national security, our space industry, our supply chain? And, you know, Mr. Horn and Mr. Peay, I'd like you to respond to that.

Mr. HORN. We're incredibly vulnerable right now. The Chinese Government has shown their hand and their plan. They have not made any attempt to hide it or to even distract from what they plan to do, and they have done it sequentially now with multiple materials, much as they did previously when the Japanese were trying to optimize their own rare earth capabilities. So, as we stand right now, if we don't take drastic, immediate action to open up U.S. opportunities, we'll be in a situation where we will not be able to compete in vital national security areas that put our entire security at risk.

Mr. POSEY. Thank you. Mr. Peay?

Mr. PEAY. Yes, we don't know exactly what the impact is going to be yet, but this leaves us very vulnerable. It's why the work we're doing is so important and why we have to look across the entire supply chain from diversifying and expanding our supply, to developing alternatives, to working on our materials and manufacturing. As I said in my testimony, you know, it's not enough if we just can extract the raw materials trying to control the entire midstream. And so it's not just them cutting us off from gallium and germanium, but their control of the midstream has—also puts us in a very vulnerable position.

Mr. POSEY. In your written testimony, you mentioned equitable social performance as part of the process at the Department of Energy's approach to build a new domestic commercial infrastructure. You know, what does that mean?

Mr. PEAY. So we need to be just as—we need to be very concerned about responsible labor standards and responsible production here in the United States when we do extraction. And so other countries have abhorrent standards for child labor, for environmental standards, and so as we bring these industries back onshore, we need to make sure that we're doing things responsibly here in America.

Mr. POSEY. Very good. Thank you, Mr. Chairman. I yield back.

Chairman LUCAS. The gentleman yields back. The Chair now recognizes the gentlelady from Oregon, Ms. Bonamici, for five minutes.

Ms. BONAMICI. Thank you so much, Chairman Lucas and Ranking Member Lofgren, and thank you to our witnesses for your expertise.

I want to start by emphasizing the importance of transitioning to a clean energy economy to lower costs for families but also, importantly, to cut greenhouse gas emissions. And recognize—we all recognize that renewable energy technologies, solar panels, advanced batteries, transmission lines will all require significant amounts of critical minerals. That's not in dispute.

Many of these high-demand minerals can be found in vast quantities and deposits in the deep ocean seabed, so I want to raise the concern and the issue about deep-sea mining. I know Ranking Member Lucas mentioned the Salton Sea, but deep-sea mining is something I'm concerned about. I want to note that the International Seabed Authority prohibits deep-sea mining on international sea floors, but some coastal nations—Norway, for example—are investing in deep-sea mining technologies to ramp up stocks of critical minerals.

I work on a lot of ocean health issues, so I'm raising this issue because I note that deep-sea mining can present significant risks that could harm marine life, ecosystems. Sediment agitation, for example, could expose buried organic carbon, disrupting water flow and nutrient cycling for deep-sea life. The released carbon dioxide could then increase ocean acidification, which is an issue that we've been working on in a bipartisan basis that affects our marine life and shellfish industries, for example.

So, Mr. Peay, you state in your testimony that the Department of Energy is exploring investments in surgical mining techniques and technologies. Deep-sea mining techniques do involve—typically involve—including remote devices—large remote devices that crawl along the seafloor and use grinding wheels to break up the hydrothermal vents. So do these surgical methods apply also to deep-sea mining? And what research is the Department of Energy conducting to understand the environmental effects and technological barriers to deep-sea mining?

Mr. PEAY. Yes, thank you for your question. So we're currently not doing any deep-sea mining research. I'm aware of some of the projects and work you're talking about. What we're looking at with the future of mining is really that we understand that there's—in conventional mining, there's a lot of challenges. There's a lot of environmental impacts, a lot of waste material that comes from it. But our department has a lot of expertise on the subsurface, and we want to leverage that to try to find ways to extract ore without having to do large open pit mining, without putting people underground in underground mines. You know, it's kind of similar to what we did in shale on how we can understand the subsurface. Can we access the minerals, pull it out without having a lot of waste that comes up. And so that is what we're evaluating. This is not a program that we have started yet. We're evaluating if this is an area that DOE can provide help to industry and to our country.

Ms. BONAMICI. I appreciate that.

I'm going to ask Mr. Mulvaney. Considering the increased demand for critical minerals and the unknown long-term environmental effects of deep-sea mining, can you talk about what research might be needed to determine the viability of deep-sea mining as a potential alternative to land-based mineral extraction?

Dr. MULVANEY. I'm not as familiar with the deep-sea mining issues specifically. But in general, when we're looking at opening up new areas for resource extraction, things like programmatic environmental impact statements or marine spatial planning could help identify where the particular conflicts are and to see whether or not there are possibilities for agreement on where there might be less disruption, whether that's on land or sea.

Ms. BONAMICI. I appreciate that. Is anyone on the panel doing any research on—Dr. Caers?

Dr. CAERS. Yes. So with Coble Metals, we looked into deep-sea mining as these nodules contain cobalt.

Ms. BONAMICI. Correct.

Dr. CAERS. There has been extensive research on the effect of moving materially on the ocean floor. There is a project in Peru that's shown that if you start doing that, the plumes, the bentonite blooms will travel hundreds of kilometers away from the source that you're disturbing.

So deep-sea mining, it's often shown as, we're going to just pick the nodules up from the floor. That's not where—how it works. You really start to excavate things. The alternative to me—and coming back to this laparoscopic mining—is just again, hydrate deposits. For example, in—we're working in—Cape Smith is the northern part of Quebec where there's already a mine called the Raglan mine, which is 3 percent nickel, and you can mine that very laparoscopically. Essentially, the ore body is only 500 meters wide with an underground mine. If you stand there at that area, you will see a building.

So while in the United States we're mining at such low grade that we have to use these very large open pit mines. So not all mining is the same, and the mine program that the DOE has——

Ms. BONAMICI. I see my time has expired. Mr. Chairman, as I yield back, I request unanimous consent to enter into the record a briefing paper from Ocean Conservancy about the overall risks and uncertainties that deep-sea critical mineral extraction poses to climate adaptation.

Chairman LUCAS. Seeing no objection, so ordered.

Ms. BONAMICI. Thank you, and I yield back.

Chairman LUCAS. The Chair now recognizes the gentleman from Florida, Mr. Webster, for five minutes for questions.

Mr. WEBSTER. Thank you, Mr. Chairman, and thank you, each one of you, who has come. It's a very interesting subject and also a very timely one.

I guess the one thing that caught my mind when I was listening to the testimony was from Dr. Mulvaney. You spent a good little section of your time talking about minerals and other things that are not even—they don't even come close to recapturing those, that they're just, I guess, thrown away or whatever, done away with. So the actual recovery of some was good, a few, but not all. What—where—what's the first step we would take to increase the amount of reclaiming of the used minerals?

Dr. MULVANEY. I think one of the major barriers to particularly an emerging industry where you're just starting to get end-of-life products at high—your volumes aren't high enough. You need to have high enough volumes. An early action item would be to have takeback and collection systems. Just that step of reverse logistics, getting things from people's homes back to a centralized location can make that recovery process much cheaper to people who are interested in developing recycling programs. We've seen in Europe, for example, the development of a takeback and collection system in solar panels has not only led to increased recycling rates—95 percent of solar panels in Europe are recycled—but they also have fostered a reuse market just by having large volumes of materials recollected. So that would be my first action item is to have some kind of takeback and collection system that falls under an extended producer responsibility program.

Mr. WEBSTER. So I've toured some—maybe one area like that where this company collects computers. Maybe they pay for them, I don't remember if they did or not, or just collect them. And then they capture back silver, other things out of those. Is that when you're talking about, something like that? They go down and they take every little piece that's in there and separate it out and gather the—what can be reused, and they do it.

Dr. MULVANEY. Yes, that's correct. In Japan, for example, they have very good collection of flat panel displays, even cell phones that have indium tin oxide so they can recover the indium. So—and again, that's all aided by having strong takeback and collection systems that make it more economically viable for people who are dealing with waste. You know, waste industries don't get to pick what they—what they're dealing with, so having someone bring things in concentrate, things that are scattered across many households or businesses can help foster those——

Mr. WEBSTER. Does the government have a role in that in any way?

Dr. MULVANEY. Either government or industry associations are the two primary ways that you could develop a takeback and collection system. Some States and some—and the European Union, for example, have the waste electronic—waste and electronic equipment directive that requires the takeback and collection of any electrical equipment. We don't have anything like that in the United States, which means that States are left to design their own programs.

Mr. WEBSTER. So is it profitable so that people would engage in that activity?

Dr. MULVANEY. Yes. I think now, there are—you know, Germany just opened a very, very large solar panel recycling facility, and that's all because now they can go easily collect, you know, several thousand solar panels at once instead of having to go get, you know, 10 or 20 at every single individual household. So just having that reverse logistics is really, really, I think, a gamechanger for industries that want to develop that.

Mr. WEBSTER. Thank you very much. I yield back.

Chairman LUCAS. The gentleman yields back. The Chair now recognizes the gentlelady from Michigan, Ms. Stevens, for five minutes.

Ms. STEVENS. Thank you, Mr. Chair. I'd like to ask unanimous consent to insert in the record a letter by the American Critical Minerals Association. They represent a diverse swath of critical mineral supply chain from producers to end users, and I want to thank them for this letter and engaging their stakeholders with all of us here today.

Chairman LUCAS. Without objection, so ordered.

Ms. STEVENS. It's a good letter, Mr. Chair, I promise.

Chairman LUCAS. You always have good letters.

Ms. STEVENS. So I couldn't imagine a more important hearing and topic for Congress, and so glad that we're approaching this in a bipartisan way with a very diverse array of voices from academia and the government and the private sector.

We hear you loud and clear that we are in a perilous and risky moment as it pertains to, yet again, our overreliance, particularly on the CCP (Chinese Communist Party), for critical minerals and materials. And it's not just the materials or the minerals themselves. It's the refining process, as Mr. Baroody mentioned. Upwards of 90 percent has to take place in China. And the directive of taking corrective action, as Mr. Horn advised, is heeded here, not only in this Committee, but the Select Committee on U.S. Strategic Competitiveness with the CCP that I feel very privileged to sit on.

And so the question I do want to ask, though, is what is the corrective action? Some of you mentioned in testimony that we passed a *CHIPS and Science Act,* much of which came through this very Committee, something that we were all very proud to work on in a bipartisan way. Is that the type of model that would work here, particularly with what we did with *CHIPS,* $52 billion, a large investment from the Federal Government, $52 billion dollars being administered by the Department of Commerce? Before $1 was allocated, though, we received notice that $200 billion of private sector investment was put into the marketplace.

Now, it's not just as simple as that because we've got another layer here that our environmentalists also care about, which is permitting reform. So is there palatability here? And, Mr. Peay, I don't want to put you totally on the spot on this one because I got some questions for you, but maybe for our academia and private sector partners, you could kind of chime in here on corrective action we need to take because there's a problem. There's been a problem for 15 years. We need to get in front of it, and we need to make sure it's not just the United States, too. Baroody, you're talking about, hey, United States needs to do it. We've got trade relationships. You know, we've got trade agreements we can pursue, too, here. We've got AUKUS (Australia-United Kingdom-United States). We've got USMCA (United States-Mexico-Canada Agreement). So next big bold ideas about corrective action, anyone for the taking? Mr. Horn?

Mr. HORN. Well, thank you, Congresswoman. And I would say in short, a part of your question, yes, that was absolutely a step in the right direction, and in my opinion, it was consequentially huge in motivating the private sector, the investor base to actually mobilize and get more involved, and I see that every single day.

As far as the trade and international relations, I think that's a key part, and I think what it really comes down to is transparency and accountability of all parties. You know, I remember back in the 1990's, there was the blood diamond issue where, basically, it became exposed that, you know, engagement rings were being done on the back of violence and child slave labor. That's happening again today. It should not be permitted or allowed.

I think that the distinguished fellow panelists that are speaking about scientific innovation and solutions absolutely have solutions that are far superior to anything that the PRC or the Russian Federation is using, but we yet allow our allies and trade partners to use essentially that dirty supply. And it's hard to compete with something that's done on the back of slaves to be frank. So I think we need to have that level of accountability and transparency on all the materials that go into this energy transition and technological revolution.

Ms. STEVENS. Right. And it likely isn't just the awareness piece, which is so deeply critical, but it is guardrails. It is rules for the road. It is bringing along our allied partners. And certainly, the other piece to this is environmental practices as well because we're all living here on planet Earth.

But let me just conclude by saying this. This is a very robust topic and one that we are going to continue to chew on as the U.S. Congress, and we certainly welcome your input. I will be submitting questions for the record. Recyclability and synthesizing remains a topic of interest.

And with that, Mr. Chair, I yield back.

Chairman LUCAS. The gentlelady yields back.

The Chair recognizes the gentleman from Texas, Mr. Weber, for five minutes for questions.

Mr. WEBER. Thank you, Mr. Chairman.

Mr. Peay, in your testimony, you raised the alarming fact that out of the 50 critical minerals that the United States has identified, we rely on foreign nations for more than 50 percent of our requirements for 31 of those minerals. Perhaps more alarming is that we rely entirely on foreign nations for another dozen or so. That leaves about roughly seven critical minerals that the United States is able to, quote, "adequately produced domestically," end quote. Can you tell—can you list those seven minerals for us? Can you tell us what they are?

Mr. PEAY. I'll have to—I don't have that off the top my head, but I can get that for you.

Mr. WEBER. OK. Please do get that for us because we need to be working on that.

And you're aware that—and we need a lot of permit regulations that need to be changed so that if we want to have a mine that, I don't know, mines some of those minerals, in some—in another hearing yesterday, I literally said that sometimes it takes longer to get the permit than it does to build the actual facility that's going to mine whatever that is, and it shouldn't be that way.

So given—I'm staying with you, Mr. Peay. So given that the—and I hope you'll stay with me. So given that the United States produces energy more efficiently, cleaner, and safer than any other nation, I'm inclined to believe that we can do the same with critical mineral and processing. How do you recommend Congress working with the DOE and EPA (Environmental Protection Agency) to cut the red tape to get past those permitting problems and actually for our domestic mining industry to grow, which would lead us to a more—a secure supply chain that we all need? Your thoughts?

Mr. PEAY. Yes, so you're absolutely right that domestic mining, the permitting takes an incredible amount of time. It takes a long time to prove a resource. We can do better than that, and we need to develop the technologies for what the future of mining will look like where we can do it quicker, more surgical in pulling up the ores that we need. So we need to improve our drilling technology, our in situ extraction technology, our mapping of the subsurface and find and characterize where the minerals are so that we can be laser focused on how we pull it up.

I don't have recommendations on the legislative changes to make on permitting. That is kind of out of my purview.

Mr. WEBER. But you would agree the permitting system is broken?

Mr. PEAY. I would agree it takes way too long and is an impediment.

Mr. WEBER. Mr. Caers, would you also agree that the permitting system is broken?

Dr. CAERS. That's not within my purview of understanding. Sorry.

Mr. WEBER. OK. Well, stick around. We'll learn you some.

Mr. Horn, how about you?

Mr. HORN. I would say it absolutely needs reform, significant reform if we want to meet any of our environmental protection and manufacturing goals.

Mr. WEBER. Dr. Mulvaney?

Dr. MULVANEY. I think that there could be improvements in the permitting reform, but GAO reports that the No. 1 reason for mine delays is because of insufficient mine plans and insufficient information in those mine plans or major changes to mining plans, so maybe, coupled with better science and understanding of that subsurface, maybe people proposing those developments would have a better idea of what their actual plan would be, and that would actually help new projects move——

Mr. WEBER. You think there could be problems with permitting? What did you think about my statement that sometimes it takes longer to get a permit than it does to actually build a facility?

Dr. MULVANEY. That is—mining is a very disruptive activity, so sometimes projects take a long time because they have substantial impacts. They need to reach out to Native American tribes, for example, and get, you know, consultation. There's a lot of stakeholders involved. So, yes, I think things can certainly be done faster. There's interagency coordination that could be improved. I think that that was also a thing that the GAO reported. But yes——

Mr. WEBER. So that needs to be our focus.

Dr. MULVANEY [continuing]. I hear your sentiment. I appreciate——

Mr. WEBER. Yes.

Dr. MULVANEY [continuing]. That sentiment that is taking too long. I'm not sure——

Mr. WEBER. Right.

Dr. MULVANEY [continuing]. *National Environmental Policy Act* permitting, I'm not sure that's the major problem.

Mr. WEBER. Is it—I'm trying to get my glasses focused. Is it Baroody? Is that how you say it?

Mr. BAROODY. Baroody.

Mr. WEBER. Baroody was my next guess. What—how about you?

Mr. BAROODY. I think it does need some reform. For example, look how long it takes to permit a nuclear reactor, much more time to do that than it does to build one. And now we're going to small modular reactors. We need to look at that very closely because they can be, you know, a very—a panacea to help, you know, small—bring nuclear reactors to into—into service that can be small and portable and——

Mr. WEBER. OK.

Mr. BAROODY [continuing]. Things of that nature. So I think there is a reform necessary in my opinion.

Mr. WEBER. All right. Well, let the record show that at least three out of five think that there's a problem. Isn't that a majority?

So, Mr. Chairman, I yield back.

Chairman LUCAS. By Texas math.

The gentleman—I thank the gentleman.

And the Chair now recognizes the gentleman from New York, Mr. Bowman, for five minutes for questions.

Mr. BOWMAN. Thank you so much, Mr. Chairman.

My first question is to Mr. Peay. In 2022, the White House implemented the Justice40 Initiative to Executive Order 14008, which mandates that 40 percent of benefits should flow to disadvantaged communities. How's the DOE ensuring that the goals of the Justice40 Initiative are adhered to as extraction ramps up around the country?

Mr. PEAY. Thank you for your question. So we've embedded this throughout the Department. We have people working on this both from our office that reports to the Secretary, but also all the way down to our program offices. We have individuals on the team that are focused on our community benefit plans and the Justice40 Initiative. And all of our funding—well, nearly all of our funding opportunities and awards that go out require a community benefits plan, and we've also been doing direct engagement with communities now. An example is when you look at some of the DAC (direct air capture) hubs and hydrogen hubs, there's extensive community engagement that went into those awards. And so it's deeply embedded, and then we're tracking and reporting up, you know, all of our qualified programs.

Mr. BOWMAN. What have been some of the challenges you've faced as you sought to embed the Justice40 Initiative in the work that you're doing at the DOE?

Mr. PEAY. Yes, I think—I mean, there's been several challenges, some that is just as we're looking at ensuring that we're meeting some of these different requirements. Some of the work we do is inherently lab-based, and so ensuring that we're figuring out which ones are qualified programs and what is not. There's been a lot of learning and getting the resources that we didn't have. We didn't have people trained or experienced in kind of these community outreach programs, and so we've had to hire new staff and train current staff on how to do that and engage with communities better. So those have been some of the challenges.

Mr. BOWMAN. Thank you. Mr. Baroody, in your testimony, you mentioned that K-Tech has been working on ore recycling operations in South Africa, a place that has been marred by human rights abuses and environmental contamination in mining industries. How can we ensure that all companies operating internationally in places like South Africa reverse this trend moving forward?

Mr. BAROODY. Well, the company that's doing the work in South Africa, Rainbow Rare Earths, has just put out an ethical statement about that very issue that you just mentioned, and they are going to take every step necessary to make sure that everybody is treated equally, that the employment is—the employees are hired regardless of background or sex or anything like that. And so they're doing their job, I think, in South Africa to help that situation along.

Mr. BOWMAN. Thank you. This next question is to anyone who wants to respond. I introduced a bill called the *Green New Deal for Public Schools* where we highlight the need for clean energy in schools across the country. The critical materials assessment report by the DOE identifies copper, platinum, aluminum, and other minerals are essential—as essential for clean energy technologies. How can we ensure that we prioritize international collaboration on the materials that we need most for clean energy? Yes, please.

Dr. CAERS. Yes, I think international collaboration and particularly with Australia is very important, and our Australian allies are also struggling, as you know, with not just the mining, but also the processing of materials which gets shipped to China.

The second I would mention is Africa. Even though in the DRC (Democratic Republic of Congo), it's a very challenging situation, I think it's a good opportunity now for the United States to engage with the DRC, and actually, in Stanford, Material-X, we've been starting to do that as well, and that could just start from education and showing our goodwill to kids there. And, for example, we are funding tens of scholarships for female students in the DRC and

Zambia, and those things go a very long way. And I think the United States can play a very important role there.

Mr. BOWMAN. All right. Thank you, Mr. Chairman. I yield back.

Chairman LUCAS. The gentleman yields back. The Chair recognizes the cardinal from Tennessee, Mr. Fleischmann, for five minutes.

Mr. FLEISCHMANN. Thank you, Mr. Chairman, and I thank the distinguished panel and the discussion today.

The distinguished Chairman referred me as the cardinal. I am the Chair on Appropriations, the Energy and Water Subcommittee, which funds all the wonderful work that our National Labs do, DOE does, and the like, so I come to this hearing with a strong support for our National Labs. I am the Republican Chair of the National Labs Caucus. I work with my colleagues on the other side of the aisle on that, I think they're our national treasures.

If I may, may be a bit parochial, my great State of Tennessee, as well as numerous other Appalachian States, have suffered substantial—or actually have substantial unconventional sources of rare earths and other critical minerals in the form of mine wastes, mineral sands, and other streams. To the panel, how can we leverage these as national assets?

Mr. HORN. Thank you, Congressman. I think you—you bring up a very good point in terms of, I would say, two topics, one, the successful commercialization of the great work that labs such as Oak Ridge and others that—are doing in the innovation space, and then also the, I would say, mobilization of material recovery as a part of renovation of a lot of these metal dumps and waste piles.

So what is, I think, not really understood is that there is technology that does currently exist that actually can economically transform waste tailings piles into valuable battery materials and rare earths. We have a partner that's in the process of building out a project that does it in Missouri that essentially takes some of the highest grade tailings from, you know, a couple hundred years of ore mining and production. It's not as far away as people think. You know, in that particular example, that was an Oak Ridge technology that is now in the process being commercialized.

We see, for obvious reasons, significant interest in the investors that are looking in this sector, understanding, I think, that we're really talking about something that has minimal downside. You're cleaning up areas that need that renovation, and at the same time, you're optimizing some of the key sources that would reduce in some of these cases such as dysprosium and terbium, our reliance on China to nothing, right? We would be totally self-sufficient and an actual exporter. So I think we need to prioritize truly commercializing the right technologies because I think we're on the wave of an innovation revolution, should we do so appropriately.

Mr. FLEISCHMANN. Thank you, sir. I so appreciate your answer to that question. It's spot on.

Would anybody else like to weigh in? I do have another question. Yes, please, gentlemen. All of y'all.

Mr. PEAY. I would just say quickly, so this is right in our space that our program does on developing these unconventional feedstocks. Early—earlier this month, I was in West Virginia at one of our pilot facilities where we're doing this with acid mine drainage.

I've also been in North Dakota where we're doing this with coal lignite. And through the infrastructure law we have, we're going to do this at commercial scale with $140 million commercial-level project.

Mr. FLEISCHMANN. Thank you, sir. And, Doctor?

Dr. MULVANEY. I'll just add that one of my—my understanding, one of the challenges with using tailings and things like that is characterizing what's actually in each tailings pile. There's a lot of heterogeneity, so more research to characterize those tailings. What's in them and what could be extracted, I think, would be helpful.

Mr. FLEISCHMANN. Thank you, sir.

A follow up question on recycling, spent magnets and other sources offer huge opportunities from which we can mine rare earths. How could the government help encourage more recycling and reuse of rare earths? And what do you see as the biggest R&D challenges to recycling and the reuse of spent magnets?

Dr. MULVANEY. I'll start by saying I think Federal comprehensive waste electronical and equipment management standards, you know, we have a national takeback policy. We landfill a lot of copper, for example. We landfill or send to smelters materials that we can't recover and things like that. So, you know, closing the loop, first step is to try to collect those materials that would otherwise end up in waste flows because once something ends up in a landfill, the percentage is just too low to go back after it.

Mr. FLEISCHMANN. Thank you, sir. Well, it looks like I'm just about out of time. Again, gentlemen, thank you so much for a wonderful, comprehensive, informative hearing.

And, Mr. Chairman, I yield back.

Chairman LUCAS. The gentleman yields back.

The Chair now recognizes the gentlelady from North Carolina, Ms. Ross, for five minutes for her questions.

Ms. ROSS. Thank you, Chairman Lucas and Ranking Member Lofgren, for holding this extremely important hearing, and to all of our panelists for joining us today.

The importance of the hearing cannot be understated as we work toward a clean energy future. In order to meet our goals, we must address the need for critical minerals and materials that help us produce that clean energy. The surge in demand for critical minerals and materials is estimated to increase between 400 and 600 percent in—up until 2040 to meet these goals. And in my home State of North Carolina, which has been a leader in solar energy and has the potential to lead the East Coast in offshore wind energy, this is crucial.

My district is home to a robust workforce and educational institutions that are helping our Nation transition to clean energy, and I look forward to continuing to work with this Committee to support my constituents and the challenges of this transition.

My first question is even more pedestrian than most of my colleagues' questions. What we have heard from the McKinsey report in February revealed that there are workforce shortages in mining. So even if we permit the mines, we build the mines, somebody's got to work in the mines, and that the number of mining engineering graduates in the United States has dropped precipitously.

I represent NC State University, which is the land grant university that produces a lot of these engineers. But there's been a 39 percent reduction between 2016 and 2020, and a lot of the projections indicate that we'll likely not have the workforce supply, whether in mining, engineering, or other fields, to fulfill our national mineral needs.

I'd like anyone on the panel to address how NSF, DOE, your institutions should invest resources to best address this workforce shortage? And whoever wants to start. Yes, Dr. Caers.

Dr. CAERS. Yes, that's an excellent question. At Stanford, you know, we don't have mining, and one of the reasons, of course, is mining isn't attractive to the current new students. But when you say we can do mining and revolutionize it with digital and AI, suddenly, there are tons of kids in my class that say we want to do mining. So I think it's not just looking at the stream that we currently have of mining engineers and mining engineering schools. It's also to tap into the new population of students who want to do cool stuff with digitization and AI and apply that to whatever they see because many of those students are disappointed when they go into commerce or they go into gaming and they have to do—apply their AI to really unnecessary things. So I think that's where we can make a big difference.

Ms. ROSS. Does anybody else have anything to add? Yes, Mr. Peay?

Mr. PEAY. Yes. So developing an educated and trained workforce is absolutely essential. So we talked about how we've offshored the supply chain, but when we did that, we also offshored our brainpower with that and all of our expertise. So this is something we have to do. We've started doing some of this already. You know, we have a university research program in our office, and so we've—this year, we had two awards under that, one to a minority-serving institution to look at geology, and then the other is looking at improving critical minerals from coal-based sources. But this is something we've got to address as well.

Ms. ROSS. Dr. Mulvaney, did you have anything to add? I do have another question. Or did somebody—Mr. Horn?

Mr. HORN. Just very briefly, I would say it comes down to redefining what mining truly is. Right now, we're talking about mining that does cleanup, that empowers technological innovation. You know, it's not the same kind of mining when, you know, my great grandfather was a breaker boy in a coal mine, getting underpaid and basically dying of black lung. It's a very different story. It pays highly, and it's absolutely critical to everything we're doing on the technical side.

Ms. ROSS. OK. I'll submit my other questions for the record. But I also think it's important for us to invest in our community colleges because it's not just the people who do the cool AI or figure things out. It's sometimes the people who supervise the—that crew that's going to be out there. Thank you, and I yield back.

Chairman LUCAS. The gentlelady yields back.

The Chair recognizes the gentleman from California, Mr. Issa, for five minutes for question.

Mr. ISSA. Thank you, Mr. Chairman.

Mr. Horn, my colleague from California asked around the question of lithium in the Salton Sea. I just happen to be the Congressman contiguous to the Salton Sea. I'm—except during Santa Anas, my district is upwind of the pollution that comes off of that ever-drying body of sort of water. As it dries up, when there are Santa Anas, it's a tremendous pollution. So in my district, we have an odd situation. We want to mine because, at the same time as we're mining, we're eliminating an environmental waste. Many companies have already made significant investments. They believe that there is, in fact, usable quantities of lithium, and they're putting their money where their mouth is.

Do you agree that that's the kind of thing, at a minimum, that we should find a way to encourage when it's a known pollutant, a known environmental problem, and the mining of it actually will cleanup that pollutant?

Mr. HORN. Congressman, I would say absolutely. I think there's a misunderstanding when it comes to lithium production via DLE and other technology applications. So while we look at a variety of technical applications of brine sources, they're not all created equal, and it's really about matching the right technology with the right ppm content in the brine, right? So we have, you know, ppm projects that we're working on in the—you know, Smackover region that are high in lithium. They require a separate kind of technology than what I believe could be used in Salton Sea and lower ppm bodies that I still think with the right technology could be highly economical.

Mr. ISSA. Well, you know, the late Sonny Bono spent most of his career trying to save the Salton Sea, and when I inherited the region, I, too, became concerned about a body of water that, as it dried up, wasn't just environmentally a problem for wildlife and in flyovers, but in fact is worth saving for other reasons.

Back to the lithium, though, you said it's not a form of mining that we've known in the past, that realistically, is almost harvesting by comparison, not much different than taking salt out of the ocean. So my question to you, and it's not intended to be a political one, but I think it's important. California has mandated effectively lithium batteries because it's mandated EVs. At the same time, our Governor is in fact taxing mining. Is there a message there that you can figure out of why you would mandate something and then make it much more expensive at a time in which batteries are the single most determinate product for whether EV succeeds or not?

Mr. HORN. I would say it's a—you know, from my understanding, a lack of understanding the connection, right? I assume positive intent. I don't try to guess——

Mr. ISSA. Right, nobody in their right mind would give you a subsidy to buy an EV car and then make the subsidy offset by artificially creating an increase in the price of the product.

Mr. HORN. Yes, it's counterproductive and counter-logical, I think what there needs to be is a true understanding on how we get to end results and how we do it in the cleanest and safest and most socially protected manner possible, right? Because what you're talking about with the lithium example, I love it because we work in the DLE space, right? You're talking about water purification.

You're talking about beneficiation of the actual environment, and that is the means that we're producing, in my opinion, a preferable product compared with slave labor done with open pit mining in Central Africa. I mean, it's just—there's no comparison. And I challenge anyone that believes in electrification to try and make the case that it's OK to do that on the back of child slaves.

Mr. ISSA. Let me ask a closing question for all the witnesses, and it's not intended to be rhetorical, or it's just intended to be a statement about the country we live in. Is there any major mining or any major country in the world that has better human rights, better work rights, or better environmental rights when it comes to how you mine than the United States? Or, to put it another way, aren't we the cleanest, best place to mine if what we're looking at is mine it here or mine it there? Either way, it's going to be mined?

Mr. HORN. Absolutely. I mean, we've talked about the amount of time it takes to permit the cleanest mines in the world. You know, that is a consequence because we have the highest standards, flat out, in the world.

Mr. ISSA. Anyone else want—is there a controversial—controversy here, or that's a—pretty much a given that we do it better and cleaner, and if we're going to have it done somewhere in the world other than United States, it will be less clean, it will be less environmentally fair, and it certainly will be less fair to its workers. Thank you, Mr. Chairman. I yield back.

Chairman LUCAS. The gentleman's time has expired.

The Chair will now recognize the gentleman from Illinois, Mr. Sorensen, for five minutes for his questions.

Mr. SORENSEN. Good morning. I want to thank Chairman Lucas and Ranking Member Lofgren for convening this hearing and our witnesses for being present today.

The *Inflation Reduction Act* focused many of its critical minerals provisions on tax credits, which are being implemented through the Department of Treasury. Guidance from Treasury on 45X, the advanced manufacturing production tax credit, requires that—manufacturers to sell their unprocessed, high-purity aluminum to an unrelated third party before they can access the credit. I represent workers at Arconic in the Quad Cities of Illinois and Iowa who produce high-purity aluminum and shape it into aluminum sheets or plate before they sell it to a third party.

Congress intended for a wide array of companies to qualify for 45X. However, Treasury's current guidance likely precludes one of the largest domestic manufacturers of high-purity aluminum from accessing the credit. Mr. Peay, how has the Treasury Department relied on the expertise of you and your colleagues at the Department of Energy as they work to implement these highly technical tax credits?

Mr. PEAY. Sir, this one is out of my purview, but I do know that there's technical assistance that goes on between DOE and Treasury.

Mr. SORENSEN. Thank you for that. Also in my district, we have an electric vehicle manufacturer Rivian in my district in Illinois. However, according to the company, the structure of the *IRA* does not allow the company to secure lithium specifically from South America because the lithium cannot be refined before it is imported. And so this does not allow the company the access to the *IRA* tax credits. It creates an immense cost and delays Rivian's path to profitability, which secures the 7,000 workers in my district their jobs.

Mr. Peay, to you again, the intent of the *IRA* is to support the domestic renewable energy sector. But with limited access to refining capabilities in the United States, should Congress take action to allow companies to access *IRA* tax credits when they purchase critical minerals refined in an allied foreign country?

Mr. PEAY. So I know that's the intent of the tax credit. I can't comment on if there should be legislative changes or Congress changes to how it's implemented. I'd have to refer you to Treasury for a comment on that.

Mr. SORENSEN. Does anyone on our panel today find this troublesome?

Mr. HORN. Congressman, I actually testified on this subject before another Committee relatively recently, and I think what it comes down to is proper oversight and implementation. These are difficult, complicated measures to actually enforce an impact, so I think that the way forward, which I think has been started and is in progress with this Administration, is to have central oversight from White House leadership, ensure that there's that proper level of coordination and implementation of a lot of these executive and legislative actions. So I think what it really comes down to is further empowerment of some of the White House coordinating entities in terms of ensuring proper interagency collaboration and implementation.

Mr. SORENSEN. Do you think that there's more work that Congress should be doing on that?

Mr. HORN. I—my recommendation would be continued encouragement of the White House to enable that level of coordination and oversight related to that as well, too. I believe that the White House desires and is attempting to do that. Any way that they can be supported in that implementation by the Congress, I think, would be beneficial for all.

Mr. SORENSEN. In my last minute to you, Dr. Mulvaney, I serve as the Ranking Member on our Committee's Space and Aeronautics Subcommittee, I've heard from aerospace stakeholders in my district that some companies are turning to Europe for R&D dollars due to the funding landscape here in the United States. These dollars come with requirements that some of the work be done in that country providing the funding. Have you found this to be a problem in the critical mineral sector?

Dr. MULVANEY. I understand it is, and I think my colleague might be able to answer that even a little more clearly if that's OK.

Mr. SORENSEN. Correct.

Dr. MULVANEY. Do you mind speaking to that, Jef?

Dr. CAERS. Well, yes, so as I mentioned in my statement, all of our funding has come from foreign governments or—not from companies or institutions because the United States is not investing in this particular area of mineral exploration. And I think what we have done with the group is also look at this as, you know, Americans, right? Which country should we be collaborating with, and which companies should we be collaborating with? And we've clearly said in our group, there are companies and countries we will just not collaborate with. But it will be better for the United States to support much more in the mineral exploration from inside so groups like myself don't have to go outside the country to get funding.

Mr. SORENSEN. Let's make it in America.

Dr. CAERS. Yes.

Mr. SORENSEN. Thank you all. I yield back.

Mr. WILLIAMS [presiding]. Thank you. Mr. Obernolte from California is recognized for five minutes.

Mr. OBERNOLTE. Thank you very much, Mr. Chair. Thank you to all of our witnesses on this really critically important topic.

Mr. Peay, I wanted to start with you if I could look around Max's big head. So you said something in your testimony that I thought was really important. You said that the lack of processing and refining often poses a greater threat than the actual supply of critical minerals themselves, and I've absolutely found that to be true. In my district is the Mountain Pass rare earth mine, which is the only active rare earth mining and processing facility in not only the United States but North America right now. So they really fill a critically important niche in our national security and our access to critical minerals.

But I can tell you—and also the—to your point, they've developed an incredibly innovative technique for processing the rare earth materials onsite rather than transporting them and processing them elsewhere, which I think is, you know, really admirable. But in my time in Congress, it seems like every year something comes up with that mine having trouble with sometimes it's Federal agencies, sometimes it's State agencies, sometimes it's local agencies, sometimes it's a permitting problem, sometimes it's a problem with emissions. And it's just—they struggle every single year, and most of those impediments are government-caused. What can the Department do to help companies like MP Materials that owns that mine keep that kind of mining and processing facility here and—the capability here in the United States?

Mr. PEAY. Yes, so Mountain Pass, is a very important resource for us, and to your point, ships nearly all of its rare earths to China. So what we need to do is focus on expanding the U.S. supply base and doing that through traditional mining, through improving our traditional mining through things like unconventional feedstocks, recycling, having more secure international partners. And then all the projects that DOE is working on throughout the supply chain, it's—you know, it's a private-public partnership when we do these things, and moving things to commercialization as quickly as possible is really key.

Mr. OBERNOLTE. I hope we can all keep working together on that. It's a real problem.

Also, I next wanted to ask the whole panel a question that has really been weighing on my mind and that's very pertinent to this topic of critical minerals because so many of the critical minerals now are going into the supply chain for electric vehicles. And we started with a problem with supply with electric vehicles. We had a Natural Resources Committee hearing last year in which the testimony was we'd need to quadruple worldwide copper production to convert the current year's manufacture run of vehicles to all electric.

And now, as time goes on, it becomes clear that we have a problem with greenhouse gas emissions because if you include the emissions of mining, the materials that go into the motors and the batteries, and the emissions that are involved in recycling within their lives, you know, it's not a slam dunk that EVs are cleaner. It depends on how much you use them. So, you know, really, it's gotten people thinking about what we can do to improve that. So give me some hope here. Is technology going to provide us with a solution to that? Or should we be looking at other technologies such as hydrogen? You know, what does the supply chain look like there?

Mr. HORN. Congressman, I think it's really about looking at holistic intent and implementation once again. Kind of just to go back to your previous question about MP, I think there's a lack in follow-through in terms of permitting tied to Federal awards of financing, right? I think that, you know, MP has been the subject of multiple DPA awards. Why would there not be mandated permitting tied to that for implementation? Similarly, with technological implementation into the sector—and I don't think it's as simple as someone would try to portray it as simply EV-related. It's really more about technological innovation across the board because these elements are just as critical in defense and technology implementation across the board.

But what it really takes is essentially doubling down on the right technologies. But we have to look at technologies not as science projects, but as options to commercialize and outcompete our competitors and to provide a better series of products because that's currently what we have. That's what we're looking to invest in with GreenMet and other companies that we're working with. That's the way forward.

Mr. OBERNOLTE. Right. Thank you. Well, in my remaining seconds here, let me just point out that the urgency of onshoring the production of those materials, particularly as it concerns solutions like electric vehicles where we're trying to reduce greenhouse gas emissions because we can control the emissions of mining and processing that occurs here. If we allow the offshoring of that production, we are just also offshoring those emissions, and we have no control over how our—the emissions that do occur, and so that adds urgency to the testimony that we've received tonight—today.

But I want to thank you very much for your service and your testimony here, and I yield back, Mr. Chairman.

Mr. WILLIAMS. Ms. Salinas is recognized for five minutes.

Ms. SALINAS. Thank you, and thank you to the Chairman and the Ranking Member for holding today's hearing and to our witnesses for participating.

Mr. Peay, you addressed the Department's work to develop alternative technologies to reduce our dependence on critical minerals, and we had a robust conversation today. ESS, a company based in my district, received such support from ARPA–E (Advanced Research Projects Agency—Energy) over 10 years ago and is now a reliable provider of large-scale iron flow batteries for grid storage applications. Do we have the right Federal incentives in place to balance the need for ongoing R&D with the need to accelerate adoption of existing technologies that potentially have the capacity to reduce future dependence on critical minerals?

Mr. PEAY. Yes, so that valley of death between research and commercialization is always a major concern. One of the really exciting things about the infrastructure bill funding is the fact that we're bridging a lot of that. I mean, we've been doing work now for 10 years on getting rare earth elements out of these unconventional feedstocks, and that started just in the lab, and then we've had pilot projects. But now with the infrastructure law, we're going to be doing this at commercial scale, and so having the funding to bring public and private partners together and get projects to commercialization really is key.

Ms. SALINAS. Thank you. And when DOE supports the R&D behind such technologies, are there additional tools outside of what we've been seeing in the *Inflation Reduction Act* to help private industry bridge that gap from lab to commercial viability? So what more can we be doing outside of what the *Inflation Reduction Act* is proposing?

Mr. PEAY. Yes, so there was one section in the bill that I think would be good to get funded, which is 40210, critical minerals mining and recycling research. And so that was authorized but not appropriated in the infrastructure law, and so we think that is important. And then what more to do, and I've talked about this already, but I'll say that, again, is really investing in—so we know, whether we do recycling or unconventional feedstocks or international imports, that we still need to have a domestic mining capability, and so investing in ways to improve it, to do it better, do it cleaner, safer, less impact, that is really key. And having research here at DOE and with partners at USGS is really key.

Ms. SALINAS. Thank you. And this is for the panel. As several of you have already mentioned, China dominates processing for many critical minerals, and some materials are heavily concentrated in few countries. I serve on the congressional Executive Commission on China, where we recently held a hearing on China-dominated cobalt supply chain, and I'm worried that the lack of U.S. involvement from companies, we really have no domestic cobalt refining capacity and no U.S. mining companies operating in the DRC. And it really limits our ability to influence both labor and environmental standards of these operations. How can we improve public-private collaboration to encourage U.S. industry to participate actively across the entire supply chain for these materials? And anyone who wishes to answer.

Dr. MULVANEY. I can start. Setting standards like recycled content standards, I think, could help. There was recent research out of the University of California Davis that found, for cobalt, a realistic recycled content requirement could be 11 to 12 percent cobalt, 7 to 8 percent lithium, or 10 to 12 percent nickel by 2030. So that would—just know—just setting recycled content standards sends a signal to the market and developers of recycling industries to know that there is a potential home for the materials that they're recovering and making.

Ms. SALINAS. Thank you.

Dr. MULVANEY. So it's one place to start.

Ms. SALINAS. Thank you. Yes, Dr. Caers.

Dr. CAERS. Yes. So specifically to cobalt, cobalt is often an element that co-occurs with other things, right? It's not copper, zinc, and things like that. I think that Alaska in particular is a good territory to think about that. There's a lot of zinc mining going on. That means there's a lot of tailings available, and there's very likely also a lot of cobalt in these tailings and copper. And, as my colleague said, one of the difficulties with that is still the characterization of that material.

The second thing that I can say is that if we are doing that, we're going into the tailings, why not just look at the waste stream itself today, right? So instead of, say, dealing with the waste that's already been generated, let's deal with the waste that we're generating today, and I think there's a lot of opportunities there.

Ms. SALINAS. Thank you again to the panel. I yield back.

Mr. WILLIAMS. Thank you. The Chair recognizes Mr. Babin from Texas for five minutes.

Mr. BABIN. Thank you, Mr. Chair.

Mr. Horn, as we've all heard today, rare earth and critical materials are an important part not only of consumer products, but also defense products such as missile guidance systems and aircraft engines. And China uses its supply chain dominance as geopolitical leverage, even threatening embargoes against the United States and other Western nations.

The United States identified this vulnerability decades ago and is in the process of shoring up rare earth supply chains, including building processing facilities in my home State of Texas and my neighboring State, Oklahoma. According to one of the leading cyber forensic firms in the world, Mandiant, the Chinese Communist Party has engaged in an influence campaign known as DRAGONBRIDGE, comprising a network of thousands of inauthentic accounts across numerous social media platforms, websites, and forums that have promoted various narratives in support of political interests of the People's Republic of China. Mandiant reported that one of these campaigns is specifically directed at the United States' rare earth industry and intended to prevent any competition to the Chinese Communist Party near monopoly on these rare earth elements and critical minerals.

Specifically, Mandiant found evidence that DRAGONBRIDGE targeted two projects, those that I mentioned in Texas and Oklahoma, that could alleviate dependence on China. This astroturfing campaign conducted by the Chinese Communist Party manufactured environmental concerns and expressed opposition to the development of the projects. It looked like real stuff, but not.

We've seen this tactic before because, in 2018, this Committee produced a report highlighting exactly how Russia used similar tactics to undermine U.S. natural gas production. U.S. mineral extraction and processing regulations and safety practices far exceed China's. Furthermore, Chinese-backed companies are known to use child and forced labor. What impact would further limitations on U.S. production spurred by Chinese Communist Party propaganda have on the United States' national security and economic competitiveness? And have we seen any elements of these Chinese Party influence campaigns seep into U.S. regulatory policy? Very briefly, if you can.

Mr. HORN. I'll try to answer that quickly, Congressman.

Mr. BABIN. Yes, sir.

Mr. HORN. So, you know, I guess to first state it really comes down to a comprehensive look at what's going on. DRAGONBRIDGE is real, and it's the obvious solution. My previous career as a Green Beret, I did a lot of analysis on enemy use of what they have in terms of overall effect. The Chinese have realized very effectively that they can use their financial resources to influence, impact just about anything. And so DRAGONBRIDGE is an example of how they have done very adeptly mobilization of resources that can stop U.S. projects.

I can't speak to you the level that they've influenced the U.S. Government. I know that they have tried in every way possible to do so in every other aspect of our society. And I can say that if we do not correct this, not only is this a national security threat, it's a big boon to child slavery and strip mining on the other side of the planet that cannot be forgotten as we look at this electrification focus.

Mr. BABIN. Amen. Thank you very much.

Dr. Mulvaney, a lot of conversation today is rightly focused on how we can bolster U.S. critical material supply chains. What are the U.S. public and private sectors doing to research alternatives to rare or costly critical minerals rather than trying to increase production? And are there specific research programs underway to identify more abundant or cost-effective alternatives to these materials?

Dr. MULVANEY. I think the lithium-ion battery spaces may be a place where we're starting to see some of that, and some of it's in research and development. Sodium-ion batteries, for example, may offer partial solution to replacing some of the lithium-ion batteries. Even in the industry itself, we've seen a big shift from lithium-ion batteries with cobalt and manganese and nickel to batteries that don't contain any of those materials or much lower quantities. So——

Mr. BABIN. OK, thank you. Back to Mr. Horn, China employs a command economy with state-controlled industrial policy. Here in the United States our strength is our vibrant and innovative private sector. What is the private sector doing in terms of R&D on critical material mining not directed by the Federal Government? And what advantages does private sector R&D have over state-directed R&D?

Mr. HORN. I would advocate that the combination is the most effective. However, in my opinion—and obviously, I'm biased because I'm speaking from a private perspective—I think that private R&D is really what drives that commercialization. But I think Federal can assist that and increase it. I think what we once again really need to look at is doubling down on the right technologies that can truly be commercialized to actually outcompete the Chinese because I absolutely believe that we can. I believe we have several we're working on. We'll create a premium product and do it in a more cost-efficient and environmentally protected manner.

Mr. BABIN. Thank you. Thank you for your service, too.

I have another one, but I'm out of time, so I yield back. Thank you.

Mr. WILLIAMS. Mrs. Foushee is recognized for five minutes.

Mrs. FOUSHEE. Thank you, Mr. Chairman, and to all the witnesses for appearing before us today.

I am proud that North Carolina and my district, North Carolina's 4th, are national leaders in research and development and in producing clean energy technologies like solar-powered energy. We are creating clean jobs and a clean energy ecosystem as we strive to meet the Biden Administration's goal set forward to transition our energy infrastructure and our economy toward a cleaner future away from reliance on fossil fuels.

Last September, Secretary Yellen visited my district in Durham and in Chapel Hill to highlight the promise of solar and renewable energy and how Federal investments that we're making today will pave the way toward a more sustainable and prosperous future. And earlier this year, I joined President Biden in my district on his Investing in America tour, where Wolfspeed, a semiconductor manufacturer, announced the largest investment in manufacturing in North Carolina history. And instead of relying on minerals made overseas, we are bolstering our domestic supply chain in chips that will be made in my district that will be used to power electric vehicles and batteries that will be produced in North Carolina just down the road from my district at VinVast, which is an auto manufacturer.

RTI, an independent nonprofit research institute headquartered in my district, is a partner of multiple offices within DOE, including yours, Mr. Peay, DOE's Office of Fossil Energy and Carbon Management. RTI's Energy Division is helping to lead the way in R&D and in demonstration of innovative process technologies in the areas of gas separations, syngas processing, catalysis, CO_2 capture and utilization, and biomass conversion. I'm hopeful and inspired by their work that, through advancements in science, we can help promote national and worldwide goals of reliable, sustainable, and economically viable energy supplies beyond fossil fuels.

So, Mr. Peay, can you talk about other leading-edge research priorities of DOE and your office that we in Congress and on the Science Committee should be learning more about?

Mr. PEAY. Yes, so our carbon management program, as you mentioned, is critically important. I want to talk about another thing we're doing, though, that is a priority for myself and for my boss, which is our work on methane mitigation and our methane mitigation technologies. And there's a White House initiative and task force around methane and reducing methane. But something we're doing right now is around creating a framework for consistency on how we are measuring methane and reporting it and verifying it. And we're working with international partners on that initiative.

So it is very important that we address methane emissions and—from the oil and gas sector and that we do it quickly. It's where we can make the biggest impact in really the shortest amount of time, and we're really encouraged with the work in that area.

Mrs. FOUSHEE. Thank you for that.

Dr. Mulvaney, in your testimony you mentioned utilizing the purchasing power of the Federal Government to help set producer standards to aid in recovering critical materials and minerals. Can you please expand on this? And can you also describe the types of requirements that could be tailored to improve industry design standards?

Dr. MULVANEY. Sure. The Environmental Protection Agency recommends the EPEAT (Electronic Product Environmental Assessment Tool) standard be used for Federal procurement of computers, for example. And recently, we, as part of a joint committee, established an ultra-low carbon solar standard, which requires that manufacturers of polysilicon and some of the supply chain pieces that go into solar panels are made in a sustainable way with very low carbon. That, I think, helps with the domestic production issue because a lot of the solar supply chain today is in China and is in very coal-intensive electricity grids.

So, you know, expanding the types of products that are purchased through the EPEAT programs, I think, would be a good example of how the Federal purchasing could drive more domestic manufacturing and build a domestic supply chain.

Mrs. FOUSHEE. Thank you. That's my time, Mr. Chair. I yield back.

Mr. WILLIAMS. The Chair recognizes Mr. Franklin from Florida for five minutes.

Mr. FRANKLIN. Thank you, Mr. Chairman.

Mr. WILLIAMS. Sir.

Mr. FRANKLIN. Mr. Baroody, K-Tech has a long history of partnering with local universities who enter into cooperative agreements with National Labs like the Pacific Northwest National Laboratory (PNNL). In your experience, what are some of the benefits of working with both the leading National Labs such as PNNL and universities such as Florida Polytechnic University?

Mr. BAROODY. Thank you for the question. They have good staffs that can help us work because we're a small company, and we have a limited staff. So they can take the workload off of us for a lot of things that they do well, and that we can help them and direct them in the way that we think can be most efficient for the use of their people.

And we are actually submitting, together with the Florida Institute of Phosphate Research (FIPR) and the Pacific Northwest National Laboratory, a bid to the Department of Energy to extract rare earths from phosphoric acid sludges, which is another place where you can find a lot of rare earth materials. And the sludges are a byproduct of the phosphoric acid refining process, and they tend to be waste products.

And one of the things I always wanted to say is that, how do you reduce mining? Well, use the products that are already there like the phosphogypsum that we're doing—dealing with in South Africa. We're going to clean that up, by the way, and the gypsum is going to be created as a result of taking the rare earths out and the fluoride out. It's going to be sold to third parties. It's going to be able to be used for wallboards. It's going to be able to be used for agricultural purposes and road base materials. So that's a that's another way that things can be done effectively.

Mr. FRANKLIN. Well, I hope you're successful in that project with phosphogypsum because, obviously, we have a lot of that in Florida, and if we can stabilize that material and also turn it into a good, that would be a huge win-win, so I appreciate the efforts there.

With—mentioning the Florida Institute of—Florida Industrial and Phosphate Research Institute, FIPR, Dr. Patrick Zhang there has said that we could satisfy nearly 50 percent of the U.S. demand for many of the critical rare elements—or rare earth elements just from Florida alone. That's a bold statement. If he's even directionally accurate to any degree, that would be wonderful news, and because I also know there's a lot of smart people in other places working on things like that. Do you share his optimism?

Mr. BAROODY. Well, I do in a way. We have to do the test work to make sure it works and it's economical. I think that's the key behind a lot of this research is, is it economical?

Mr. FRANKLIN. Right.

Mr. BAROODY. Because if it isn't economical, then there's no sense in doing it. And you have to be careful about how—you know, you're not going to create a bigger mess after you've done this than you started with. But I think he's got a good idea. I mean, there's—the gypsum in Florida, there's a billion tons of gypsum and 24 stacks in central Florida.

Mr. FRANKLIN. Right.

Mr. BAROODY. And so that's a problem for the long term. Now it's somewhat mildly radioactive, so that has to be dealt with, too. But I think there's ways to go about doing that, and the rare earths in the gypsum in Florida is not quite the same as it is in South Africa or Brazil because they come from different deposits that were mined. They're igneous deposits in South Africa and Brazil. The deposits that were mined for phosphate in Florida and many other places in the world like Morocco and Saudi Arabia are from sedimentary deposits where the rare earths don't tend to concentrate as much in the gypsum and there's not as much in the raw ore to start with. So—but there's good potential there, I think, for that.

Mr. FRANKLIN. OK.

Mr. BAROODY. And I can raise one other point? There's fluoride in the gypsum stacks in Florida. It's very acidic. It's about 1 percent fluoride saturated through all of that billion tons of gypsum. The United States is almost totally dependent on imports of fluoride for use in making hydrofluoric acid and the derivatives of hydrofluoric acid.

If you can take the—we have a process at Technologies that has been patented, and we—we're promoting it with several companies that we can take the fluoride out of the pond water, make hydrofluoric acid and a silica product that can be utilized in tire manufacturing and things of that nature, and I think that needs to be looked at, too, as well.

Mr. FRANKLIN. OK.

Mr. BAROODY. So, anyway, I just wanted to bring that up.

Mr. FRANKLIN. Great. And thank you, Mr. Chairman. I have other questions I'll submit for the record, but I yield back.

Mr. WILLIAMS. Thank you. The Chair recognizes Ms. Lee for five minutes.

Ms. LEE. Thank you, Mr. Chair, and thank you to all of our witnesses for your time and expertise on this critical area of research of resource development.

The history of mining in the Pittsburgh region is intertwined with the economic development that fueled our Nation's growth. Needless to say, such growth came at a significant cost to the environment and the communities that call this region home. We've come to a time of reckoning where we have to realize and adapt to the fact that the resources we try to extract from the earth can't mean we send communities to an early grave.

Critical minerals are essential to U.S. energy independence and economic growth. They're vital components in clean energy technology such as solar panels, wind turbines, electric vehicles, and transmission systems. What's more critical is that we do all in our power to serve, protect, and empower people, the human element, when considering how to shape our regulatory environment.

A few weeks ago, before the—or, excuse me, the Thanksgiving holiday, I and my colleagues here voted to avoid a government shutdown. Since we resumed work, it seems that appropriations bills are no longer a priority in 2023, which is sad, seeing that the NSF, through the *CHIPS and Science Act of 2022,* has been authorized to support research and development to advance critical minerals mining strategies and technologies but has not been appropriated any funding to process with such work. Therefore, it's reducing the amount of mining needed through improvements in battery technology, second-life applications for vehicle batteries and better recycling is key to reducing harm. In my State of Pennsylvania, the Center for Critical Minerals at Penn State is working to identify innovative ways to extract these valuable materials in more sustainable ways from an abundant source of pollution in our State, coal waste.

And in light of ongoing conflicts and humanitarian crises around the world, I would be remiss to highlight how our demand for these critical minerals that are found abundantly and extracted in nations like Congo often result in child and exploitative labor, environmental abuses, and safety risk. While many of our duties are in service to our own constituents here domestically, we can't forget that the ramifications of our actions have global consequences. We must remain thoughtful and vigilant.

Dr. Mulvaney, what are the technological gaps that currently exists that limit mineral extraction from waste materials and corresponding assessment of quality and quantity of those recycled materials?

Dr. MULVANEY. I think, as we said earlier, the characterization of what's actually in the waste, this is sometimes one of the challenges. The toxicity that—where we might have materials that are valuable bound up in materials that are potentially toxic, that could be another barrier to recovering some of these materials. But that's—you know, these are things, I think, that could be figured out and with more investment in looking at those strategies, I think, you know, closing these gaps is really critical to getting that circular economy in those materials.

Ms. LEE. What existing and developing environmentally sustainable approaches are there for the extraction, separation, processing, and manufacturing of critical minerals.

Dr. MULVANEY. Could you repeat that one more time?

Ms. LEE. Yes. So what are the existing and developing environmentally sustainable approaches? So, as we're talking about, you know, extraction and manufacturing, are there environmentally sustainable approaches that we could prioritize?

Dr. MULVANEY. I think some of the non-mining techniques might be areas that we start with. I think, you know, despite the concerns about direct lithium extraction, for example, there are potentially opportunities there to recover materials from those resources.

Ms. LEE. Dr. Horn, China dominates processing and refining of the critical minerals essential to a clean energy transition, and yet the methods they use to process and refine these minerals and elements are extremely disruptive to our environment. How can Federal research funding help us compete with China's monopoly on processing and refining and ensure that we're truly achieving clean energy?

Mr. HORN. Thank you, Congresswoman. I don't want to sound overly optimistic because I know a lot of this has been about threats, but the technology really is there from a U.S. perspective and in ways where we can cleanly outcompete PRC industry, right? They're working with a command economy. They have no regulations, no oversight. We have all of those, and what it has resulted in is decades of research that is now coming into commercialization. So there are technologies that can take tailings, even coal waste, and economically turn it into battery materials in various forms. And so I think we need to support those technologies, especially the ones that have investor interest and potential to go fully commercial and double down on that, and then that is the way we will get there organically.

Ms. LEE. Thank you so much, and thank you to the panel. I yield back.

Mr. WILLIAMS. Thank you. I now recognize myself for five minutes.

Quick question. Mr. Peay, is your father General Binnie Peay? My father-in-law is Colonel Marshall McCree, and I'm still trying to convince my wife that it was a good idea to—that he allowed her to marry a nuclear submarine officer. So he is quite beloved in our family.

Mr. PEAY. Well, thank you.

Mr. WILLIAMS. Yes, our families knew each other.

I want to jump in. I have a little bit of experience in mining and treating acid mine drainage and trying to precipitate metals out and treat different waste streams out of leech mines, for example, out of tailing mines for the gold industry and a lot of research around that. I would not pretend to be an expert, but I've touched it a few times, including binder for backfill in nickel mines in Ontario, et cetera. So I'm super interested in this.

But I want to, if I may, have the juxtaposition between Mr. Horn and Mr. Caers, is that right? And, you know, I hear the national security mandate. I certainly share that concern and that priority that we get moving on this, and yet I find, Mr. Caers, your testimony that we need to do it in a—we need to be exploiting these minerals and where they exist and in concentration to make them economically viable and environmentally responsible. I know we will do that.

But, Dr. Caers, do you mind first, you know, saying—do we have enough information right now to start—if we had investors to go attack these, do we know where these minerals are today?

Dr. CAERS. I would say that the answer to that is no. So the Department of Interior has been tasked to map the entire United States through the USGS. But I've talked to my colleagues at the USGS, and they're wonderful geologists, but they do not have the technology innovation equipped to do that. I work for a startup company in Silicon Valley, Coble Metals, that have 150 people employed. Half of them are data scientists and artificial intelligence experts, and half of them are geologists, and they are mapping very large areas in the world, including entire countries. I don't see that present currently, that technology and that innovation present——

Mr. WILLIAMS. If I may just, you know, the critical mineral list is long and growing. Let's focus just on uranium. Just given the history of the cold war—and I know USGS, you know, collects core samples and keeps them for a long period of time—it seems like we would have discovered a lot of the good sources for uranium. I see yellow cakes up to $80 a pound, and it may actually be viable, you know, if we were to start domestic mining. Do we have enough information to restart uranium mining?

Dr. CAERS. I am not familiar with the uranium part. Sorry.

Mr. WILLIAMS. OK. Mr. Horn, to you, do we have enough information to jumpstart and accelerate this in the prescribed manner that has the concentration to make it economically viable instead of——

Mr. HORN. I would respectfully disagree with my colleague and say that we absolutely do. I'll just give a little bit of a vignette to try and reinforce that. So my chief geologist led a lot of the government efforts previously, spending a career at USGS and DOE. I think he would be the first to contend that it's going to be the private sector that needs to lead to the proper utilization and optimization of tailings and other resources.

I understand probably that you're aware as well that not all tailings are created equal. Acid mine drainage, gob piles, though I wish we could turn them all into cash and paydirt, it just can't be done with the current technology. However, there is current technology that can do it. I can show you, you know, if you'd like, a tailings pile that I believe has a defendable NPV (net present value) of $3 billion based off of the concentration. Is that every tailings pile? No.

And I would say as far as uranium, we have as much resources as we need a domestically as well, especially if you're using advanced methods of recovery. ISR (in situ recovery) recovery, which is being opened up and developed in Texas right now, that can be the solution, rather than relying on Russian-influence sources that are no longer available.

Mr. WILLIAMS. I just want to give Mr. Peay an opportunity to jump in here because you sit at the nexus of a lot of this kind of data. How do you feel about our knowledge that we could go out and successfully begin exploiting opportunities to buildup our ability to mine critical minerals?

Mr. PEAY. Yes, I mean, I think we are in a great position. Our work on unconventional feedstock, that's taken 10 years to get where we are today is about to explode, and there's a massive amount—significant amount of critical minerals that we can get from unconventional feedstocks. The work we have done in our office on the subsurface for years on oil and natural gas and shale, the work that geothermal has done can be revolutionary to the mining industry, so we have a lot of opportunities here domestically.

Mr. WILLIAMS. I just want to respect my colleagues. Thank you very much.

The Chair recognizes Mr. Casten, for five minutes. Thank you for your answers.

Mr. CASTEN. Thank you, Mr. Chair, and I appreciate you all being here. Good news is we're nearing the end.

The—I want to just level set a little bit, and, Mr. Peay, I want to get to a question for you because I've never seen a good answer to the question that I have in my intuitive head, so as you listen to this, tell me if you think my intuition is wrong.

Let's say all of us got together tomorrow and we want to go out and build a coal plant. We're going to require hundreds, thousands of tons of material, for steel, for aluminum, for copper, for rare earth metals, for the high-temperature parts of the combustion system, the catalytic controls on the back end for—to take out the acid-rain-forming compounds, maybe electrostatic precipitator, and then we're going to get the whole thing built, and then we're going to need hundreds, thousands of tons an hour of coal to run the thing, plus the diesel fuel to cart the coal ash away, plus all the trucks bringing the water treatment chemicals in.

If, on the other hand, we built a solar field and some—you know, some wind turbines and some efficiency, we'd also need thousands of tons of stuff, different tons of stuff, to be sure, but then we don't need any ongoing stuff. I'm using the technical term.

So, Mr. Peay, has DOE or anyone done an analysis of how many tons of stuff do we have to dig out of the earth in a carbon-intensive world every year? And how many tons of stuff do we have to dig out of the world every year in a carbon-neutral world every year?

Mr. PEAY. So what we need to do in the near term is about four to six times what we're currently doing, but——

Mr. CASTEN. I get the transition, but I guess I ask the question—and if you don't know the answer, that's fine, but I—you know, there's a rich conversation here. And I agree with everything that everybody said. We should have environmental justice concerns and everything else. But we—you know, Chevron did some bad stuff in Ecuador. That's a serious environmental justice problem, right? And if we need less stuff, then those issues become smaller.

Mr. PEAY. Yes, I mean, I think one of the—you know, the key pieces—and when we talk about some of the international supply concerns around critical minerals versus a fuel like oil and natural gas is, you know, we don't constantly need it, and it's not immediately disruptive to our economy, even when there is a supply shock. It is something that we can continue to reuse. It goes into products. It's not something that's dependent on an ongoing, daily basis. So there are differences. It's not a one-for-one.

Mr. CASTEN. Yes. And the national security issues are obviously—and they're different, right? There was a time when we were nervous about German coal, but, you know, we've moved on.

Dr. Mulvaney, I want to shift to you. I really appreciate all of your—you keep reminding us of the value of recycling, and I appreciate that. This Committee, last term, we had a field hearing not far from my home, which was convenient out by Argonne talking about battery recycling technologies. And I wonder if you could just level set us again on this one. My understanding is that of all of the plastics we currently put into the recycling stream, not all the plastics will use, what we put in, what, maybe 5 to 10 percent gets recycled? Do I have that right, actually like turned into something useful?

Dr. MULVANEY. Yes, a lot of it's down-cycled, so it goes into different quality products as you can't really recover the polymers.

Mr. CASTEN. Well, I'm talking about something just gets thrown away because I don't rinse out my milk jug or, you know——

Dr. MULVANEY. Right. Yes. Probably, yes.

Mr. CASTEN. So I guess what I'm wondering is, are there lessons from our failure to effectively structure a plastics recycling industry that we should not repeat as we think about recycling industries for these critical minerals so that we actually get closer to 100 percent recovery?

Dr. MULVANEY. Probably not in the sense that household plastics and things like that, they're usually just waste management issues for the local communities. I think there are lessons to be learned from other metals recycling. So, for example, I often hear something like 90 percent of all the steel is—we've ever made is all still in products because we recycle that pretty continuously, and those are lessons that we can—those are—that's a great example of a circular economy, and I think we can continue to drive thing—drive the loops in that direction.

Mr. CASTEN. Yes. There's a rich conversation about gold versus silver on that front as well.

So I guess I just leave—and if you have any comments now or for the record, one of—when we did this field hearing, one of the takeaways from the scientists we had there was that the battery recycling facilities we're building right now are recycling up to a chemistry that is useful for today's batteries but is almost certainly not going to be useful for the batteries—the battery chemistries we're going to be using 13, 15 years from now when that material enters the recycling stream. And their recommendation to us was that we should be thinking about what we need to do from a policy perspective to get purity of materials that's—can enter into a lot of different chemistries.

And if any of you have thoughts, and I'm—my time's up here—on what should we be doing. Is that a business issue, is it a regulatory issue, to try to make sure, as we build out this recycling, that we're building recycling facilities that are going to be useful for the materials that we're going to need once they get into that value chain?

And I'm going to have to yield back unless the Chairman will yield anybody time to answer that question.

Mr. COLLINS [presiding]. We've got a number of people that are wanting to ask questions, so—all right, thank you.

The Chair now recognizes himself for five minutes.

Very interesting topic. You know, I sit on the House Natural Resources Committee as well and have spent quite a bit of time going across the country with field hearings, just start out with and let you know that. And a lot of these field hearings we've been having is on critical minerals and the lack of being able to get permits to even mine, and to the point to where, you know, we're down to three smelters, and 80 percent of our mining that we do is processed in China. And, of course, we want to bring everything back home, even including chips, which you can't manufacture chips here because you can't mine the critical minerals to get it. So it's in every Committee that we sit in, it seems like everything is going back to how do we get back to the United States and how do we do our critical mining?

And, Dr. Caers, I got a few questions. In your testimony you mentioned that Mineral-X receives funding primarily from foreign investors. Who's the largest foreign investor, would you say?

Dr. CAERS. Morocco.

Mr. COLLINS. Morocco?

Dr. CAERS. Yes, we do lots of work on the phosphate value chain in Morocco. For example, as my colleagues at—Morocco phosphate is—creates a lot of waste, and we're using artificial intelligence to design a new system of mining and processing——

Mr. COLLINS. Yes.

Dr. CAERS [continuing]. In Morocco. We'd love to do that in the United States. We just can't get any funding.

Mr. COLLINS. So China has made it a point to let everybody know that by the end of 2045 or 2049, whichever one, that they want to be the leader in everything, socially, economically, space, the whole nine yards. And they have been very good at getting the technology from the United States in one of two ways. Either they do investments as a foreign company or they outright steal the technology. Either way, they get it. And so how do you ensure that research security in this industry, this critical industry, and safeguard these advancements so that they don't end up in the hands of countries like China?

Dr. CAERS. Well, I can only talk to artificial intelligence because that's the technology that we're using. And I think it's critical that not only we've been developing this AI for what we're doing now, generative AI, open AI, things like that, but also develop AI for upskilling technology in these sectors, the mining industry, et cetera. So I think that's a great opportunity for the United States to be a leader. We are a leader in artificial intelligence, but we can also be a leader of using artificial intelligence in traditional industries, and that is not happening today. And I think that's very important because I see a lot of work done in China on using artificial intelligence in various resources industries, and so I think we need to invest in that such that the Chinese——

Mr. COLLINS. Are they an investor?

Dr. CAERS. No, they don't invest in us.

Mr. COLLINS. OK.

Dr. CAERS. Yes.

Mr. COLLINS. All right. Mr. Horn, I also want to echo thank you for your service. It's people like you let my kids grow up to be free, and we owe our veterans a debt of gratitude we probably could never repay.

But—and I also—this isn't my question, but you mentioned coal and how we could—we actually—coal waste, you can take care of it now. And I find it funny. I was just visiting a power generation plant near my home, coal generator, had four units. They closed one from a neighboring State. It was the cheapest power they could produce, and clean. But yet, from a public perspective, they quit using coal to manufacture power in a time when we have record inflation and people are spending more than ever on everything from food to energy. So I thought that was kind of telling what you had to say there.

But in your testimony, you stated the need to streamline the government regulatory process for critical mineral mining. What regulatory hurdles currently stand in the way of innovation and commercialization for mining critical minerals, and what can Congress do to help remove these things?

Mr. HORN. Well, thank you, Congressman, and thank you for your kind words.

I mean, it's a challenge dealing with this subject because we don't want to lower ourselves to the Chinese standard, right? And what we do every time, we buy materials that are sourced through their slave labor, their disastrous environmental policies as we adopt their terrible policies as our own. We cannot do that. So I'm not advocating for China to replicate what they're doing. What I'm advocating is we take a holistic look at this. Much like you indicated that there can be uses for coal that are actually environmental pluses, right? Remove carbon from the atmosphere. It's things of that nature.

We need to do the same thing with consideration of permitting, right? We've got a partner who is in the process of permitting a mine that has, essentially, like I said, the rare earth—on a heavy perspective—solution that would allow many other projects to work in the United States to include some that were brought up today such as MP Materials and others that need those heavies in order to actually convert to the true optimization that we're looking for.

So I would say what there needs to be is truly end-state-driven evaluation of the permitting process, and there needs to be tight oversight over every single one of these agencies from Congress to ensure that implementation is allowing a lot of these key projects to move forward to give us the environmental solutions that we're looking for.

Mr. COLLINS. Thank you. I know I'm out of time, but, Mr. Peay, I want to echo that. Thank you for your service as well.

So, with that, the Chair yields to Mr. Lieu of California for five minutes.

Mr. LIEU. All right. Thank you, Mr. Chair, and thank you to the witnesses for your time and your expertise.

I'm a Democrat, so I don't oppose government intervention in the free market, provided certain conditions are met. I just want to know if those conditions are met. And I'm curious why in this particular industry we want to increase U.S. taxpayer dollar funding. I'm not opposed to doing that, but I just want to ask some basic questions. And let me just first—I don't think it's sufficient to say, oh, because it's helpful to the defense industry, therefore, we should put U.S. taxpayer dollars into it. There's lots of things that are helpful to our national security, such as educating our children well, having a trained workforce. I can think of 57 things that we would, you know, put Federal funding to do.

So my first question is pretty basic, and it follows on something I thought Professor Caers said. So you said we're the leader in artificial intelligence, and yet, we don't apply this to mining or rare earth minerals, and we should have more investment. But why doesn't the private sector figure that out? Why doesn't the private sector just go in here and go, hey, we can do all this stuff and then sell these rare earth minerals for a lot of money? Why does the government have to be involved in subsidizing private industry here? Anyone can answer that.

Mr. HORN. Yes, I'll take a first stab at that, Congressman, if you don't mind. So——

Mr. LIEU. Yes.

Mr. HORN [continuing]. Having served as a senior government executive and now in private sector, I've seen a little bit of both sides of the fence. And I will say it's very complicated. The constraints in the free market that our companies operate under, profitability is mandatory essentially, there needs to be a business case for everything that's done. And we're currently competing against several adversaries that have command economies that use zero regulation and oversight and use State money essentially to outcompete what I believe are our better products, services, and manufacturing.

So my view of government funding in this sector is that it's essential to serve as a catalyst to get the private market truly into this space where they can outcompete some of these adversaries. I would not say it should be eternal funding, but I would say short-term funding to kind of spur this new activity and investment calculus that's, I think, drastically needed right now.

Mr. LIEU. OK. Thank you. Are there certain rare earth minerals that the United States simply doesn't have even if we were to try to mine it? Or do we know that?

Mr. PEAY. I mean, I believe we have access to all the rare earth metals—rare earth elements, unless someone wants to contradict me to that. The problem is we don't have the rest of the supply chain.

Mr. LIEU. And why is it that we don't have—why is it that China has all these processing facilities and nobody else in the world does?

Mr. PEAY. I mean, we used to have it, right? It—I mean, we used to lead the world in processing rare earths decades ago, and then through some of the reasons that were talked about, you know, a country that can manipulate its markets has been able to, just through economics, things have moved over there because we can't compete, and so the industry was allowed to move to China. And essentially, we just stopped doing it, and now we're realizing as a country that we put ourselves in a serious position.

Mr. LIEU. So what you're saying is we could next year just start processing these things or building facilities to process these minerals, just that it won't be profitable? Is that basically what you're saying?

Mr. PEAY. So it's not just about building the facilities in the industry for doing the refining and processing. The other problem is when it's gone away, we've lost the entire workforce, all the education, the people skilled in trades and engineers and that whole process. And so it's not as easy as just saying, well, let's, you know, have the Defense Department, you know, use the DPA and get something built. We've got to build back the entire capacity that was lost.

Mr. LIEU. Yes, go ahead.

Mr. HORN. If I could just add to that, and I don't want to play geologist, I think the only rare earth element that we don't have is promethium because it has to be constructed. It doesn't naturally occur. But it's not of high use anyway. I guess what I would say is that we are close in a lot of those areas to actually commercializing things, more so than people would realize.

There is a workup period, though. There is a workup period, and there is a high standard that the private sector is looking, right? When I propose a project, my investors are expecting a 10X return or they're going to say it's safer to go to another industry. That's what we're up against, and that means that it takes some time and some incentives from the Federal perspective to actually outcompete the other options in commercial real estate and other sectors.

Mr. LIEU. Thank you. I appreciate it.

Mr. COLLINS. The Chair now recognizes Mr. Tonko from New York for five minutes.

Mr. TONKO. Well, thank you, Mr. Chair, and I thank Chair Lucas and Ranking Member Lofgren for holding this hearing and thank our witnesses for being here today to share their expertise on this very important topic.

Last Congress, I was proud to work with my colleagues to pass sweeping legislation to accelerate our clean energy transition, create good-paying jobs, and advance our scientific research enterprise. As implementation of these legislative efforts is underway and the demand for critical minerals continues to grow, we must ensure that they are an enabler rather than a bottleneck for the clean energy transition. This is why it is essential that we work now to guarantee that critical materials are being sourced in a sustainable, in an ethical, and in an informed and environmentally sound manner. One facet important for protecting human rights and upholding high labor and environmental standards is, indeed, transparency. We must be able to see where materials are coming from and going to.

So, Dr. Mulvaney, in your testimony, you discussed components of the recent EU battery regulation. Another portion of this regulation is increasing supply chain traceability with technologies like the digital identifiers, also referred to as battery passports. So, doctor, what role do you think the development of tools like these for traceability could play in strengthening clean energy supply chains?

Dr. MULVANEY. I think those tools could play a big role. We definitely need to have more visibility into these supply chains. I see this with the solar industry, for example. The solar industry went into turmoil for a couple of years with the accusations of forced labor, and they couldn't figure out where materials were coming from. We've been advocating for, you know, transparency in supply chains for a very long time. They still can only look one tier deep in their supply chain, so we need to be looking tier two, tier three all the way back to where the materials are actually sourced from. So I think a combination of those tools but also requirements to look further and deeper into the supply chain are critical.

Mr. TONKO. Well, thank you.

And, Secretary Peay, in your testimony, you also highlighted the need for mineral source traceability and verification capabilities. Can you expand upon DOE's efforts in this space, please?

Mr. PEAY. Yes. So as we're looking at improving domestic mining, part of that is to ensure that we're having traceability of our minerals, and then we need to understand the international supply chain as well so that we know that what we're getting has been responsibly sourced.

Mr. TONKO. Thank you. And would anyone else care to comment on the need for supply chain transparency? Mr. Horn?

Mr. HORN. I would just state the obvious, that it's absolutely essential. Transparency, accountability, you know, honesty of sourcing is how this sector needs to be built. There needs to be no secret, and I honestly believe that daylight is the best disinfectant to prevent against anything that we don't want to be supporting. So there are nefarious forces out there that see well-intended desires to push forward with energy transition and other things of that nature that are looking to capitalize on it in a negative way. We could prevent that by mandating transparency and accountability across the supply chain.

Mr. TONKO. Thank you. In addition to bringing visibility to supply chains, I believe there's work to be done to ensure that safe and effective recovery, recycling, and reuse play a role in these supply chains. It is crucial that we prepare now for rapid growth of different types of waste from increasing and evolving clean energy technologies like batteries and solar panels or even wind turbines. To do this, we must improve and expand our current toolbox of technologies and strategies.

Secretary Peay, in your testimony you discuss diversity—diversifying supplies of critical materials, including recycling from end-of-life systems like wind turbines and exciting DOE initiatives like the wind turbine materials recycling prize. Can you speak to any gaps you see in the technologies or infrastructure needed for recycling different types of products and how efforts like these can help close them?

Mr. PEAY. Yes, and so something that was mentioned earlier is about how the needs and purities will change in the future from the products that'll be coming to end of life, and so our Office of Science is doing some of that work on fundamental chemistries to look at some of these products, and that's really important. And then everything we can do to make recycling more efficient will be able to help what's already happening in industry because we're already seeing some great companies getting into this like Redwood Materials and others.

Mr. TONKO. Thank you. Well, I'm out of time. But, Mr. Baroody, I had a question for you, but I'll have the Committee get it to you, and we'll get it in writing.

Thank you, gentlemen, again for your expert testimony and input. With that, I yield back.

Mr. COLLINS. Thank you, Mr. Tonko.

The Chair now recognizes Mr. Miller of Ohio for five minutes.

Mr. MILLER. Thank you. I'd like to thank the Chair and the Ranking Member for holding this morning's hearing, which has now gone into the afternoon, and for our witnesses for joining us here.

Before this hearing, my team and I talked with some companies in my district in northeast Ohio that work daily with the critical minerals and materials we're focusing on now to hear about some of the specific challenges they're facing. I think the most common issue that I heard about in these conversations was the short supply of graphite, as well as some others. So I'm glad that the Committee is addressing the issue of critical minerals and materials today.

My first question is for Mr. Horn. Mr. Horn, I understand that GreenMet looks at innovation and technology trends in the sector. How can emerging technology areas like artificial intelligence and machine learning be leveraged to enable us to strengthen our mineral security and avoid the shortages I'm hearing about from my constituents?

Mr. HORN. Thanks for the question, Congressman. I would say that AI can be implemented into all technical innovation across the entire supply chain. The projects that we're looking at with our partners to implement it span for mineral sourcing and scouting similar to what some of the other witnesses have spoken up to. I think there's a lot that can be done there that AI can optimize.

We're also looking at capabilities of automating portions of the metallurgy and separation cycles in U.S. facilities where, you know, I honestly believe we can outcompete the Chinese on a cost basis because we can actually find ways to use implementation to outprice them on their own labor practices, which I think is—it sounds impossible. I think it can be done. I stand by that challenge.

So I think AI and technology can be implemented in a way to give us an innovative edge over our adversaries in China and Russia and allow us to actually produce the kinds of revenue and returns where investors and companies like myself can bring in larger commercial entities to double down and truly support the U.S. reemergence as the dominant producer in this category.

Mr. MILLER. Yes, thank you for that answer, and I could not agree more with your assessment.

My next question is for any of the witnesses. In each of your opinions, does the United States have the necessary workforce needed to develop a domestic supply chain for critical materials?

And if not, what are some of the hurdles that we will face in trying to meet this need? For any of the witnesses, please chime in.

Dr. MULVANEY. I'll start and say no, we don't have that right now. And I think one strategy perhaps to advance the workforce is to embed in funding opportunities, workforce development opportunities like the Justice40 Initiative, I think, could be paired with apprenticeships and internships and things like that working in these industries, so—to get students excited, to get the workforce excited. So that—but the answer is no, I don't think we have the workforce yet.

Mr. MILLER. Yes, Mr. Peay?

Mr. PEAY. I'll add to that. Yes, getting both university-level training and trade training is really important. We've lost a lot of these skill sets as this industry has moved overseas. We have a relatively small program on university training research, and we've been able to do some work on critical minerals at universities. So it's things like that if we can expand—and I do like the idea of how you can pair things with funding opportunities to get training for people new to these projects would also be super beneficial.

Mr. MILLER. Thank you.

Mr. HORN. One thing I'd add, Congressman, is I think a lot can be done from the private sector, right? I fully endorse and support academic and government efforts. However, I think there's a misunderstanding, especially with some of the younger generations, my own included, in the nature of these jobs, how high paying they can be, how essential they are to technological innovation. You know, it doesn't matter how old you are, but if you'd like an iPhone or a tablet or any forms of social media, this is critically essential for all of those.

Mr. MILLER. Yes, and I don't mean to just jump in, but, look, I'm 35 years old, which means that I didn't graduate from high school too long ago, OK? And so when I was going through the high school process, everyone told me that I needed to go to college. Otherwise, I was never going to be successful, OK? I wanted to be a United States Marine. I ended up doing that anyway but after I went to college. But it wasn't what I wanted to do.

And we have jobs out there right now within the trade industry, which is down 2 percent across the board, so it doesn't surprise me to hear all of you say that we don't have the need that we have. But we have carpenters right now in the State of Ohio, we're 2,000 short to build the Intel project, which is a billion-dollar project that we have in the State. If we are down 2 percent across the trades, and we have no one to work in your industry in critical minerals and materials, which is vital to what this Administration is pushing, once again, vital to what this Administration is pushing and their agenda, how do you get there? And it's—I mean, make it make sense.

And I don't mean to go on a rant, but it's simply not true. We have jobs out there that will pay over $100,000, steelworker, pipefitter, carpenter, welder, to elevator technical operator. The most-needed job in all of Ohio pays $160,000. I can go on. I'm over my time. But we do have a serious need within this country when it comes to technical education and reinvigorating that work ethic within our younger generations.

And, Mr. Horn, I agree, your generation and mine, unfortunately, you know, we need to step it up and the ones underneath us and not get indoctrinated by social media.

Thank you. I yield back.

Mr. COLLINS. The Chair now recognizes Mr. Mullin from California for five minutes.

Mr. MULLIN. Thank you, Mr. Chair. I am somebody who graduated from high school a very long time ago.

Thank you to our witnesses. Dr. Mulvaney, great to see you again, sir. I had the privilege of asking you some questions at our Natural Resources Committee, on which I sit. We discussed rare earth mineral collection and recycling programs or the lack thereof. We discussed—and you have all mentioned—the mineral supply chain is increasingly important as we continue to make progress on a range of new technologies.

Since we spoke, my office did some additional research on the circular economy and took a look at what Europe is doing on this and its waste from electrical and electronic equipment or the WEEE (Waste Electrical and Electronic Equipment) directive that you had mentioned. Thank you for bringing that to my attention.

So my question is for you, Dr. Mulvaney, or others if they want to chime in. If the United States were to pursue something along the lines of this directive, what are some of the top lines from the WEEE that you would recommend that we mirror? And are we starting from scratch in the United States, or is there some movement on this already?

Dr. MULVANEY. I think the takeback and collection system and the recycled content are probably two—the top headlines there. And I think some States are starting to develop these for particular products. So California, for example, has a bunch of State-level extended producer responsibility programs for other sectors that have waste issues, mattresses, paint waste, stuff like that, that costs local governments a lot of money to dispose of. So I think that that's one piece.

And I'll just add one thing that I think is really important about takeback and collection, which is the prevention of fires. We've had a lot of fires that have happened at municipal waste recovery facilities, and they're usually caused by pretty small consumer electronic batteries. So by having takeback and collection programs, we could avoid costs on local governments. Those are million-dollar facilities, often.

Mr. MULLIN. One of those was in my district, as a matter of fact, inspired some State-level legislation that, unfortunately, did not make it across the finish line. But thank you for that.

And then just a quick follow up, some of the lessons maybe from the EU's experience that we should take into account as we move forward in our own approach?

Dr. MULVANEY. Well, I think on the optimistic side, when the EU set up these takeback and collection programs for solar panels, they found reuse markets. And obviously, reusing these devices that generate electricity still at pretty high quantities, 80 percent, 70 percent of their initial capacity, is a lesson to be learned. By—just by stockpiling these materials, you could find second uses of them more often.

Mr. MULLIN. All right. Thank you for that. I yield back.

Mr. COLLINS. The Chair now recognizes Mr. Frost of Florida for five minutes.

Mr. FROST. Thank you, Mr. Chairman.

A strong critical mineral supply chain is essential, but we can also support alternatives to critical mining that can help fuel a clean energy future. Mining critical minerals is safer and more efficient than mining dirty fossil fuels, but that doesn't mean that it's 100 percent safe. Critical mineral mining can present challenges to workers' health, our forests, wildlife, and indigenous populations, something I learned a lot about. I just did a trip to Chile, Colombia, and Brazil, and specifically, when I spent time in Brazil and Chile, we met with a lot of indigenous leaders and populations that brought that up. It's why I'm glad that the Biden Administration is thinking about how we can mine sustainably, but we can also decrease demand for mining and support the alternatives.

Dr. Caers, there are alternatives to critical mining out there such as sodium-ion batteries, but I know there's challenges to their use. What guidance is needed from Federal agencies to help the research and development of commercially viable alternatives?

Dr. CAERS. Yes, sodium is a very interesting—sodium will definitely be used for stationary, but it's likely not going to be used for EVs in the next foreseeable future, and that's just to do with the material properties of thermal stability and also heavier. So that means that we are pretty much—you're going to work with the lithium-ion battery for—particularly for EVs.

I think what the challenge is perhaps that can be is to really look at how mass manufacturing of batteries needs to work because we can always invent a battery in a lab and then even do a pilot or make a battery, but to get that to mass manufacturing is a huge challenge because, you know, there are technologies such as the solid-state battery that people talk about, but it's very difficult to mass manufacture them. So we always tend to forget about this mass manufacture. So investment in manufacturing and the technology to do that is equally important in this way.

Mr. FROST. Thank you. Mr. Peay, the DOE sees the value of critical mineral recycling, spent batteries, earbuds, et cetera. What are some ways that DOE is working to make critical mineral recycling a practical way to mitigate the needs for new mining?

Mr. PEAY. Yes, so we're looking at every part of the supply chain, and so from diversifying supply to looking at alternative technologies that we can have, so better alloys, materials. Recycling is a key part of that process that we're looking at as well, and so what are things we can do to improve some of the chemical processes in recycling or some of the—or just some of the processing steps that we go through? But those are some of the key items we're looking at.

Mr. FROST. How can Congress assist in encouraging the research and development of this recycling?

Mr. PEAY. So just continued support that we've been getting. We really appreciate the bipartisan support that this Committee has given and what the infrastructure law has been able to take from the—from lab scale and get—deploy now is key, and so the continued support is much appreciated.

Mr. FROST. Thank you. Thank you. It's important to remember that a shortcut to meeting demand is reducing demand, and we can reduce the demand for critical mineral mining by increasing usage of commuter rail, EV, powered mass transit, et cetera. Urban planning that encourages safe and practical commuting by biking or walking is helpful, too, and I want to give a shout-out to Orlando Bike Coalition and Orlando YIMBY in Sunrise, Orlando, for the work that they do at advocating for that at our local municipal level.

As we meet the demand for critical minerals to achieve a clean energy future, let's also promote alternatives to make our green economy as safe as possible. Thank you so much for being here, and I yield back.

Mr. COLLINS. Thank you.

I thank the witnesses for taking the time to provide this valuable testimony and the Members for their questions. The record will remain open for 10 days for additional comments and written questions from the Members.

This hearing is adjourned.

[Whereupon, at 12:59 p.m., the Committee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

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Responses by Mr. Ryan Peay

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

Mr. Ryan Peay, Deputy Assistant Secretary for the Office of Resource Sustainability, Office of Fossil Energy and Carbon Management, U.S. Department of Energy

QUESTIONS FROM REPRESENTATIVE SCOTT FRANKLIN

Q1. Mr. Peay, in July the Department of Energy released its Critical Materials Assessment, which evaluated a variety of materials for their criticality to global clean energy technology supply chains. The final list of critical materials did not include phosphorus. I think that was a mistake for the following reasons:

First, phosphorous is an essential component of lithium iron phosphate batteries – known as LFP -- which are safer and have a longer lifespan than lithium-ion batteries, while not requiring the use of costly critical minerals including cobalt and nickel. For that reason, many of the top auto manufacturers, including Tesla, GM, Ford and Rivian are moving quickly to adopt lithium iron phosphate batteries.

Second, I would argue that supply chains of phosphorous are very tenuous. China dominates the global market for LFP batteries, and to avoid becoming completely dependent on them, it is critical that we establish a domestic manufacturing base for battery-grade purified phosphoric acid.

Mr. Peay, given the rapid evolution of the market for LFP batteries, and the growing awareness of the criticality of phosphorous, will DOE reevaluate its decision to exclude phosphorus from the Critical Materials list?

A1. Lithium iron phosphate (LFP) batteries are of increasing importance, however, based on the recent analysis conducted as part of the DOE's 2023 Critical Materials Assessment, the share of phosphorous that is used for energy applications is expected to remain relatively small, and is not expected to be exposed to significant enough supply risk to be considered critical at this time.

On July 31, 2023, DOE released its 2023 Critical Materials Assessment, which evaluated materials for their criticality to global clean energy technology supply chains based on a methodology DOE established in 2010 and that has been applied in 2010, 2011, 2019, and 2023. Based on the results of the Assessment and pursuant to authority under the Energy Act of 2020, DOE determined the 2023 DOE Critical Materials List, which

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includes 18 critical materials for energy and all critical minerals.[1] The 18 critical materials for energy include all materials assessed as critical or near critical in the short or medium term.[2] Links to the 2023 DOE Critical Materials List and the 2023 DOE Critical Materials Assessment are given below.[3]

DOE issued a request for information on May 31, 2023, to solicit public comment on the data and information to support revision of the initial Critical Materials Assessment and improvements to the assessment's methodology.[4] The assessment of phosphorous was revisited by DOE based on the comments received, alleging that phosphorous demand is expected to experience a shortfall for use in lithium iron phosphate (LFP) batteries, geo-concentration of production is outside the U.S., and that agriculture is a competing use. DOE provided further clarification that the Critical Materials Assessment considered high LFP adoption scenarios, geo-concentration of production outside the U.S., and agriculture as a competing use in the assessment of phosphorous. More details can be found in the Critical Materials Assessment report in section 4.3.15. Ultimately, phosphorous was not assessed to be critical under the DOE methodology.[5] DOE anticipates updating the assessment every three years.

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1 The critical minerals list is designated by the Secretary of the Interior acting through the Director of the U.S. Geological Survey.

2 [2] Uranium was excluded from the list. Section 7002(a) of the Energy Act of 2020 restricts the listing of critical materials to "any non-fuel mineral, element, substance, or material" and therefore DOE did not designate uranium as a critical material.

3 Link to the Final 2023 DOE Critical Materials List: https://www.energy.gov/cmm/what-are-critical-materials-and-critical-minerals; Link to the 2023 DOE Critical Materials Assessment: https://www.energy.gov/sites/default/files/2023-07/doe-critical-material-assessment_07312023.pdf

4 https://eere-exchange.energy.gov/Default.aspx#Foald82fa533b-3d3e-4b49-839d-9ddf13d56f40

5 https://www.federalregister.gov/documents/2023/08/04/2023-16611/notice-of-final-determination-on-2023-doe-critical-materials-list

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QUESTIONS FROM REPRESENTATIVE TOM KEAN, JR.

Process Optimization

Q1. Do the witnesses all agree that maximizing process yields, increasing purity levels, and mitigating environmental impact are crucial to the development of the critical materials supply chain?

A1. DOE agrees that maximizing process yields, increasing purity levels (when appropriate), and mitigating negative environmental impacts are crucial to the development of secure domestic critical materials supply chains. The DOE is making major efforts in all these areas to minimize impacts to communities, especially those with environmental justice concerns.

Q2. I understand that advanced modeling or process simulation can make a difference of 30% - 40% in increasing productivity of projects. Would the U.S. benefit from mandating the use of rigorous simulation models for the design and operation of pilot plants, demonstration facilities, and scale up production. I can assure you that in many other industries you would never build a large plant without rigorous modeling.

A2. Process simulation is an important tool to model and optimize metal refining and extraction operations. Process modeling is encouraged in DOE-sponsored work on recovery of critical materials. In the mineral processing industries, samples are often sent to a mineral processing lab, where experienced mining engineers thoroughly characterize the source material, and suggest optimum processing pathways.

In 2023, DOE established a process modeling research program specifically for critical materials within its national labs using BIL funding—the Process Modeling for Mineral Sustainability (ProMMiS) Initiative. ProMMiS supports Critical Materials RDD&D within the DOE, to accelerate novel technologies towards commercial deployment, and to build capabilities to support the acceleration of the design of commercial scale critical materials processing and refining facilities. The ProMMiS tools are built upon existing

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software platforms, such as ASPEN, with the goal that they will eventually be used more broadly for commercial scale CMM operations.

Environmental Sustainability

Q3. Do we all agree that there are significant environmental concerns around the extraction and recycling of critical materials?

A3. There are significant environmental concerns around the extraction and refining of critical materials. DOE is pursuing research to mitigate these environmental concerns. During recycling, wastes first are physically sorted to preconcentrate materials of economic value. There normally are little to no negative environmental concerns for this initial step in recycling. The separation, recovery, and refining steps that follow the physical sorting can have environmental concerns, which the DOE is working to mitigate.

Q4. Given that, should we be requiring rigorous modeling to protect the environment and what risks do we face by not adopting such a standard in our material extraction strategy?

A4. There are a number and variety of wastes, byproducts, and ores that can serve as feedstocks for domestic supply chains of critical materials, and there is no one size fits all strategy for extracting and processing these materials, as is true for more traditional ore bodies. The DOE is working with EPA and others to develop strong environmental standards for critical material supply chains. In this process, stochastic and other modeling approaches are being considered as part of the standards development and would be able to take into consideration the potential environmental benefits (such as carbon removal through mine tailings) and impacts. As models for extraction, processing, and refining methods improve, they will be more frequently featured in standards development.

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QUESTIONS FROM REPRESENTATIVE HALEY STEVENS

Battery Recycling

Q1. Recovering critical minerals from used energy storage technologies, including electrical vehicle batteries, is critical to the creation of a true circular economy. The *Infrastructure Investment and Jobs Act* provided funds for existing battery recycling activities at the Department of Energy.

Can you provide an update on how DOE is advancing our recycling technology of batteries, including through commercialization pathways?

A1. DOE has a wide range of programs that improve the performance of batteries made with recycled materials, reduce the total cost of recycling, improve the environmental impacts of the recycling process, and support the infrastructure and commercialization of these technologies. Success in these programs will ensure a robust and secure domestic supply chain for next generation batteries.

DOE's Office of Energy Efficiency & Renewable Energy (EERE), through annual appropriations, supports innovative battery recycling R&D through its ReCell Center and the United States Advanced Battery Consortium (USABC). The Center, comprised of national laboratories and university members, is working to lower the cost and environmental impacts of recycling to ensure future supply of critical materials and decrease energy usage compared to raw material production. The Center focuses on the direct recycling of materials, advanced resource recovery, design for sustainability, and modeling & analysis. The work focuses on the discovery of innovative ideas in the lab, and scaling to the pilot level. The ReCell Center has taken an end-of-life battery, directly recycled it, and made the components into a new battery at lab scale with performance on par with virgin battery material from mined sources. Once such technologies are more mature, the USABC will work with industry to further the development and bring the product to commercialization.

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In addition to R&D funded through annual appropriations, the Bipartisan Infrastructure Law provided $200 million in total funding for electric drive vehicle battery recycling and second life applications and $125 million for consumer electronic battery recycling and collection programs. In 2023, DOE awarded $74 million of the $200 million to 10 projects to advance recycling technologies and processes for EV battery recycling and reuse.[6] On December 18, 2023, EERE announced a second funding opportunity of $37 million to reduce EV battery recycling costs.[7] This second phase will reduce the costs associated with transporting, dismantling, and preprocessing end-of-life electric drive vehicle batteries for recycling. For consumer electronics batteries, DOE released a funding announcement during the summer of 2023 to increase the participation by consumers in existing battery recycling programs; improve the economics of recycling these batteries; assist states and local governments in establishing battery collection and recycling programs; and help retailers implement programs to collect, sort, store, and transport consumer electronics batteries.

The most successful technologies from EERE's portfolio are then evaluated by DOE's Office of Manufacturing and Energy Supply Chains (MESC), which assists industry in financing the infrastructure needed to create a robust domestic battery supply chain. (DOE's Loan Program Office can also function as a financing tool for industry.) MESC's Battery Manufacturing and Recycling Grants Program, appropriated within the Bipartisan Infrastructure Law, provides grants to ensure that the United States has a viable domestic manufacturing and recycling capability to support a North American battery supply chain.[8] On October 19, 2022, DOE announced the selection of fifteen projects that were ultimately funded, and that are catalyzing over $5.8 billion in public/private investment to extract and process lithium, graphite, and other battery

[6] https://www.energy.gov/articles/biden-harris-administration-announces-nearly-74-million-advance-domestic-battery-recycling
[7] https://www.energy.gov/eere/vehicles/articles/doe-announces-37-million-reduce-ev-battery-recycling-costs
[8] https://www.energy.gov/mesc/battery-manufacturing-and-recycling-grants

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materials; manufacture components; and demonstrate new processes. Specifically related to recycling production, Cirba Solutions was awarded close to $75 million to expand and upgrade their lithium-ion recycling facility in Lancaster, Ohio, and Ascend Elements was awarded $316 million to create cathode precursor material from recycled battery materials.

Through their partnership, DOE's EERE and MESC offices work hand in hand to develop next generation recycling technologies and processes that produce recycled batteries with better or equal performance to batteries made from virgin, mined materials. DOE works to scale these technologies and bring them to commercialization so that MESC and LPO can finance the infrastructure needed to support a secure domestic supply chain that will support our country's electrification and decarbonization goals.

Q2. What barriers is DOE observing in operationalizing battery recycling at scale that Congress should consider?

A2. Cost and performance are the biggest concerns regarding battery recycling at scale. DOE is trying to lower the costs associated with collecting, transporting, dismantling, preprocessing, and postprocessing end-of-life electric drive vehicle batteries. Additionally, DOE is working on improving the performance of batteries made from recycled material. While early testing shows performance on par with batteries made from virgin mined material, industry is still hesitant given the long-time horizon needed to qualify batteries for electric vehicles as well as the heavy financial burden associated with warranties.

Additionally, the large-scale physical collection and sorting of batteries is a significant challenge for battery recyclers, as is having secure offtake agreements that guarantee a purchaser of the metals recovered from the used batteries. The variety of battery

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chemistries and casing materials, and the thermal runaway hazards associated with lithium batteries are other issues of concern for battery recyclers. DOE-funded work is helping make great progress on all these issues.

<u>Alternative Materials</u>

Q3. The Department of Energy and the National Energy Technology Lab have made recent advancements that demonstrate the feasibility of alternatives to traditionally mined critical minerals, including recovery efforts from coal waste.

Can you provide an update on how the Department of Energy is advancing our understanding of alternative materials and supporting demonstration and commercialization of these advancements?

A3. There are a number of unconventional feedstocks (waste and byproduct materials) that could potentially serve as sources for critical materials. These include coal ash, waste coals, petroleum cokes, red mud, garnet abrasives, steel slags, mine tailings, smelter flue dusts, produced waters, municipal solid wastes, municipal sewage sludge, e-wastes, asbestos impoundments, and phosphogypsum byproducts. Many of the DOE efforts on unconventional feedstocks as sources for critical materials are summarized in The Report to Congress "Recovery of Rare Earth Elements and Critical Materials from Coal and Coal Byproducts", May 2022.[9]

DOE's Office of Fossil Energy and Carbon Management is advancing the use of unconventional and secondary resources to extract, separate, produce, and recover both rare earth elements and critical minerals and materials. This effort started in 2015, with coal, coal by-products, coal-based acid mine drainage, power generation combustion fly ash, coal preparation refuse or tailings, and lignite as DOE's primary feedstock resources.

[9] https://www.energy.gov/sites/default/files/2022-05/Report%20to%20Congress%20on%20Recovery%20of%20Rare%20Earth%20Elements%20and%20Critical%20Minerals%20from%20Coal%20and%20Coal%20By-Products.pdf

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DOE has previously issued six Funding Opportunities and Request for Proposals, and recently three Bipartisan Infrastructure Law (BIL) Funding Opportunity Announcements (FOAs), and supports over 40 academic, small business and national laboratory recipients to develop and validate the technical feasibility of using conventional and advanced separation technologies. To date, DOE has developed—from concept through construction and operation—five first-of-a-kind bench/pilot-scale facilities. DOE is currently pursuing Front-End Engineering Design (FEED) studies, for a potential Demonstration-Scale facility for production of 1-3 metric tonnes per day of mixed rare earth oxides (MREO) from coal-based feedstock materials in the 2027-2028 timeframe. DOE is also evaluating additional unconventional rare earth element- and critical minerals and materials-containing resources, such as brines and produced waters.

<u>Additional Background and Specific Examples</u>

The University of Kentucky developed a small pilot-scale system that integrates both physical and chemical separation process (acid leaching). West Virginia University and its partners developed a large bench-scale facility for a cost-effective process with minimal environmental impact to recover Rare Earth Elements (REEs) from solid residues (sludge) generated during treatment of acid mine drainage (AMD) as well as raw AMD fluids. This project took advantage of naturally occurring processes that occur in coal mines and associated tailings that liberate, then concentrate, REEs. Findings showed elevated concentrations of REEs, particularly in low-pH AMD, and nearly all precipitating with more plentiful transition metals in the AMD sludge.

The University of North Dakota's large bench-scale facility has substantially simplified the acid leaching REE extraction process for economic benefit. The "by-product" of upgraded lignite can be used for carbon ore products, such as activated carbon, graphite, building materials, and upgraded fuel. The hydrometallurgical processes remove impurities using commercially available equipment and requires no novel chemicals. This process is low-cost with minimal environmental impacts, operating at ambient temperature and moderate pH for mineral processing.

Recently the University of North Dakota and West Virginia University have expanded their efforts to pilot-scale demonstrations, with very promising results. The North Dakota effort focuses on lignite coal as a feedstock to produce rare earths, gallium, and germanium. The West Virginia work is employing the solids associated with acid mine drainage to produce rare earths, manganese, nickel, and cobalt.

Physical Sciences, Inc. (PSI) researchers have demonstrated potential to produce economically scalable REE-rich concentrates (also containing Scandium) and commercially viable co-products from coal ash in their small pilot-scale facility. The environmentally safe and high-yield physical and chemical enrichment and recovery processes were developed and are being utilized at the small pilot-scale facility run by PSI's partner, Winner Water Services, Inc. The work, sponsored by DOE, has garnered positive results, and the Department of Defense has recently funded PSI to continue their work on coal ash as a feedstock for critical materials.

Additionally, advancements have been made at developing synthetic graphite and/or battery anode materials from coal and coal wastes. NETL's Research and Innovation Center discovered that iron oxide is a surprisingly effective catalyst for converting coal to graphite at around 1500°C (much lower than the typical 3000 – 4000°C). Additionally, both the catalyst and acid used to recover it can be recycled and reused to produce graphite that performs well in lithium-ion battery tests. DOE supported R&D of Semiplastics' technology to utilize domestic, abundant, and inexpensive coal-derived lithium-ion battery anodes as an alternative to graphite. This technology received the Voltage Award from the Battery Innovation Center, which recognizes an emerging

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

Mr. Ryan Peay, Deputy Assistant Secretary for the Office of Resource Sustainability, Office of Fossil Energy and Carbon Management, U.S. Department of Energy

company and/or technology with the highest potential to make a difference in batteries and electrification. Coal-derived lithium-ion battery anodes have been tested extensively in 18650 cells, an industry standard size used in battery electric vehicles such as the Tesla Models S & X.

DOE's Office of Energy Efficiency & Renewable Energy (EERE) is advancing lithium extraction from geothermal brines through multiple efforts, including selections for a funding opportunity on Lithium Extraction and Conversion from Geothermal Brines[10] and the Geothermal Lithium Extraction Prize. This work is coordinated through the Lithium RD&D Virtual Center, which is a United States Government-led center for promoting cooperation on lithium supply chain related topics across the United States.

EERE's Critical Materials Innovation Hub (CMI), a DOE Energy Hub led by Ames National Laboratory and managed by the Advanced Materials & Manufacturing Technologies Office (AMMTO), began Phase III of operation in November 2023. CMI 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. CMI's refreshed project portfolio includes a research focus area on Expanding & Diversifying Supply.[11] Alternative materials being explored include lithium from mudstone, coproduction of platinum group metals, phosphate minerals, phosophogypsum waste, and residue from industrial processes.

One of DOE's strategic pillars for the DOE Critical Materials Program is developing alternatives to produce new materials (e.g., alloys) that are less rare and can be

[10] https://www.energy.gov/eere/ammto/funding-selections-fy22-ammto-gto-lithium-extraction-and-conversion-geothermal-brines

[11] https://www.ameslab.gov/cmi/enhancing-diversifying-supply

substituted for existing critical materials, as well as designing manufactured parts and systems that require little to no critical materials to function. These actions help reduce demand and partially offset the need for virgin materials.

The following are examples of progress DOE is making under this strategic pillar. All involve critical materials that are used in high-grade rare earth permanent magnets: neodymium, dysprosium, and terbium. In addition to national defense applications, consumer electronics, sensors, and other technologies, these magnets are essential components of EV motors and offshore wind turbine generators. China currently dominates the supply chain for rare earths and permanent magnets, posing economic and national security challenges for the United States. Developing alternatives to critical rare earths and other critical materials is one way to help secure reliable domestic supply chains for the clean energy transition:

- Critical rare earth free cerium gap magnets: Researchers at the CMI Hub are developing solutions to the "gap magnet problem." In the permanent magnet mass market, there is a wide gap in performance between two main groups. On the lower end are weaker but inexpensive magnets, which are used in motors, alternators, refrigerator magnets, and other applications. On the higher end are strong, much more expensive critical rare earth-based magnets, such as neodymium iron boron magnets (NdFeB), used in EV motors and wind turbine generators. The critical material, neodymium, is being used in some applications that are not weak, but do not need the highest performing materials. Led by Ames National Laboratory—and in partnership with Bunting-DuBois, a private magnet solutions firm in Pennsylvania—CMI has produced a compression molded, bonded magnet using the abundant rare earth element cerium (Ce). CMI's Ce gap magnet outperforms ferrites in strength and is produced more energy efficiently. Potential uses include automotive sensors and other "middle energy" applications, freeing up critical rare earths like neodymium, praseodymium, and dysprosium, and terbium for more demanding clean energy technologies. CMI, Ames, and Bunting-DuBois won an R&D 100 Award in 2023 for this breakthrough that offers an alternative to critical rare earths and saves energy in the process.

- ARPA-E SCALEUP Program: Another example of alternatives to CMM for use in magnets comes from ARPA-E—this one in the demonstration phase. Experience across ARPA-E's diverse energy portfolios, and input from a wide range of investors and industry stakeholders, indicates that pre-commercial "scaling" projects are critical to establishing that performance and cost parameters can be met in practice for potentially transformative technologies. The Seeding Critical Advances for Leading Energy technologies with Untapped Potential (SCALEUP) program builds on ARPA-E's primary R&D focus to support the scaling of these high-risk new technologies across the full spectrum of energy applications. In November 2022, ARPA-E announced its second cohort of SCALEUP awardees, all eight of which were private firms whose technologies were previously funded by ARPA-E and could demonstrate both a viable path to commercial deployment and the ability to attract private sector investment. One of the awardees was Niron Magnetics of Minneapolis, which received $17.5 million. Niron is working to commercialize the world's first powerful permanent magnet made without critical materials.

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QUESTIONS FROM REPRESENTATIVE SUMMER LEE

Q1. What steps is the Dept. of Energy taking to support and empower communities in building out a circular economy as it relates to critical minerals?

A1. DOE is exploring the use of domestic wastes and byproducts as feedstocks for production of critical materials. There are a number of domestic waste and byproduct materials that could serve as sources for critical materials, and these include coal ash, waste coals, petroleum cokes, red mud, garnet abrasives, steel slags, mine tailings, smelter flue dusts, produced waters, municipal solid wastes, municipal sewage sludge, e-wastes, asbestos impoundments, and phosphogypsum byproducts. The use of these wastes and byproducts will enable the clean-up of waste sites, as well as producing new jobs for local communities. The CORE-CM Initiative is a regional effort that FECM is leading, forming coalitions of industry, academic, state, tribal, non-governmental, and other organizations in many regions across the country to evaluate the potential for establishing critical material supply chains from secondary and unconventional sources.

Additionally, DOE has numerous education outreach programs (from middle school through university levels), and is supporting university mining programs, to develop a trained critical materials workforce. DOE's Office of Fossil Energy and Carbon Management (FECM) hosts the University Training and Research (UTR) Program, which funds early-stage R&D and student development at U.S. colleges and universities. In FY23, the UTR program released funding opportunity announcement (FOA) DE-FOA-0003002. The FOA provides grant funding up to $17.7M, and FECM is expecting to make up to 21 awards, including for two areas of interest related to critical minerals.

DOE's Office of Energy Efficiency & Renewable Energy (EERE) has several prize initiatives to advance circular economy approaches:

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- The Lithium-Ion Battery Recycling Prize focuses on identifying innovative solutions for collecting, sorting, storing, and transporting spent and discarded lithium-ion batteries — from electric vehicle (EV), consumer electronics, industrial, and stationary applications — for eventual recycling and materials recovery.
- The Geothermal Lithium Extraction Prize is designed to find solutions that de-risk and increase market viability for direct lithium extraction (DLE) from geothermal brines. Advancement of DLE technologies allow for improved methods that lower costs, lessen environmental impact, and further the mission to turn the threat of climate change into an opportunity to revitalize the U.S. energy and critical materials supply chain.
- The Wind Turbine Materials Recycling Prize is designed to help the United States develop a cost-effective and sustainable recycling industry for two high-impact categories of wind turbine materials: fiber-reinforced composites and rare earth elements.

Finally, DOE's funding announcements for projects under the Inflation Reduction Act or Bipartisan Infrastructure Law call for Community Benefit Plans, which ask organizations to submit plans to engage with communities and to provide benefits to their members.

Responses by Dr. Jef Caers

Questions submitted by Representative Tom Kean, Jr., Committee on Science, Space, and Technology

Process Optimization

1. Do the witnesses all agree that maximizing process yields, increasing purity levels, and mitigating environmental impact are crucial to the development of the critical materials supply chain?

Yes, I agree. Optimization of process yield and purification needs a holistic approach that includes characterization of the critical mineral during mining. This holistic approach, which is not used to do will also reduce waste on both mining and processing, and hence reduce environmental impact.

2. I understand that advanced modeling or process simulation can make a difference of 30% - 40% in increasing productivity of projects. Would the U.S. benefit from mandating the use of rigorous simulation models for the design and operation of pilot plants, demonstration facilities, and scale up production. I can assure you that in many other industries you would never build a large plant without rigorous modeling.

Yes, modeling is essential, but also need to be supported by actual data. Currently data acquisition along various components of the processing chain, starting from mining, is not taken comprehensively, or with the optimization of a processing plant in mind.

Environmental Sustainability

3. Do we all agree that there are significant environmental concerns around the extraction and recycling of critical materials?

Yes there are, most of these concerns can be mitigated by more comprehensive exploration, which allows choices to be made on where to mine, instead of being stuck with the limited known assets/discoveries. Exploration should also focus on small-scale but high-grade deposits. Currently the mining grade in the US have been declining for a while which results in destructive open pit mining

4. Given that, should we be requiring rigorous modeling to protect the environment and what risks do we face by not adopting such a standard in our material extraction strategy?

Yes, comprehensive modeling both of air pollution and of groundwater contamination is essential. Often the hydrogeology near mines is not well understood since too few measurements ae taken which makes modeling challenging subject to significant uncertainty, which results in poor decision making.

Responses by Mr. Drew Horn

Responses from Drew Horn, GreenMet to questions submitted for the record:

Questions submitted by Representative Rich McCormick, Committee on Science, Space, and Technology

1. What level of investment are you seeing from the United States private sector to set up a robust domestic critical materials supply chain, and what hurdles has the federal government placed in its way?

- U.S. private capital investment is thus far following the Federal government's lead on investment and has invested more heavily at the manufacturing end of the supply chain. Until the Federal government de-risks and prioritizes the upstream supply chain by pairing greater public funding with policies that improve the permitting timelines and processes for mining, processing and refining, private investment will not be as robust at the front end of the supply chain.

  a. Congress must ensure that the government is a catalyst for innovation NOT a hindrance. In your opinion, what are the most logical areas where the federal government can come in and assist with what industry is already doing?

  - A big deterrent to investment is the huge inefficiencies in the permitting process. Uncertainty and delay associated with permitting drastically reduces our global competitiveness. On top of that, investors are worried about Chinese State-Owned Enterprises (SOEs) ability to flood the market and put American companies out of business at any moment. Without the whole of the supply chain out of adversarial control, American investors will always feel the existential risk of being flooded out of the market by China at any moment. This is why 'uninterruptable' must be a core pillar for reshoring the critical mineral supply chain.

2. In the national security vein, the Department of Defense houses the Defense Production Act (DPA) Title III office. The office's mission is to ensure our domestic supply chains are less reliant on foreign manufacturing and finds, analyzes and fixes our own shortfalls in our defense industrial base. In your opinion as an industry expert, how can the administration leverage Defense Production Act Title III to address critical mineral supply chain gaps?

   a. Would you recommend that Congress raise the issue with the Defense Department?

- DPA is a great vehicle for prioritizing upstream funding. The administration can and should leverage DPA Title III to address critical mineral supply chain gaps. For example, two projects well suited for this type of funding are the Wyoming-based "Bear Lodge Rare Earth Project," and the Missouri-based Caldera tailings reclamation project at Pea Ridge, between which we can meet all domestic heavy rare earth demand without looking beyond our borders. Congress should continue to maintain checks on the DOD to ensure that this process is efficient and beneficial for domestic projects to maintain our capabilities at home.

Questions submitted by Representative Tom Kean, Jr., Committee on Science, Space, and Technology

Process Optimization

1. Do the witnesses all agree that maximizing process yields, increasing purity levels, and mitigating environmental impact are crucial to the development of the critical materials supply chain?

- Yes. We must leverage Federal research funds and assets to develop and support processing, refining and metallurgy techniques that maximize yield and improve purity levels in the most environmentally responsible way possible. By enhancing both yield and purity, we can ensure that the oxides, alloys and metals being produced are best positioned to meet our more complex national needs and better able to compete against a Chinese monopoly. Based on our experience with partners such as Rare Element Resources and CVMR, as well as our knowledge of the work of the national labs and the Critical Minerals Institute, these kinds of innovative processes exist and are being proven out to commercial scalability at this moment. Congress must do everything it can to help bring these modern technologies forward to commercial scale quickly and ensure that there are agreements and incentives in place to sustain those companies as they compete on an unlevel playing field.

2. I understand that advanced modeling or process simulation can make a difference of 30% - 40% in increasing productivity of projects. Would the U.S. benefit from mandating the use of rigorous simulation models for the design and operation of pilot plants, demonstration facilities, and scale up production. I can assure you that in many other industries you would never build a large plant without rigorous modeling.

- Rigorous modeling is something our client Rare Element Resources (RER) has done alongside General Atomics affiliate UIT for their rare earth element processing and separation demonstration plant. The advanced modeling or process simulation is being done to increase productivity of the process as you aptly note, Representative Kean. They are doing it because it is a critical step in the design process that will lead to better data from the demonstration scale plant to be used in the design of a commercial facility. RER has performed extensive modeling of their proprietary technology, and they have done this seamlessly as it has given them a leg up on competitors. Modeling and simulations are inherently part of most state-of-the art technology. That said, it is not their intent to share the results of that modeling with any party, as inevitably it would end up in the hands of the Chinese, which would clearly be detrimental to new process development. All this to say, yes, the U.S. could benefit, but the information should never be shared if we intend to stand up a U.S. supply chain for critical materials. Government mandates, in this case, are unnecessary to incentivize profitability, but could potentially hinder future development.

Environmental Sustainability

3. Do we all agree that there are significant environmental concerns around the extraction and recycling of critical materials?

- Not necessarily. Energy transition targets, manufacturing needs, and regulatory uncertainty have created challenging conditions and strained supply chains. GreenMet explores new and adaptive ways to de-risk mining projects and create value in every step of the supply chain while prioritizing the need for maintaining environmental and regulatory standards that outshines our adversaries. A clean, electrified future for the US means we cannot rely on a supply chain interrupted by a Chinese monopoly that produces critical metals like rare earths with a process and wastes that are so toxic, they would be prohibited in the United States. The development of US refining capabilities will provide opportunity for Science, Industry, Innovation, Environmental Accountability, and Advanced Technology to create a new set of assets for our nation. By leveraging Federal research assets and R&D funding sources to support public and private innovation in processing, refining and metallurgy we can have these materials through better processes, with less environmental burdens, and production dedicated to the advanced products and systems for US technologies. Many of these capabilities will be the first facilities of their type and can reflect the excellence of American innovations as commercial scale production of critical materials is manifested. This production will be leveraged to produce critical materials with zero toxic byproducts and zero direct carbon emissions. It is reasonable to expect that the advanced manufacturing capability will become the global standard for production and allow the US to lead in supply, technology innovation, and environmental excellence.

4. Given that, should we be requiring rigorous modeling to protect the environment and what risks do we face by not adopting such a standard in our material extraction strategy?

- GreenMet is committed to U.S. based processing and metallurgy for critical minerals that are not only cost-efficient, but also environmentally responsible. We should be requiring rigorous modeling to protect the environment. The first crucial step in this is requiring federal applied research funding tailored to prioritizing advancements in technology which will directly result in better environmental standards while enabling robust U.S. competition in the global market. By not having such standards we risk falling into techniques our adversaries have adopted that continually do not prioritize the environment and cause greater and longer-lasting damage to the planet. Further, we must ensure that Federal R&D resources are invested longer and further into the development process to ensure commercial scalability.

<u>Questions submitted by Representative Haley Stevens, Committee on Science, Space, and Technology</u>

<u>Alternative Materials</u>

The Department of Energy and the National Energy Technology Lab have made recent advancements that demonstrate the feasibility of alternatives to traditionally mined critical minerals, including recovery efforts from coal waste.

1. From an industry perspective, what do you see as promising alternatives to traditionally mined critical minerals and materials that the Department should be investing in?

    - With adequate funding provided, the Office of Science is uniquely positioned within the federal R&D structure to enhance our nation's innovation capabilities and deliver new technologies critical to our future economy and national security. I have visited Oak Ridge and been extremely impressed with the knowledge and understanding the team there demonstrates on the importance of developing modern technologies GreenMet fully believes that all the critical minerals on our USGS list, as well as a few that have been excluded, are indeed critical. However, the end product uses of some of these minerals are of greater importance to our national agenda. It is important for us to prioritize the research, funding and re-shoring of mining, processing, and manufacturing capabilities for the elements and minerals that most directly support our needs in defense, energy and critical infrastructure and technology to ensure that we are prioritizing our national security, energy independence and economic stability. We need to explore all innovative technologies in mining as well as exploring and freeing up the ability to tap into the rich resources we have sitting in waste piles, also known as tailings, from prior mining. Permitting tailings exploration and mining will provide more immediate access to many of the rare earth elements and critical minerals we need to meet our national imperatives, reduce current waste, clean up old mine-sites and further validate and identify resources in existing mines. However, to tap into many of these tailings resources, we must make it beneficial to those mine owners and address permitting hurdles such as those related to mitigating the thorium present in many tailings that contain rare earth elements. The additional permitting requirements that result from these small amounts of thorium make engaging in tailings reclamation more complex than many companies are willing to undertake. While not an exclusive alternative to permitting new mines, re-mining coal waste and tailings cleans up legacy pollution, yields minerals vital to national security, and creates good jobs.

Questions submitted by Representative Summer Lee, Committee on Science, Space, and Technology

1. What role must the US play to ensure that we support our partners in the international community to prevent environmental degradation, labor exploitation, and human rights abuses?

- Ending the use of child and slave labor in critical mineral extraction is important to me, as a father, and to GreenMet as the leading voice for a U.S. critical mineral supply chain. Re-shoring all steps in the critical mineral supply chain, including mining and processing, will provide an ethical and environmentally responsible alternative to those abusing children in the pursuit of cheaper, easier methods of extraction. Once those alternatives are available with true traceability and accountability, our global standards and expectations can be elevated. If we do not permit domestic mining and processing as an alternative to the current status quo, then we are, in fact, endorsing the use of child labor and environmentally devastating methods of extraction and processing.

Responses by Dr. Dustin Mulvaney

Date: December 28, 2023

To: House Committee on Science, Space, and Technology

From: Dustin Mulvaney, Professor,
Environmental Studies, San José State University,

Re: Questions For the Record, The Role of Federal Research in Establishing a Robust U.S. Supply Chain of Critical Minerals and Materials, House Committee on Science, Space, and Technology, November 30, 2023.

To the Committee leadership and members, Please see replies to the committee members who asked for questions for the record. Thanks again to the staff and the committee for their work on these topics. I look forward to your continued consideration of these issues.

Sincerely,
Dustin Mulvaney

Questions submitted by Representative Tom Kean, Jr., Committee on Science, Space, and Technology

Process Optimization

1. *Do the witnesses all agree that maximizing process yields, increasing purity levels, and mitigating environmental impact are crucial to the development of the critical materials supply chain?*

Thank you for the question Representative Kean. Please see these responses in bold below.

Maximizing process yields for critical materials is important in both manufacturing and end of life materials recovery. Mitigating environmental impact is important to the development of critical materials supply chains because it helps ensure that projects that can be built responsibly and to the highest standards can have make up for those impacts. This is why things like the lithium excise tax in the Salton Sea region is a program worth following, as those funds are intended to be directly reinvested into the community through mitigation projects that for example improve air quality by requiring emissions reductions or by restoring parts of the Salton Sea, which is a major source of air pollution in the area as the lake retreats and exposes hazardous dust.

2. *I understand that advanced modeling or process simulation can make a difference of 30% - 40% in increasing productivity of projects. Would the U.S. benefit from mandating the use of rigorous simulation models for the design and operation of pilot plants, demonstration facilities, and scale up production. I can assure you that in many other industries you would never build a large plant without rigorous modeling.*

The use of evaluation tools for scaling up production from pilot to commercial production would benefit from more insights. The cost of materials in supply chains and prices for

materials produced is probably something that has greater implications for the successful development of new techniques for extracting materials from for example wastes. Here advanced modeling of for example mining wastes or heavy metals in groundwater under remediation could be used to better characterize resources.

Environmental Sustainability

3. *Do we all agree that there are significant environmental concerns around the extraction and recycling of critical materials?*

There are environmental concerns about both extraction and recycling of critical materials. Extractive industry impacts can be avoided through better recovery of materials in waste, but these facilities also must employ clean processing and recovery methods. For example, recycling lithium ion batteries can help avoid demand for lithium, cobalt, manganese, graphite, and other metals. However, some extraction techniques that used incineration for example could exacerbate air quality or facilities could generate high levels of dust or heavy metals could be very important environmental justice and public health concerns.

4. *Given that, should we be requiring rigorous modeling to protect the environment and what risks do we face by not adopting such a standard in our material extraction strategy?*

Rigorous modeling of materials demand and waste diversion strategies that lead to advance materials recovery could be a net environmental benefit. The most important standards for materials extraction are those related to human rights, labor, and environment.

Questions submitted by Representative Summer Lee, Committee on Science, Space, and Technology

It's important to me that research and development into how we interact with subsurface critical minerals caters to the safety and wellbeing of human beings on the surface, along with remembering that we share this planet with all the flora and fauna, and we are obligated to protect such as well.

1. When discussing opportunities for deep-sea mining, no human beings call the seafloor home; however, are there environmental justice concerns must we remain vigilant for?

Thank you for the question Representative Lee.

All types of mining impacts deserve attention. More than just deep sea mining, but also mining that impacts sea beds including on the continental shelf should be thoroughly assessed before even pilot production occurs. It is crucial to remember that these activities involve more than just mining, but also waste disposal which can often be more significant in terms of anticipated impacts.

Environmental justice concerns that would be of concern nearby deep sea mining activities including increased metal contamination and bioaccumulation of metals in fish and seafish near mining sites, or other route of exposure. Loss of revenue from ecotourism from noise or other disturbances to marine wildlife could also impact communities.

Below are several additional readings on the topic. I look forward to your continued consideration of these issues.

Further reading

Bloomberg. US claims huge chunk of seabed amid strategic push for resources. December 22, 2023. https://www.mining.com/web/us-claims-huge-chunk-of-seabed-amid-strategic-push-for-resources/

Drazen, J. C., Smith, C. R., Gjerde, K. M., Haddock, S. H., Carter, G. S., Choy, C. A., ... & Yamamoto, H. (2020). Midwater ecosystems must be considered when evaluating environmental risks of deep-sea mining. *Proceedings of the National Academy of Sciences*, *117*(30), 17455-17460. https://www.pnas.org/doi/abs/10.1073/pnas.2011914117

Earthworks. Seabed Mining. https://earthworks.org/issues/seabed-mining/

Hughes, D. J., Shimmield, T. M., Black, K. D., & Howe, J. A. (2015). Ecological impacts of large-scale disposal of mining waste in the deep sea. *Scientific reports*, *5*(1), 9985. https://www.nature.com/articles/srep09985

Responses by Mr. Thomas E. Baroody

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

Thomas E. Baroody, President & Chief Executive Officer, K-Technologies, Inc.

Questions submitted by Representative Scott Franklin, Committee on Science, Space, and Technology

Mr. Baroody, as you know, China dominates the global market for rare earth elements. This poses a real threat to our national security.

I understand your company is involved in a project to explore the feasibility of extracting rare earth elements from phosphogypsum, a byproduct of phosphate mining that is currently stored in large stacks.

1. Can you talk about the great potential of this project?

RESPONSE: With the technology that we have developed at K-Tech and expect to soon co-patent with Rainbow Rare Earths, for the very first time in the history of the United States we will be separating individual battery metal rare earths oxides for commercial uses from phosphogypsum (PG). The most important of these oxides – neodymium and praseodymium - are absolutely fundamental to the historic global shift to green energy, defense sector technologies and America's high-technology future.

And right now – today – the United States is almost wholly reliant on China for its supply of these critical elements. According to a study by the Center for Strategic and International Studies, China processes 90% of the world's rare earths – including nearly all of the small amount currently produced inside our own country which is shipped to China for processing.

Additionally, in December 2023, China announced a ban on rare earths extraction and separation technologies. We believe this will only tighten U.S. supply chains and those of our allies.

What we are doing at K-Tech is helping to secure America's national security when it comes to these critical materials—we are bringing our rare earths products directly to the U.S. for the Western supply chain, and depending on certain circumstances, RRE may erect the key separation and purification facility in the U.S. to process the South African REE concentrates that would be made there.

One thing should be made clear. Our process for extraction of REEs from PG may not be economically suitable for PG that is made from marine based sedimentary phosphate ores such as are prevalent in about 95% the world (including Florida). This is because most of these deposits only contain about 10-20% of the REEs compared with the igneous carbonatite phosphate ore deposits that are found in South Africa, Brazil, and Russia. Therefore, even though our technology can efficiently remove and process REEs from these sedimentary ore deposits, the lower REE quantities that can be recovered could render the process uneconomical. This would have to be examined on a case-by-case basis.

Of note, however, the major U.S. based phosphate producer Mosaic has large carbonatite phosphate ore reserves that are currently being mined and processed in Brazil. Rainbow has an agreement with Mosaic for extracting REEs from the PG that is currently being produced in that country using our joint technology. Rainbow hopes to soon start test work with K-Tech on PG from that source. If things work out, it could be possible that the above-mentioned separation and purification facility built in the U.S. could be expanded to process the Brazilian based REE concentrates in addition to those from South Africa.

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

Mr. Thomas E. Baroody, President & Chief Executive Officer, K-Technologies, Inc.

Questions submitted by Representative Tom Kean, Jr., Committee on Science, Space, and Technology

Process Optimization

1. Do the witnesses all agree that maximizing process yields, increasing purity levels, and mitigating environmental impact are crucial to the development of the critical materials supply chain?

RESPONSE: I can't speak for the other witnesses, but the answer to this question is generally YES.

2. I understand that advanced modeling or process simulation can make a difference of 30% - 40% in increasing productivity of projects. Would the U.S. benefit from mandating the use of rigorous simulation models for the design and operation of pilot plants, demonstration facilities, and scale up production. I can assure you that in many other industries you would never build a large plant without rigorous modeling.

RESPONSE: The normal procedure leading to the financing and construction of any large process-based mineral/chemical project is to first start with a laboratory based "bench" testing program that uses relatively small quantities of the starting material to be processed to a desired finished product. If that program, which can generally cost in the range of $200,000 – $500,000, yields the desired result, then a rough process flow sheet (block diagram) can be developed with a preliminary material balance. From this block diagram, an order of magnitude capital and operating cost estimate can be made, where the capex is accurate to ±35-40% and the opex to ± 25-30%. If the project looks economical at that point, the next step would be to proceed to a pilot plant test program, where much larger samples would be tested on key parts of the process in a continuous manner, i.e., which would simulate a commercial plant. The cost of a pilot program would be in the range of 5-7 times the cost of the bench test program. From the pilot plant program, a front-end engineering design (FEED) program can be undertaken by a specialty engineering firm at a cost approximating the cost of the pilot program. This would generally provide about 20% of the final engineering for the overall plant, from which capex and opex estimates could be developed to an accuracy ±10-15% and 5-10% respectively. If the project looked economical at this level, this should be sufficient information to allow commercial financing of the overall project and procedure with final engineering, procurement, construction, commissioning, and startup of the commercial plant.

The foregoing modelling procedure is generally required by most banking and financial institutions that would provide debt financing to build the project in combination with equity financing from the

owner and/or other investors. So, I don't see where the U.S. government needs to mandate any particular simulation model to enable a project to proceed, as the steps listed above have to be generally acceptable to institutional investors and bankers in the private sector before they would provide the financing necessary to go forward with the project. Now if the U.S. government were to invest in the project via a grant or other mechanism, their modelling requirements would have to certainly be considered.

Environmental Sustainability

3. Do we all agree that there are significant environmental concerns around the extraction and recycling of critical materials?

RESPONSE: Again, I can't speak for the other witnesses, but the answer to this question from a broad perspective is generally YES. However, it should be noted that from an environmental standpoint, the primary or initial extraction and processing of critical materials from the earth will generally create many more environmental issues to deal with compared with the recycling of materials that have already been mined and processed and are no longer useful.

One example that our company is involved with is the use of phosphogypsum (PG), a waste product of the phosphate industry, that is currently stacked in huge piles, some over 200 feet high in the U.S., (Florida alone has over a billion tons). K-Tech, in conjunction with Rainbow Rare Earths Ltd., has developed a process to use PG as a feedstock for producing certain purified rare earth elements (REEs) required for the battery and magnet industry for EVs and other industrial and military applications. In this process, after extracting the REEs from the PG, the gypsum is cleaned up and restacked for sale in various industrial applications, such as wallboard, road base material, cement admixture, and fertilizer. So, from a waste product (PG) standpoint, we are creating several usable products that will eventually reduce the PG stacks to zero.

4. Given that, should we be requiring rigorous modeling to protect the environment and what risks do we face by not adopting such a standard in our material extraction strategy?

RESPONSE: I don't know if modeling is the answer to this issue. There are already rigorous environmental standards that must be met for new mines and chemical plants that would produce critical materials. The same goes for recycled materials. The modeling described above required to build a new project, be it a new mine and processing plant, or a recycle project, will have to incorporate adherence to existing environmental laws and standards. So, adding some sort of environmental modeling to this effort would seem to me to be overkill.

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

Mr. Thomas E. Baroody, President & Chief Executive Officer, K- Technologies, Inc.

Questions submitted by Representative Haley Stevens, Committee on Science, Space, and Technology

Global Competitiveness

Critical minerals and materials have numerous applications throughout the modern economy, including in key aerospace and defense applications. However, a vast majority of these key components are controlled predominantly by China. Our reliance on Chinese-controlled critical minerals and materials is an economic and national security concern.

1. Can you highlight the risk to our national security that our reliance on Chinese-controlled supply chains create for our defense capabilities?

RESPONSE: According to a variety of reliable sources, China possesses about 60 percent of the world's reserves of rare earths elements, and processes about 90 percent, meaning that most countries, including the U.S., ship REE to the PRC. That means that our defense needs for REE (missiles, tank systems, lasers, guidance systems, and military communications) could be compromised.

It is imperative that the U.S. should expand its sources of RRE material, processing, and transportation, including those in Africa and Latin America.

2. Solving our critical minerals and material issues will take a whole-of-government approach. How can the Department of Defense and the Department of Energy better collaborate to solve this issue? Also, how can they help advance alternative materials through joint research and development efforts? The Department of Energy and the National Energy Technology Lab have made recent advancements that demonstrate the feasibility of alternatives to traditionally mined critical minerals, including recovery efforts from coal waste.

RESPONSE: All efforts in the U.S. should be focused on recovery of critical materials from a variety of waste products that already exist. These include coal and metal mine tailings and waste piles, chemical plant waste streams and impounded pond systems, red muds from bauxite processing, phosphogypsum (PG) stacks, phosphoric acid sludges, etc.

The recovery of high purity REEs from PG was cited in the answers to questions from Representatives Franklin and Kean above. There is also the potential for recovery of REEs and other critical minerals from red mud waste ponds created in the removal of alumina (aluminum oxide) from bauxite ores via

the Bayer process. The alumina is then used to make aluminum metal by electrolysis of a molten bath of alumina in cryolite in a carbon lined pot or cell via the Hall-Heroult process.

In the production of phosphoric acid by the reaction of phosphate ore with sulfuric acid, the liquid phosphoric acid at 24-26% P2O5 strength is first filtered from the by-product phosphogypsum (PG) waste. It is then evaporated up to 54% P2O5 strength for shipment. During the evaporation process a sludge is created in the acid that contains fairly high concentrations of REEs which can be extracted from this waste material. The Florida Industrial Phosphate Research Institute (FIPR) and the Pacific Northwest National Laboratories (PNNL) are working together to develop a process to recover REEs from these sludges. K-Tech is participating in this effort via use of its CIX/CIC process to recover individual purified target REEs from the mixed REE concentrate that would be produced. FIPR and PNNL have applied for a U.S. DOE grant for this work.

Appendix II

Additional Material for the Record

LETTER SUBMITTED BY REPRESENTATIVE HALEY STEVENS

American Critical Minerals Association

November 30, 2023

Representative Frank Lucas
Chairman
Committee on Science, Space & Technology
United States House of Representatives
Washington, DC 20515

Representative Zoe Lofgren
Ranking Member
Committee on Science, Space & Technology
United States House of Representatives
Washington, DC 20515

Dear Chairman Lucas, Ranking Member Lofgren, and Members of the Committee,

As you convene today's hearing on "The Role of Federal Research in Establishing a Robust U.S. Supply Chain of Critical Minerals and Materials," the American Critical Minerals Association (ACMA) applauds your leadership in elevating the importance of research and development in the advancement of an independent and secure US critical minerals supply chain. Public and private investment in research and development must advance solutions to ensure the United States is moving strategically and expeditiously toward countering Chinese control of the global critical mineral supply chain.

ACMA is an industry association that welcomes members from across the critical minerals supply chain, including raw material producers, processors, recyclers, suppliers, manufacturers, and end users, as well as academic institutions and other stakeholders. ACMA's mission is to support the advancement of the domestic critical mineral processing and recycling sectors in a sustainable and responsible manner and for the benefit of our nation's economy and security. Therefore, ACMA encourages Congress to advance policies that will support the growth of an independent and secure critical minerals supply chain – whether streamlining responsible permitting of the upstream extraction of minerals, funding and advancing innovative separation and recycling technologies, or establishing multilateral agreements with allies that share our interests.

It is increasingly apparent that the national security and economic risks associated with our reliance on foreign sources of minerals transcend any single economic sector, such as energy or transportation. In fact, those risks also threaten the growth of our national defense systems, as well as aerospace and additional manufacturing interests such as the production of semiconductors, electronics, specialty steel, and medical devices.

The reality of China's dominance over the global critical minerals supply is daunting. The resulting imbalances in the global market will only worsen without aggressive and persistent U.S. action on a variety of fronts. It is clear that in order to make meaningful progress the U.S. and its allies must further develop and scale numerous methods for producing, processing and refining critical minerals.

In addition to conventional production, we must advance policies and funding that support greater manufacturing efficiencies to reduce the need for virgin materials, build out our ability to reuse and recycle minerals from end-of-life products, and grow our ability to separate minerals from waste streams, amongst other efforts. In particular, the ability to reclaim and recycle certain critical minerals embedded in products at end-of-life (EOL) that are already sitting within our borders presents an important opportunity.[1] Since

[1] In fact, the IEA estimates that – globally -- recycled copper, lithium, nickel, and cobalt from spent batteries could provide for 10% of the demand for these minerals.

numerous minerals can be reclaimed and reused with little to no degradation in quality and performance,[2] growing recycling capacity should be a key piece of the United States' critical minerals strategy.[3] A robust and sustained effort by the Department of Energy and other federal agencies to innovate in this area will meaningfully serve to advance such an effort.

Therefore, as the Committee considers the role of federal agencies in the critical minerals supply chain, ACMA encourages you to consider policies and maintain funding for vital R&D programs that:

- Advance additional funding at the Department of Energy to incentivize the development, deployment, and scaling of processing and refining capacity in the United States;
- Further incentivize domestic recycling initiatives, for the reclamation and reuse of critical minerals from end-of-life products across the economy;
- Maintain and grow R&D initiatives to increase manufacturing efficiencies;
- Seek to develop and deploy technologies that employ alternative materials in advanced batteries and other applications;
- Advance workforce development initiatives to ensure our nation's next generation of workers is prepared to meet the future needs of our manufacturing sector;
- Ensure that the federal government is finalizing grants and other funding opportunities designed for the advancement of critical minerals interests in a timely manner; and
- Direct comprehensive data collection and analysis of technological barriers to better understand the potential to reclaim and recycle critical minerals from end-of-life products.

Whether for batteries, defense applications, clean transportation, renewable energy, medical devices, semiconductor production, or other manufacturing needs, our nation and our allies need predictable, secure and sustainable access to critical minerals. Investing in innovation is key to ensuring we are able to achieve this goal. The American Critical Minerals Association is grateful for this Committee's examination of these vital issues and looks forward to providing continued support for bipartisan efforts to advance policy goals that will secure our clean energy future and regrow our nation's manufacturing sector.

Sincerely,

Sarah Venuto
President
The American Critical Minerals Association

cc: Members of the Committee on Science, Space and Technology

[2] Gregory Barber. "Recycled Battery Materials Can Work as Well as New Ones." www.wired.com. Accessed September 23, 2023.
[3] According to the IEA, "the projected surge in spent volumes suggests immense scopes for recycling. Policy makers can help realise the potention through three specific actions: (i) facilitating the efficient collection and transport of spent batteries; (ii) fostering product design and labelling that help streamline the recycling process; and (iii) harmonising regulations on international movement of batteries." The Role of Critical Minerals in Clean Energy Transitions. ww.ies.org/reports. Accessed September 24, 2023.

ARTICLE SUBMITTED BY REPRESENTATIVE SUZANNE BONAMICI

June 2020

Ocean and Climate Discussion Series

Considering the Deep Sea as a Source of Minerals and Rare Elements

Ocean Conservancy®

This brief reviews the climate-related implications of deep-sea mining, including associated environmental risks. It identifies multiple knowledge and governance gaps that must be closed to fully evaluate whether deep-sea mining offers an acceptable way to obtain critical minerals, and concludes that deep-sea mining should not be allowed unless and until these uncertainties are resolved. It is part of Ocean Conservancy's "Ocean and Climate Discussion Series," which provides science-based analysis to inform the global dialogue on integrating ocean issues into climate policy.

Introduction

A global shift to renewable energy is central to solving the climate challenge. The batteries and digital technologies needed to support this shift require critical minerals including the chemical elements copper, silver, gold, zinc, manganese, cobalt, nickel, tin, and rare earth elements (REEs). Terrestrial mining currently satisfies the demand for cobalt, lithium, and REEs, but demand and supply chain risks are growing, increasing the interest in securing these materials elsewhere. Abundant stores of these elements have been discovered in specific seafloor environments. However, the full implications of deep-sea mining (DSM) for climate mitigation and adaptation, as well as its environmental costs, are insufficiently researched and highly uncertain.

This brief provides policymakers with an overview of the climate-related implications of DSM, including associated environmental risks. It reviews the state of knowledge concerning the mitigation and adaptation implications of mining in deep-sea environments, and highlights the current state of DSM governance and activity. Many uncertainties remain about the full consequences of DSM for ocean carbon storage and biodiversity, and about whether DSM offers an acceptable alternative to land-sourced or recycled materials. Industrial DSM should not be allowed unless and until these and other uncertainties are resolved.

Current State of Knowledge

Deep sea systems provide a wide array of critical benefits to life on Earth, including fisheries, carbon cycling and storage, drug precursors, element processing, and even cultural and educational significance. These benefits are highly interconnected because they involve similar mechanisms, environmental features, or species (1). 40% of fish are now caught below 200m (2) and these naturally slow-growing species are increasingly overfished (3). The deep ocean is minimally studied – only 2% of deep ocean observations come from depths below 500m. Nevertheless, two centuries of limited samples and recent excursions of manned and unmanned devices have uncovered more than 400,000 named species, a small fraction of the millions thought to be present in the deep ocean (4).

Deep sea habitats where critical elements are found, like seamounts (underwater mountains), hydrothermal vents, cobalt rich crusts, and metallic nodules, host unique species that can only live in the extreme conditions found around those locations (5). For instance, microbes hosted by tubeworms or crabs living near hydrothermal vents or growing in mats on mineral substrates are primary producers that depend on hydrothermal vent fluids for energy (6), and they sustain a wide variety of predatory deep-sea species. Polymetallic/ferromanganese nodules provide important habitats for microbes that generate food from chemical sources and provide a major food source for other seafloor species (7). Other bottom-dwelling organisms attach to the hard substrate provided by nodules. Richly diverse deep sea ecosystems arise from these improbable starting conditions, yet these ecosystems are still not well understood.

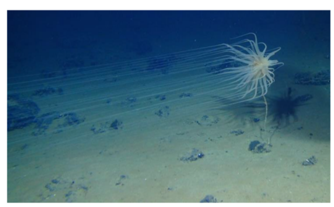

Image 1. A cnidarian that lives on sponge stalks attached to polymetallic nodules, collected at 4,100m in the Clarion-Clipperton Fracture Zone (CCZ). Image: NOAA

Authors: Sarah R. Cooley, Chris Robbins, Kalina Browne

Recovery of deep sea ecosystems from physical disturbances – including displacement, noise pollution, sediment plume spreading and settling, or crushing associated with mining activities – varies widely and relates to depth, bottom type, species present, extent and type of disturbance, and local patterns of natural disturbance (8–10). Animals in slowly changing environments like the deep seafloor are unaccustomed to physical disturbances. Recovery times of deep seafloor environments are very likely to last from decades to millennia (5,11–13), given the long lifetimes of many deep sea species (14,15) and the extremely low replacement rate of sedimentary habitat. In addition, very little is known about the interaction of disturbances from mining and other global changes. Climate-driven stressors such as ocean acidification, warming, and oxygen depletion are likely to have additive and synergistic effects on a biological community's ability to recover from deep-sea mining impacts (16).

Analysis

Mitigation

Deep-sea mining (DSM) is proposed as a way to advance climate mitigation by supporting renewable energy growth, but the global carbon cycle implications of DSM are not known. Mining activities may affect the natural sequestration of carbon in the seabed or the ocean's carbon cycle. The full carbon cycle impacts, including emissions, of DSM have not been evaluated yet.

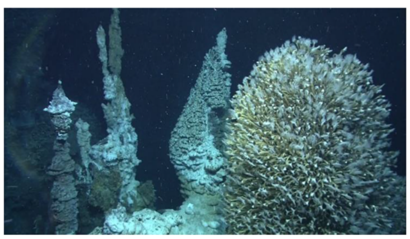

Image 2. A low-temperature sulfide chimney colonized by vent barnacles (right). Image: NOAA.

Ocean sediments contain a small proportion of the carbon naturally captured by biological activities in the upper ocean. By the time this material sinks to the sea floor, it has been recycled by marine animals and microbes many times, each time releasing carbon dioxide into the water column. In the center of major ocean basins, sedimentary materials have been so thoroughly reworked that microbial respiration cannot release much more carbon dioxide (5). Owing to their large spatial area, deep ocean areas sequester about 75% of global sedimentary carbon while continental shelf and slope sediments (although richer in carbon due to more fertilization from land-based sources and less time for recycling) sequester about 23% (5,17).

Some scientific researchers have raised concerns that mining in certain locations will agitate sediments and expose buried organic carbon, which could allow microbes to recycle sediments again and release more carbon dioxide into the deep water (5). Given the relatively long time for bottom water to return to the ocean surface (centuries) and the ability of cold, high-pressure deep water to store a great deal of carbon dioxide, any carbon dioxide released from disturbing deep ocean sediments by DSM seems more likely to promote regional ocean acidification than to escape to the atmosphere.

Microbial species support diverse deep sea communities by harnessing energy and carbon from recycling falling organic material or chemosynthesis (capturing energy to live from chemical compounds in seafloor materials or hydrothermal vent fluids). Hydrothermal vent species like tubeworms and crabs host symbiotic chemosynthetic microbes that sustain them; free-living chemosynthetic microbes and microbial mats on mineral substrates also feed a wide variety of predatory species. Microbes living on polymetallic nodules can also supply the local ecosystem with as much organic carbon as that falling from the water column (7).

Initial studies suggest that mining could severely disrupt carbon cycling by deep sea life either through habitat disruption or removal. For instance, microbial populations had not recovered 26 years after simulated polymetallic nodule mining activities in the Peru Basin in the Eastern Pacific (13). Polymetallic nodules form extremely slowly, at the rate of millimeters per thousands of years, or even possibly millimeters to centimeters per million years, suggesting that this habitat is irreplaceable on human-relevant timescales (18,19). In contrast, there are no published data on recovery from disturbance at inactive vent sites (20), but it is likely that fauna inhabiting massive seafloor sulfide deposits at inactive vents may never recover because this habitat will not regenerate.

The carbon cycle externalities of DSM, including sediment plume behavior and life-cycle analyses of carbon emissions, are not well known. DSM techniques proposed to date all involve extremely large remotely operated devices that crawl along the seafloor on continuous tracks to collect minerals and carry them to a pipe string or riser, which raises the minerals to ships on the surface, where the materials are either stored or processed (21). Each type of seafloor collection device further disturbs the benthic environment by using grinding wheels to break up hydrothermal vent structures and crusts or sonicators to separate crust materials. Both the disturbance of the seafloor and the release of waste materials into the upper ocean are expected to have substantial impacts on seafloor and water column ecosystems, which are only beginning to be investigated (22,23). Sediment plumes and released tailings (waste ground mineral materials) in the upper ocean could decrease biological productivity in the water column by physically blocking light penetration, and these plumes could even create transboundary governance challenges by crossing jurisdictional boundaries and altering water column or seafloor biological activity in a neighboring jurisdiction (24). Although DSM techniques are sure to be logistically complex and energy intensive, there is currently no industry-independent life cycle analysis of the greenhouse gas impacts associated with this mining approach (of both emissions of the mining process and any local alterations of ocean carbon storage) to compare with traditional, land-based mining.

Adaptation

DSM may represent a challenge to climate adaptation, as it will add additional non-climate stressors to an ocean system that provides important benefits to life on Earth now, and it may limit opportunities to adapt to climate change in the future. Climate change and other human impacts are already affecting deep sea systems, and exactly how much perturbation these systems can tolerate while continuing to function is not known.

Deep ocean and seafloor habitats provide a wide variety of benefits, or ecosystem services, that help sustain all life on Earth (1). Supporting and regulating functions from the deep sea include water circulation and carbon dioxide storage and exchange; nutrient cycling and carbon storage in deep water and sediments; primary production (biological energy capture via chemosynthesis); and waste absorption and disposal of material from shallower depths. Provisioning services include fisheries; oil, gas and other forms of energy; rare elements; waste and carbon capture and disposal; bioprospecting opportunities (e.g., drug discovery); and space for communications cables and military operations. Cultural services include scientific and educational opportunities, and the economic benefits that follow from those; inspiration for literature and entertainment; and spiritual wealth and well-being. Despite the inaccessibility of deep oceans, they have captured humans' imaginations for centuries and have inspired exploration and engagement with natural systems (1). These benefits are more highly interdependent in the deep sea than in other places on earth (1). DSM disruption of deep sea systems would therefore likely impair far more services and benefits than commonly thought. For example, loss of deep sea species may foreclose future opportunities to discover new medicines, understand the origins of life on Earth, or harness biological processes for waste detoxification.

Human activity and its consequences are already rapidly changing deep ocean and seafloor ecosystems that provide the biodiversity needed to support the services discussed above. Marine litter, oil and gas drilling, and mining are able to reach every depth (25), at the same time as planetary warming and atmospheric carbon dioxide levels are fundamentally altering ocean conditions. Ocean temperatures from 3000-6000m deep could rise by 1 degree Celsius over the next century (26). Ocean oxygen concentrations will decrease by as much as 0.03 mL L^{-1} by 2100, a 3.7% or more decrease (26). In waters 200-3000m deep, atmospheric carbon dioxide uptake will decrease ocean pH by approximately 0.3 units by 2100 (26). All of these changes represent large alterations in the formerly rather stable ocean environment. Together, ocean warming, acidification, and oxygen loss profoundly affect marine species. Already they are causing marine species to move poleward (27). Vertical stratification is increasing, ultimately altering the amount and timing of phytoplankton production and thus fundamentally changing the magnitude and seasonality of food production supporting the ocean food web (27). Biological recycling and export of organic carbon to the deep ocean are expected to change, as will microbial cycling of elements (27). The impacts of climate change on deep sea ecosystems are not well understood, but it is likely that changing temperature, oxygen, or pH will stress deep sea life. The addition of DSM-related disruptions to existing climate stress could be too much for deep sea species to tolerate, but this is currently very poorly understood.

Image 3. A giant bamboo coral nearly as big as a Remote Operated Vehicle on the Kahalewai seamount at close to 1,700m deep. Image: NOAA.

Governance

Seabed activities that occur within national boundaries are subject to a country's own regulations. Currently several known mineral exploration licenses have been issued within EEZs, primarily in Pacific island countries, as well as Japan, New Zealand, Norway, Portugal, and Sudan. Papua New Guinea is the only country that has issued a mining/exploitation license, but seabed mining activities there are currently halted owing to a combination of public resistance, funding difficulties, and legal challenges (28). Other nations have enacted laws either governing deep-sea mining (Cook Islands, Tonga, Portugal, United States) or integrating it with existing policies on offshore petroleum activities (New Zealand, Papua New Guinea) (29).

Deep-seabed activities that occur in the area outside national jurisdiction ("the Area") are controlled by the International Seabed Authority (ISA) (30). The ISA is an independent organization created under the 1982 UN Convention on the Law of the Sea (UNCLOS) to manage seabed resources and to ensure that measures are in place to protect the marine environment from the potentially damaging effects of mining activities within the Area. UNCLOS does not specifically mention climate change, and so does not answer questions arising about DSM and climate mitigation or impacts on deep sea systems from DSM and climate change.

Many key details about regulation of DSM in the Area are unresolved. The ISA/UNCLOS framework requires participants to apply the precautionary approach, to develop strategies dealing with potential environmental impacts, to implement best environmental practices, and to conduct environmental impact assessments. If those obligations are not met, the sponsoring state could be liable under international law (29). The ISA's Mining Code (currently drafted but not yet adopted) lays out draft regulations on exploitation of mineral resources in the Area. The draft includes specific information about practices, monitoring, and contingency plans (29). But other aspects of DSM governance remain unclear, such as how the ISA will abide by foundational UNCLOS concepts of: distributive justice to allocate the benefits from deep sea extraction (29,31); developing a transparent decision-making process where humans' many interests can be recognized and represented (31); and ensuring that no serious injury (and therefore inequity) follows from transboundary sediment plume movement (31). There is no provision for evaluating and permitting DSM in a broader global context that examines the human, economic, and emissions tradeoffs of mining in terrestrial vs. ocean environments; the possibility of securing critical elements through alternative means such as developing new recycling approaches or minimally destructive mining techniques; or the development of new materials that could preclude the need for these elements in the first place.

Foundational information is lacking that would support precautionary management, assessment of environmental impacts, and use of best practices to sustain the deep ocean systems needed especially for climate adaptation. For instance, the tolerance of seafloor environments to disturbance is not well established, and little is known about the substitutability of one seafloor ecosystem for another. Regular follow-up monitoring is difficult. There is concern that DSM places indigenous peoples and their rights at risk; in the South Pacific, DSM-associated vessels were said to have disturbed fish populations, harmed water quality, and disrupted traditional fishing and cultural activities (32). Human communities where onshore processing would occur may also suffer from environmental degradation akin to that associated with terrestrial mining and mineral processing (29,32,33). Questions also remain about whether DSM is even necessary as recovery and recycling of critical minerals improves, as new materials and technologies are developed, and as global markets for these minerals change over time (33). Life-cycle analyses of carbon emissions associated with DSM and other sources of critical minerals are needed to inform the precautionary and environmental management goals of ISA.

Conclusion

It is currently unclear whether DSM would advance climate mitigation, and there are substantial concerns about its effects on climate adaptation and the health of the ocean environment more broadly. Despite the seafloor abundance of chemical elements needed for renewable energy and digital technologies, critical knowledge gaps remain about whether accessing these elements provides a net climate benefit, and what the cumulative environmental and human impacts of DSM would be.

In particular, uncertainty is extremely high about the tolerance of deep-sea ecosystems to additional disturbance on top of the climate-driven changes these systems are already experiencing. It is unknown whether DSM would endanger deep sea ecosystems' continuing ability to provide essential benefits to life on Earth (including carbon storage) now and into the future. The long-term effects of any level of biodiversity loss from DSM are poorly understood. Currently proposed methods of mining seafloor deposits rely on extremely destructive technologies like crawler tractors outfitted to crush and sonically vibrate apart rocks. Understanding is very limited about the behavior of sediment plumes and tailings from ocean mining operations, which could have significant consequences for life in either the water column or seafloor. Industry-independent life cycle analyses showing whether securing elements from the deep sea even offers a net carbon benefit are currently unavailable.

In addition, effective DSM governance is currently lacking, and needs to be further developed. This includes the need to ensure the full implications of DSM – life cycle carbon emissions, ocean biodiversity consequences, economics, and even worldwide ethical implications – are compared with the challenges of improving terrestrial mining or reducing demand for minerals through improving recycling and a circular economy. A multi-sectoral effort is needed to develop a governance framework that is inclusive of all dimensions, considers tradeoffs explicitly, maximizes transparency, and is enforceable.

Accordingly, industrial DSM should not be allowed unless and until its many scientific, economic, and ethical uncertainties are successfully resolved, and a governance and regulatory framework is in place that effectively mitigates and minimizes environmental and human impacts.

About the Authors

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