U.S. Department of Energy
Advanced Research Projects Agency-Energy (ARPA-E)

Request for Information
DE-FOA-0003356
on
Future Innovation needs for Responsible Mining of Critical Minerals (FIRM-CM)

Introduction:

The purpose of this Request for Information (RFI) is to solicit input for potential future ARPA-E research programs focused on innovative technologies and approaches for resource exploration, discovery, appraisal, mining, and processing of critical minerals. Goals of the potential programs could include:

- Increased recovery rates of critical minerals;
- Minimized hazardous mine tailings;
- Reduced energy consumption from any/all stages of mineral development;
- Minimal carbon emissions from any/all stages of mineral development;
- Minimal aquifer and hydrological disturbance on the mining sites;
- Rapid data development/use for permitting and mine planning from governments and local communities;
- Autonomous operation in remote environments; and
- Increased access to deeper, more diffuse, hotter, lower grade resources.

ARPA-E is seeking information from universities, non-governmental organizations, small businesses, large businesses, federally funded research and development centers (FFRDCs), and government-owned/government-operated (GOGO) organizations regarding such transformative and implementable technologies not currently deployed for mineral extraction to facilitate the future mining of critical minerals.

Areas Not of Interest for Responses to this RFI:

Any potential program would be focused on future resource discovery, appraisal, mining, and processing of critical minerals. Approaches not of interest include:

- New metal, alloy, or other materials discovery, manufacturing, and applications;
- Incremental improvements to existing technology;
- Electrification of existing mineral handling and beneficiation systems/circuits;
- Recycling of critical metals from waste sources that are not related to mining processes; and
- Topics directly related to the extraction of hydrocarbons (e.g., coal, oil, and gas).

RFI Guidelines:

PLEASE CAREFULLY REVIEW ALL RFI GUIDELINES BELOW.

Please note that the information you provide will be used by ARPA-E solely for program planning, without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME.**

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future research programs. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI without any attribution to the source. This RFI provides the broad research community with an opportunity to contribute views and opinions.

No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E may contact respondents to request clarification or seek additional information relevant to this RFI. All responses provided will be considered, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses. **Respondents shall not include any information in the response to this RFI that could be considered proprietary or confidential**.

Responses to this RFI should be submitted in PDF format to the email address **ARPA-E-RFI@hq.doe.gov** by **5:00 PM Eastern Time on May 14, 2024.** Emails should conform to the following guidelines:

- Please insert "Future Innovation needs for Responsible Mining of Critical Minerals RFI - <your organization name>" in email subject line.
- In the body of your email, include your name, title, organization, type of organization (e.g., university, non-governmental organization, small business, large business, federally funded research and development center [FFRDC], government-owned/government-operated [GOGO]), email address, telephone number, and area of expertise.
- Responses to this RFI are limited to no more than 10 pages in length (12-point font size).
- Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential materials, designs, or processes.

Background:

The domestic supply of critical minerals in the United States (U.S.) has been a national security and economic concern since the U.S. Critical Minerals Stockpiling Act was enacted in 1939. However, the capacity for U.S. mineral resource exploration and mining has been significantly reduced over the last several decades and the U.S. has become increasingly dependent on the international supply of critical minerals.[1] Critical minerals such as nickel, copper, cobalt, lithium, rare earth elements, and platinum-group elements are key ingredients in many advanced technologies. Uses for these critical metals include computers and information services, defense industry applications, batteries for electric vehicles, and other clean energy industry technologies.[2] The transition from fossil fuels to clean energy will depend on the extensive supplies of critical minerals for the products related to energy production,

---

[1] U.S. Geological Survey, *Mineral Commodity Summaries* 2023. Reston, Virginia: U.S. Geological Survey.
[2] International Energy Agency. 2022. *The Role of Critical Minerals in Clean Energy Transitions*. Typeset, France: IEA Publications.

storage, and use.[3] As a result, the annual demand for critical minerals is increasing rapidly. For example, nickel demand from the electric vehicle sector is expected to grow globally from 92 kilotons in 2020 to 2.6 megatons in 2040.[4] With the combination of high demand due to rapid technological advancements[5] and uncertain supply due to geopolitical risks,[6] the U.S. domestic mineral supply is increasingly insufficient to support the transition from fossil fuels to renewable, clean energy sources. Further exacerbating the issue is that the current global mineral supply cannot support the U.S. transition to 100% electrification.[3] Consequently, to meet the supply and demand, the U.S. could look towards the extraction of critical minerals from both conventional and unconventional resources.

The mining industry continues to face several vital challenges, such as resource depletion, energy-intensive processes and high carbon emissions, production of solid/liquid waste, site contamination, high production costs, risks to the environment and human health, worker safety concerns and social license to build mines. The quality of extracted ores from the subsurface has decreased due to lack of new deposit development. As subsurface minable resources are rapidly depleting, it has become necessary to explore, discover, and mine critical mineral ores from the deep ground or low-grade sources. In both cases, mineral exploration and mining render additional challenges that currently deployed mining technologies may not be able to solve. For example, the mining industry's mineral beneficiation process of extracting and processing ore is one of the most energy-intensive industrial sectors. The primary energy-intensive portion of mineral beneficiation is comminution (i.e., mineral processing). Total comminution energy is inversely proportional to the quality of the ore grade. For example, copper ore grades have decreased by 25% in the past decade and the energy required to process this ore has increased by 46%.[7] Currently the mining industry is responsible for 4-7% of global carbon emissions, which will further increase with the current mining technologies for low-grade ore. Concomitant with this decrease in ore grade is also increased waste rock (i.e., gangue minerals and overburden) in the future to achieve the same unit of produced metal.[8]

Existing mining practices remove approximately 165 billion tons of rock each year when digging for ore and produce about 94 billion tons of waste rock and tailings.[9] Storage of these waste materials leads to potential liabilities for the mining companies, risk of environmental damage, and risk to nearby communities. In addition, exploration requires decades to discover and develop new reserves especially from the deep underground. Mining decreased grade ores requires excessive energy consumption, results in increased carbon emission and solid/liquid waste, and increases production cost over time.

---

[3] The White House. 2021. *Executive Order on America's Supply Chains*. Washington DC: WH.gov.

[4] Fraser, Jake, Jack Anderson, Jose Lazuen, Ying Lu, Oliver Heathman, Neal Brewster, Jack Bedder, and Oliver Masson. 2021. *Study on Future Demand and Supply Security of Nickel for Electric Vehicle Batteries*. Luxembourg: Publications Office of the European Union.

[5] Fortier, Steven M., Nedal T. Nassar, Graham W. Lederer, Jamie Brainard, Joseph Gambogi, and Erin A. McCullough. 2018. *US Geological Survey technical input document in response to Secretarial Order No. 3359, Open-File Report 2018-1021.* Reston, Virginia: U.S. Geological Survey.

[6] Ting, Ming Hwa, and John Seaman. 2013. "Rare Earths: Future Elements of Conflict in Asia?" *Asian Studies Review*, 37 (2), 234-252.

[7] Calvo, Guiomar, Gavin Mudd, Alicia Valero, and Antonio Valero. 2016. "Decreasing Ore Grades in Global Metallic Mining: A Theoretical Issue or a Global Reality?" *Resources* 5 (4), 36.

[8] Northey, S., Mohr, S., Mudd, G.M., Weng, Z., and Giurco, D. 2014. "Modelling future copper ore grade decline based on a detailed assessment of copper resources and mining". Resources, Conservation and Recycling 83, 190-201.

[9] UN Environmental Program. 2022. *Mineral Resource Governance and the Global Goals: An agenda for International Collaboration, Summary of the UNEA 4/19 Consultation*, Nairobi, Kenya: www.unep.org.

Thus, mining companies have also turned to remining existing tailings and mineral sludge for critical minerals to secure their sustainable supply and circular economy while reducing their maintenance and remediation cost.

Lastly, environmental regulations, while important for protecting human health and the environment, increase the cost of operations for the US mining industry, making the U.S. less cost competitive as compared with foreign suppliers.[10]

With an increasingly high demand for critical minerals in the U.S., the purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future research programs. It is our hope that a potential program can facilitate the transformation of the future of the mining industry to achieve the goals of the high recovery rates of critical minerals and lower energy consumption, eliminate hazardous mine tailings, reduce or eliminate carbon emissions, eliminate aquifer and hydrological disturbance at and around the mining sites, and speed up data development for permitting and mine planning by local governments and communities.

RFI Questions:

The questions posed in this section are organized into several different groups as appropriate. Provide responses and information about any of the following. **ARPA-E does not expect any one respondent to answer all, or even many, of the prompts in this RFI.** In your response, indicate the group and question number (e.g., I.1). Appropriate citations are highly encouraged. Respondents are also welcome to address other relevant avenues or technologies in the following bulleted areas, which may not fall under "the list of questions" below, nor "Areas Not of Interest" described above.

- Sensing and characterization (e.g., logging while drilling, deep prospecting, rapid mineral characterization);
- Digital subsurface applications (e.g., autonomous systems, robotics, communications, AI);
- In-situ extraction (e.g., permeability enhancement, chemical leaching, biomining, thermal processes);
- Tailings management (e.g., waste minimization/zero waste, zero water);
- Mineral traceability (e.g., fingerprinting, chemical signatures, AI);
- Marine minerals (e.g., deep-water resource evaluation technology); and
- Environmental, social, and corporate governance (e.g., communications, engagement methods, method evaluation).

<u>I. Precision subsurface and deep ground resource operations and mapping</u>

1) What physical/geophysical (e.g., electric, magnetic, acoustic, microwave imaging) technologies can facilitate the exploration of critical mineral deposits?
2) What spatial data visualization, geographic information systems, autonomous systems (e.g., drones), or remote sensing technologies (e.g., satellites and airborne sensors) could revolutionize the exploration of critical metal ores?
3) Are advanced sensing methods or tools capable of detecting underground ore mineralization? If

[10] National Mining Association. 2016. *Federal Environmental Laws that Govern U.S. Mining.* Washington DC: www.nma.org.

yes, discuss the method(s) in detail including specific capabilities, sensitivities, and limitations.

4) What techniques could be developed to improve the subsurface characterization of ore deposits to allow for precision extraction of critical minerals, including sensing while drilling?
5) What are new drilling technologies (e.g., jet drilling systems, in-hole drilling motors, down-hole hammers, turbodrills, automated and tele-operated drilling solutions or drilling system designs) can speed up drilling and save energy for drilling?
6) How can big data, neural networks, machine learning and artificial intelligence techniques facilitate subsurface and deep ground resource mapping and mineral exploration?

II. Ore mining, mineral tailings processing including in-situ extraction

7) What new or emerging chemical/mechanical/biological/robotic/other innovations are there that could facilitate the in-situ recovery of critical minerals from subsurface ore bodies?
8) What physical and mechanical techniques that can be used to improve rock fracturing, pore connection, and permeability, improve the efficacy of the in-situ extraction of critical minerals?
9) What are the physical, chemical, and electrochemical technologies that can improve the comminution efficiency of mineral ores and reduce energy consumption for grinding?
10) What are the physical (e.g., microwave, plasma), chemical (e.g., flotation agents) and electrochemical technologies that can facilitate the separation of valuable metal minerals from gauge minerals?
11) What automation and robotics can be developed and utilized for ore digging, hauling, mineral extraction, and processing to increase productivity while lowering labor costs?
12) What methods/approaches should be explored that result in maximizing use of all the extracted ore with little to no un-valorized product going to tailings or waste piles?
13) What chemical/electrochemical/biological technologies that can separate all valuable mineral components or metal fractionation to achieve the goals of total ore valorization and waste minimization?
14) Which technologies currently in use in allied sectors (i.e., oil and gas, geothermal, carbon capture and storage) could be both leveraged and also significantly augmented to have a major impact on the minerals sector? Be specific rather than general and discuss the potential pathway for this adoption.
15) What innovative technologies can be used to track mineralogy or real-time analytical sensors to monitor ore streams on conveyor belts or process liquids in pipes, so that the operators can sort and track material streams in the mine or processing plant, allowing them to get a more holistic overview of its content?
16) What are other advanced technologies drawing on adjacent technical fields or disciplines, that are currently not deployed in mining?
17) Are there emerging technologies being imagined or developed for lunar/extraterrestrial mineral recovery that may be applicable for terrestrial use? Similarly, are there terrestrial applications which could be best leveraged for lunar in-situ resource utilization or non-earth mineral recovery?

III. Social, workforce, and environmental impacts of future mining

18) What technological, methodological, and communication advances can be incorporated into outreach and engagement activities to create real benefits/values to communities (e.g., Tribes, local groups) at and near mines?
19) Are there technical approaches that if developed could reduce the time and effort needed for

environmental reviews and outreach activities for any mine permitting and planning processes by government agencies and local community?

20) What programs may be developed to meet workforce needs (e.g., skilled workers for automation systems, engineers, managers, and entrepreneurs) for the future mining industry of critical minerals?
21) What approaches for combining reviews of mineralogy/hydrology with environmental/historical/cultural sensitivity could be deployed to speed up the mining permit approval process and operational implementation?

IV. Programmatic and Policy Tools

22) What programs, policy tools, or investment approaches not currently in existence could be considered or contemplated to facilitate the previously outlined objectives?