**U.S. Department of Energy Advanced Research Projects Agency-Energy**
**United States Geological Survey**
**Defense Advanced Research Projects Agency**

# Request for Information (RFI) DE-FOA-0003480 on Three-Dimensional Characterization of the Subsurface by Advanced Modeling and Sensing Techniques

**Introduction:**

The purpose of this RFI is to solicit input for a potential Advanced Research Project Agency-Energy (ARPA-E), United States Geological Survey (USGS), and Defense Advanced Research Projects Agency (DARPA) program focused on novel approaches and innovative methods that can accelerate the exploration and characterization of critical mineral deposits in the subsurface. More specifically, a potential program would focus on advanced modeling and sensing techniques for the exploration and 3-D characterization of critical mineral deposits in the subsurface.

The U.S. is seeking to reduce its dependence on imported critical minerals due to strategic and economic security concerns, and revolutionary improvements in mineral deposit exploration and characterization will be essential to securing supplies of domestic critical mineral resources. Current state-of-the-art methods to fully characterize the extent of prospective critical mineral deposits in the subsurface require significant effort, investment, and time, and may include considerable uncertainty. Improvements in the efficiency and accuracy of methods for subsurface characterization are crucial.

Two proposed focus areas for the potential program are:

1. Enhanced data acquisition using new sensors and techniques; and
2. Three-dimensional (3-D) analysis based on advanced analytical tools such as artificial intelligence (AI) and machine learning (ML) algorithms.

It is expected that the synergistic combination of new sensors, techniques, and advanced analysis will enable the characterization of subsurface deposits faster and with higher accuracy than is currently possible. ARPA-E anticipates that these sensors, techniques, and algorithms will also be applicable to other problems in subsurface imaging. ARPA-E, USGS, and DARPA are working together to leverage capabilities on this important topic. ARPA-E is focused on critical minerals that are key to multiple energy technologies; USGS is the primary source of information on geologic energy and mineral resources (including critical minerals) and their supply chains; and DARPA is focused on breakthrough technologies which may rely on critical minerals for national security.

ARPA-E seeks 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 transformative and implementable technologies not currently deployed for accelerating the exploration and characterization of critical mineral deposits in the subsurface.

**Areas Not of Interest for Responses to this RFI:**

- Efforts that focus solely on the surface expression of critical mineral deposits without considering subsurface extent; and
- Approaches with primary applicability to non-critical mineral deposits or resources.

**RFI Guidelines:**

**CAREFULLY REVIEW ALL RFI GUIDELINES BELOW.**

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

The purpose of this RFI is solely to solicit input for ARPA-E, USGS, and DARPA consideration to inform the possible formulation of future research programs. ARPA-E, USGS, and DARPA 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, USGS, and DARPA may contact respondents to request clarification or seek additional information relevant to this RFI. All responses provided will be considered, but ARPA-E, USGS, and DARPA will not respond to individual submissions or publish 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 November 4, 2024.** Emails should conform to the following guidelines:

- Insert “<your organization name> - Response to 3-D Characterization of the Subsurface by Advanced Modeling and Sensing Techniques” in the 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, FFRDC, GOGO), email address, telephone number, and area(s) of expertise.
- In the body of your email, note which question(s) you are answering using the provided format (e.g., “Section 1a”, “Section 2b”).
- 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.

**Technical Background**:

Critical minerals are non-fuel minerals that serve an essential function in energy technology and have an elevated supply chain disruption risk.[1] Supply chain risk is based on either a primarily foreign supply or a single point of failure for domestic production. Critical minerals do not include fuel minerals (e.g., uranium) or common varieties of sand or gravel and similar materials (see a complete list in the U.S. Critical Minerals List in footnote 1). Shortages in critical minerals will have a profound impact in multiple areas, such as manufacturing, national defense, and renewable energy technologies including electronics, batteries, and solar panels.[2] Disruptions in critical mineral availability will lead to delays, shortages, and increased costs, with associated economic impacts. Therefore, reliable domestic sources of raw materials are essential.[3] The development and enhancement of a domestic supply chain for critical minerals will decrease overall risk for the U.S.[4]

Transformative changes in energy storage and generation are anticipated to require substantial increases in critical mineral production.[5] Recycling can be an approach for extracting critical minerals from waste sources, but it is typically challenging and expensive and cannot meet the increasing demand.[6,7] The U.S. needs innovations that promote efficiency and improve the success rate of mineral exploration to keep pace with the increasing demand of critical minerals.[8,9] Mineral exploration includes initial identification of a potential resource and subsequential assessment of the geological resources to determine reserves and economic feasibility of mining.[10] The multiple stages of mineral exploration include the following: locating potential deposits, staking and permitting, initial surface exploration mapping, early-stage exploration studies, core drilling, 3-D resource modeling, risk assessment, de-risking analysis, and production decision.[11] These steps are usually accompanied by geochemical and geophysical studies.

The combined exploration processes often require several years and proceed with substantial risks, as many prospects may prove to be uneconomical. In addition, mineral exploration in the U.S. has been

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[1] Nassar, N.T., and S.M. Fortier. 2021. *Methodology and technical input for the 2021 review and revision of the U.S. Critical Minerals List*: U.S. Geological Survey Open-File Report 2021–1045, 31 p. https://doi.org/10.3133/ofr20211045.

[2] International Energy Agency. 2022. *The Role of Critical Minerals in Clean Energy Transitions*. Typeset, France: IEA Publications.

[3] U.S. Geological Survey. 2024. *Mineral Commodity Summaries 2024*. Reston, Virginia: U.S. Geological Survey.

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

[5] International Energy Agency. 2024. *Global Critical Minerals Outlook 2024*. International Energy Agency Website: www.iea.org.

[6] United States Government Accountability Office. 2022. *Critical Minerals: Building on Federal Efforts to Advance Recovery and Substitution Could Help Address Supply Risks, GAO-22-104824.* Washington DC: United States Government Accountability Office.

[7] Battelle. 2023. *United States Energy Association: Critical Material Recovery from E-waste: Final Report, Sub-agreement No. 633-2023-004-01*. Columbus, Ohio: Submitted to United States Energy Association.

[8] Okada, Kazuya. 2022. "Breakthrough technologies for mineral exploration," *Mineral Economics,* 35, 429–454.

[9] Juan Alcalde et al. 2022. "Preface: State of the art in mineral exploration," *Solid Earth*, 13, 1161–1168.

[10] Rhys Samuel Davies et al. 2021. "Learning and expertise in mineral exploration decision-making: An ecological dynamics perspective," *International Journal of Environmental Research and Public Health*, 18, 9752. https://doi.org/10.3390/ijerph18189752.

[11] Robert Stevens. 2010. *Mineral Exploration and Mining Essentials*. Pakawau GeoManagement, Incorporated.

greatly hampered due to dependence on the foreign supply of critical minerals over the last three decades. Thus, the U.S. has less comprehensive 3-D geological data, limited access to subsurface geological information, and large uncertainties in chemical and physical properties of the uppermost one to two kilometers of Earth's crust.

This RFI is focused on advanced modeling and sensing technologies for accelerating exploration and characterization of critical mineral deposits in the subsurface. It is expected that development of these technologies will reduce the time, expense, and effort needed to identify local-scale targets and delineate mineral resources. More specifically, the developed technologies can be used to identify possible prospects of deposits, accelerate and improve the process of delineating mineral resources, and provide a sensible basis for making economic decisions. The key factors include expected geometry, grade, and tonnage of the ore, and the expected extraction and production system of critical minerals. ARPA-E, USGS, and DARPA are also interested in improved geologic and geophysical sensing techniques that can be combined with geochemical and legacy data. Methods for incorporating these datasets into a consistent 3-D model(s) with associated error estimates are desired.

**RFI Questions:**

The questions posed in this section are classified into several different groups, as appropriate. ARPA-E, USGS, and DARPA encourage responses that address any subset of the following topics. The variety of topics below are examples, but respondents are not restricted to responses to these topics, and innovative ideas are encouraged. ARPA-E, USGS, and DARPA do not expect any one respondent to answer all, or even many, of the prompts in this RFI.

In your response, indicate the section and question number(s) you are responding to. Appropriate citations are highly encouraged. Respondents are also welcome to address other relevant avenues or technologies that are not outlined below, except for those that fall under the "Areas Not of Interest" described above.

**Section 1: What sensing techniques (appropriate for mapping deposits of critical minerals) based on recent technological advances provide improvements over current state-of-the-art? While information on all relevant techniques would be helpful, information is particularly sought regarding:**

a. Limits, in terms of both accuracy, resolution, and ease of deployment, of current techniques;
b. Airborne (aircraft and uncrewed aerial vehicle) magnetic, radiometric, and electromagnetic measurement technologies;
c. Ground-based seismic, magneto-telluric, and gravity-sensing technologies; and
d. Novel sensors, or combinations of sensors, such as muon or quantum sensing applications for mineral exploration, either aerial, surface, or borehole.

**Section 2: How can chemical characterization of physical rocks, either as samples or in situ, be improved? Information on all relevant techniques is encouraged, but information is particularly sought regarding:**

a. Rapid characterization of drill core by chemical and/or spectral analysis;
b. Automated mineralogical characterization of physical samples, especially of drill core;
c. Down-hole measurements of physical rock properties and chemical composition;
d. Use of indirect measurements, such as water trace element composition;
e. Cross-borehole techniques;
f. Determination of physical properties such as density, magnetic susceptibility, and conductivity; and
g. Seismic anisotropy of physical samples to improve 3-D modeling.

**Section 3: How can accuracy and efficiency of 3-D subsurface modeling and simulation be improved to provide rapid estimates of orebody size, grade, and geometry? Information on all relevant technologies is encouraged, and examples include:**

a. Use of AI and ML to improve current methods in an automated fashion;
b. Digitizing geologic maps and cross-sections to construct 3-D models;
c. Digitizing borehole records and well logs;
d. Extracting analysis-ready data from legacy sources (e.g., paper and scanned documents, maps, and records);
e. Incorporating rapid data flow from sensors and techniques such as the ones proposed in Sections 1 and 2 of these RFI questions;
f. Data fusion between aerial, surface, and subsurface measurements; and
g. Reliable error estimates.