Hearing to Examine the Department of the Interior's Final List of Critical Minerals and Opportunities to Strengthen the United States' Mineral Security

Statement of

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Introduction

Chairman Murkowski, Ranking Member Cantwell, and Members of the Committee, thank you for the opportunity to speak today. I am Rod Eggert, Viola Vestal Coulter Foundation Chair in Mineral Economics at Colorado School of Mines.

As part of my university responsibilities, I am deputy director of the Critical Materials Institute (CMI), an energy innovation hub (multi-institutional, multi-disciplinary research consortium) funded by the U.S. Department of Energy and led by the Ames Laboratory. CMI is developing technological solutions to critical-materials problems as they affect emerging energy technologies.

Regarding the themes of today's hearing, I do not have specific comments on the first theme, the list of critical minerals, but am happy to answer questions.

My testimony focuses on the second theme, opportunities for enhancing U.S. mineral security. Specifically, I offer personal views on the relevance of import dependence for critical minerals, as well as on appropriate federal roles in responding to concerns about mineral security. I also describe the activities, accomplishments and plans of the Critical Materials Institute.

Critical Minerals, Import Dependence and the Role of Government[1]

A critical mineral or material provides essential functionality to a modern engineered material, component or system; has few if any easy substitutes; and is subject to supply-chain risks or longer-term concerns about availability.

As I testified previously, import dependence by itself is an incomplete and often misleading indicator of supply insecurity. Rather it is *risky* import sources that are threats to U.S. users of mineral resources and the technologies that are dependent on these resources. In fact, import reliance is good if foreign sources are available at lower costs or are of higher quality than alternative domestic sources. In many cases, imports are simply intra-company transfers within a vertically integrated company; import reliance reflects an efficiently organized supply chain in which each material handling step takes place in the location best suited to undertake this step. Approximately 62% of all U.S. imports, not just mineral resources, are intermediate products that U.S. entities use as inputs into the production of goods produced within the United States.[2]

Import dependence is a problem, however, when it puts supply chains and U.S. companies and material users at risk. Such is the case when imports come from one or a small number of production facilities, companies or countries – especially countries in which political decisions, restrictions on international trade, civil disruptions, or other developments present risks that may restrict access to materials for U.S. users.

Import dependence is one aspect of the broader and more-fundamental issue of supply-chain risk and raw-material availability. Short-term supply-chain risks may be due to: a limited number of mines, production facilities or companies (whether domestic or foreign); rapid, unanticipated demand growth for a material with small, existing markets; or reliance on by-product production of a material. Over the longer term, raw-material availability reflects: fundamental geochemical abundance of specific chemical elements; investments in basic science, mineral exploration, mine development, process engineering, and project demonstration and piloting to enable extraction and recovery of elements from rocks and minerals, manufacturing wastes and end-of-life products; environmental and social issues associated with mining lower-grade raw materials in more-remote locations; participation of industry and financial partners in syndicating deployment risk; and, finally, availability of scientists, engineers and other professionals in the disciplines necessary for assuring material supply chains.

Regarding the role of government, we appropriately rely primarily on private initiative to develop the mineral resources, materials and technologies that underpin today's society – technologies that encompass energy, health care, electronics and communications, transportation, environmental protection and national defense, among others.

But government plays essential roles in both establishing the institutional framework in which private activities occur and acting when markets do not work well. With respect to mineral resources and raw-material supply chains, government plays essential roles in:

- Ensuring the availability of raw materials necessary for national defense,
- Facilitating undistorted international trade,
- Establishing a framework for efficient development of domestic natural resources that appropriately protects the natural environment and considers not only national needs but also the interests of the communities in which resource development occurs,
- Collecting and disseminating information, as well as carrying out strategic analysis, on which both private and public decisions can be made, and
- Fostering innovation through education and research throughout the materials supply chain.

There are special roles for government to play in two specific aspects of research:

- Facilitating early-stage research and development (R&D) that is especially prone to underinvestment from society's perspective by the private sector acting alone, and
- Facilitating the commercialization of promising ideas and new knowledge created in early-stage R&D through mechanisms such as public-private partnerships. In a perfect world, any promising new idea developed at a national laboratory or university would be picked up by the private sector. In practice, however, promising ideas often languish because of insufficient communication between basic researchers and commercial developers of new technologies.

I focus the remainder of my testimony on one example of a federal investment in early-stage R&D, linking basic research with industrial and societal applications.

Critical Materials Institute: The First Five Years

As I noted earlier, the Critical Materials Institute (CMI) is a multi-institutional, multi-disciplinary consortium of national labs, universities and companies – led by the U.S. Department of Energy's (DOE's) Ames Laboratory and managed by DOE's Advanced Manufacturing Office (http://cmi.ameslab.gov).

CMI's mission is to create technological options for assuring supply chains of materials critical to clean energy technologies. Fundamentally there are three options for assuring supply chains: (a) diversify and expand the availability of critical materials throughout their supply chains, (b) reduce wastes by increasing manufacturing efficiency and recycling and (c) reduce demand by developing substitutes for critical materials. CMI carries out research in all three areas, linking basic and early-stage research with industrial needs. CMI's activities encompass process and materials engineering, as well as underlying science, for the entire materials supply chain except geoscience and mining.

CMI emerged out of the DOE's *Critical Materials Strategy* (2010, 2011), which in turn reflected a decade or so of growing concern about the availability and supply-chain security of certain minor metals that provide essential properties to modern engineered materials (see U.S. National Research Council 2008). Rare earths – an important family of minor metals with essential uses in a wide range of technologies – became the poster child of critical materials when their prices surged in 2010 and 2011, following several years in which China restricted rare-earth exports and after an ultimately temporary Chinese cut-off of supplies to Japan led to panic buying by rare-earth users. China accounts for more than three-quarters of world rare-earth production and processing, as well as some two-thirds of world use of rare earths in manufacturing.

CMI began operations in 2013. In the five years since then, it has focused principally on technology development to alleviate actual or potential supply-chain risks for rare earths, which provide essential properties for magnets in high-efficiency motors in vehicles, wind turbines, industrial motors and air conditioners; phosphor materials in fluorescent and LED lighting; and other applications. In addition, CMI carried out research aimed at recovering lithium, an essential battery material, from geothermal brines.

In its first five years, CMI issued 78 invention disclosures, filed 50 patent applications, received six patents, created two open-source software packages and won two R&D 100 awards. It licensed seven technologies to U.S. companies; see the appendix to this testimony listing these licenses and other technologies adopted by industry. Examples of these technologies include:

- Membrane solvent extraction for rare-earth separations, relevant for both primary production and recycling,
- 3D printing of rare-earth magnets to reduce manufacturing wastes,

- A cost-effective, high-throughput system for recycling rare-earth magnets from computer hard drives, and
- Replacements for the rare earths europium and terbium in fluorescent lighting.

CMI demonstrated the production of neodymium-iron-boron (rare-earth) magnets, essential in high-efficiency motors and now produced almost entirely in China, using raw materials and technologies located entirely in the United States.

CMI facilitates the commercialization of the new knowledge it creates through the active participation of its industry members.

CMI Going Forward

This month CMI began its sixth year of operation. We at CMI are continuing to work with industry to accelerate innovation and develop solutions to critical-materials problems. Building on our experiences over the first five years, we are:

- Continuing to address critical-materials problems through world-leading early-stage, applied research, incorporating machine learning and artificial intelligence where promising;
- Expanding the range of materials and technologies on which we conduct research, going beyond rare earths to expand research on lithium and initiate efforts on cobalt, gallium, indium, manganese, platinum-group elements, tellurium, vanadium and battery-quality graphite;
- Engaging with a wider range of industrial partners;
- Educating and training the leaders, technical experts and skilled professionals needed by U.S. industry to assure its supply chains; and
- Working to become a self-sustaining entity by the end of our tenth year of operation.

Among the grand research challenges CMI is focusing on are:

- Chemical separations, as highlighted by a 2016 paper in *Nature*, which identifies improving the separation of rare-earth elements as potentially revolutionary in terms of unlocking new and greater quantities of resources using less energy and with less environmental damage (Sholl and Lively, 2016), and
- Resource efficiency, enhancing the degree to which we recover multiple elements and materials that exist in a mineral deposit, manufacturing waste or end-of-life product (Söderholm and Tilton, 2012; Eggert, 2016). Innovation has the potential to improve the technical efficiency of recovery, lower processing costs and reduce environmental damage.

Closing

Technology development and commercialization are keys to assuring raw-material supply chains and mitigating risks to U.S. manufacturing, defense needs and energy security. The private sector, appropriately, has primary responsibility for managing these risks and developing the mineral resources, materials and technologies that underpin manufacturing, defense and energy.

But government plays an essential role in facilitating market activities and intervening when markets do not work well. One of these essential roles is fostering technology development, especially in linking basic early-stage science with industrial and societal needs. The Critical Materials Institute is an example of a federal investment that has accelerated delivery of technological solutions to the market place.

Thank you for the opportunity to testify today. I am happy to address any questions the Committee Members have.

References

American Physical Society and Materials Research Society. *Energy Critical Elements: Securing Materials for Emerging Technologies* (Washington, D.C., American Physical Society, 2011). Available at www.aps.org.

Eggert, Roderick G. "Critical Minerals and Emerging Technologies," *Issues in Science and Technology*, volume XXVI, number 4, 2010, pp. 49-58. Available at www.issues.org.

Eggert, Roderick G. "Minerals Go Critical," *Nature Chemistry*, volume 3, September 2011, pp. 688-691. Available at www.nature.com/nchem/journal/v3/n9/index.html.

Eggert, Roderick G. "Economic perspectives on sustainability, mineral development, and metal life cycles," pp. 467-484 in Reed M. Izatt, editor *Metal Sustainability: Global Challenges, Consequences, and Prospects* (Hoboken, New Jersey, Wiley, 2016).

Sholl, David S. and Ryan P. Lively. "Seven chemical separations to change the world," *Nature*, volume 532, Issue 7600, 28 April 2016, pp. 435-437. Available at www.nature.com.

Söderholm, P. and J.E. Tilton. "Material efficiency: an economic perspective," *Resources, Conservation and Recycling*, volume 61, April 2012, pp. 75-82. Available at http://www.sciencedirect.com/science?_ob=ArticleListURL&_method=list&_ArticleListID=1170016130&_sort=r&_st=13&view=c&md5=649aaf21c8a33c30dadf7241db3e21a0&searchtype=a.

U.S. Department of Energy. *Critical Materials Strategy*, 2010 and 2011 editions (Washington, D.C., Department of Energy, 2010, 2011). Available at: https://www.energy.gov/policy/downloads/2010-critical-materials-strategy and https://www.energy.gov/policy/downloads/2011-critical-materials-strategy.

U.S. National Research Council. *Minerals, Critical Minerals, and the U.S. Economy* (Washington, D.C., National Academies Press, 2008). Available at www.nap.edu.

APPENDIX: CMI Technologies Adopted by Industry (July 2018)

Source Diversification

- *Castable High-Temperature Ce-Modified Al Alloys*.
  Licensed to Eck Industries. First commercial sales in August 2017.
  R&D 100 Award, 2017. FLC Tech Transfer Award, 2018.

Materials Substitution

- *Aluminum nitride phosphors for fluorescent lighting* – replacing europium.
  In production testing at GE
- *Green phosphor for fluorescent lamps* – replacing terbium.
  In production testing at GE
- *Additive Manufacturing of Bonded Permanent Magnets using a Novel Polymer Matrix*.
  Licensed to Momentum Technologies, Inc.
  R&D 100 Award, 2017
- *3D Printable Liquid Crystalline Elastomers with Tunable Shape Memory Behaviors and Bio-derived Renditions*
  Patent application filed by third party.

Improved Manufacturing Efficiency, Recycling and Re-use

- *Membrane Solvent Extraction for Rare Earth Separations*
  Licensed to Momentum Technologies, Inc.
  Featured in GAO report 16-699 on Advanced Technologies
- *High Throughput Cost Effective Rare Earth Magnets Recycling System*
  Licensed to Momentum Technologies, Inc.; CRADA with Oddello Industries
- *Selective Surface Modification of $Nd_2Fe_{14}B$ Magnets to Achieve High Performance*
  Licensed to Momentum Technologies, Inc.
- *Novel 3D Printing Method to Fabricate Bonded Magnets of Complex Shape*
  Licensed to Momentum Technologies, Inc.
- *Additive Printing of Bonded Magnets Using Magnet Powders and a Polymer Composit*ion
  Licensed to Momentum Technologies, Inc.
- *A Process for the Recovery of Mercury and Rare Earth Elements from Used Fluorescent Lamps*
  Licensed to and CRADA with LCW Supercritical Technologies Corp.
- *Yttria-Stabilized Zirconia Thermal Barrier Coating Reversion Process*
  In use by GE Aerospace

[1] See Eggert (2010) and Eggert (2011), as well as two expert-panel reports in which I participated (American Physical Society and Materials Research Society, 2011; U.S. National Research Council, 2008). My testimony today on critical minerals, import dependence and government roles represents views I expressed in previous testimony before the Senate Committee on Energy and Natural Resources or its subcommittees, September 30, 2010, January 28, 2014, and March 28, 2017; the Committee on Industry, Research, and Energy of the European Parliament, January 26, 2011; and the Subcommittee on Energy and Mineral Resources, House Committee on Natural Resources, May 24, 2011.

[2] Calculated with data from https://jgea.org/resources/jgea/ojs/index.php/jgea/article/view/23