CRITICAL MATERIALS FOR U.S. NATIONAL SECURITY AND PROSPERITY

Materials such as lithium, nickel, cobalt, and rare earth elements (*e.g.*, yttrium, neodymium, and cerium) are vital to U.S. security and economic prosperity, but most of these materials are imported currently. Critical materials are defined in Executive Order 14017 as materials vital to the economic or national security of the U.S., vulnerable to supply chain disruption, and serving an essential function in the manufacture of a product, whose absence would have significant consequences.[1] The list produced by the U.S. Geological Survey in 2022 has grown to include 50 different commodities[2]. Demand for many materials will increase dramatically in the next few decades in order to meet growing global energy (see ACS statement on Energy Policy) needs while creating a non-CO_2 emitting energy infrastructure (see ACS statement on Climate Change). Dependency on foreign sources creates a strategic vulnerability to foreign government actions, natural disasters, and other events that can disrupt key materials supplies.

A comprehensive policy to address critical materials is necessary as the global economy continues to grow and the U.S. grapples with unequal global availability of certain critical materials, as well as the safety and environmental hazards associated with their extraction and processing. Critical materials available at a reasonable cost are essential for national security, renewable energy, electrification of transportation, and the U.S. economy. Developing and maintaining a sustainable critical materials industry requires a robust supply and systematic analyses of life cycle costs and benefits, including the financial and environmental impacts of exploration, discovery, extraction, and processing.

Each critical material presents different economic, environmental, or national security challenges. One-size-fits-all solutions are not applicable. The chemical properties of the critical materials are widely divergent, and policies to address shortages in rare earth elements will be different from policies for lithium. Policymakers should prioritize long-term, multidisciplinary research, development, and deployment via interagency cooperation to address these challenges.

ACS Recommendations

- Develop primary sources, processing capability, recycling, and conservation practices for critical materials.
- Provide a resilient and sustainable supply of critical materials from multiple conventional and non-conventional sources.
- Support research utilizing earth-abundant materials.
- Balance economic needs with human health and environmental sensitivities of extraction, processing and use of critical materials including those from non-domestic sources.
- Invest in research and workforce development in the entire life cycle of critical materials and alternative technologies via coordinated interagency programs.
- Enhance interagency coordination and outreach to industry, academia and the public.
- Inform the public and stakeholders on the economic, political, social and scientific issues associated with critical materials supplies especially with regard to national defense and sustainable energy.

Guidance on achieving these objectives are discussed below.

Sustainable Resource Recovery, Recycling, Conservation, and Alternatives

The ACS recommends the U.S. to increase research and development funding for the recovery and recycling of critical materials from scrap and end-of-life products, mitigating reliance on depleting, inconsistent, and non-domestic sources of critical materials. Recovery and recycling of critical materials also lessens the social and environmental impacts from the extraction of primary resources. Advanced manufacturing will be a key to increasing the recyclability of critical materials in products. Federal departments, such as Defense and Energy, should seek to optimize use, conservation, and recovery to maximize sustainability.

A key task is to study the collection of spent materials, which is the first and perhaps the most challenging aspect of recycling. Research on recycling is informed by the methods of collection, which in turn are informed (or influenced or affected) by recycling technology. In many countries, infrastructure and financial incentives for industries and consumers have increased the recycling of plastics. However, recycling batteries and their materials remains challenging. For example, waste electrical and electronic equipment is a recycling challenge but a potential source of critical materials. Policies should be enacted that ensure the U.S. retains, recovers, and capitalizes on waste that contains critical materials. This opportunity will become greater as more critical materials are required for electric vehicles.

Carbon neutral and negative technologies play a key role in addressing climate change. Currently critical materials play a key role in these technologies, which are used in alternative energy production including renewable and nuclear energy, advanced distribution, and large-scale storage technologies[3]. To meet current and increasing needs for these technologies, innovations in the production and recycling of critical materials as well as developing alternatives will be required. Environmentally benign and sustainable techniques for critical materials recovery and recycling processes should be explored. Critical materials recovery from unconventional resources and products made from more earth-abundant materials should be researched to support a circular economy, price stability, and a reliable domestic supply.

Research and Workforce Development

Addressing our critical materials challenges will require long-term, coordinated support for industry, government, and university research and development of cost-effective technologies for environmentally sensitive extraction and processing. The ACS recommends prioritizing research into new and existing geological sources, recycling, conservation, and alternatives based on Earth-abundant materials. Critical materials challenges should be viewed as research opportunities in chemical science and engineering; expanding our capabilities in their recovery, efficacy, and alternatives is the best policy for ensuring cost-effective access.

Scientific and engineering knowledge is of limited effectiveness without considering and implementing economic, environmental, and social factors inherent to the development of mineral resources. Integrating economic and social research with the physical sciences is necessary to ensure a successful critical materials policy. Therefore, a sustainable strategy should emphasize long-term multidisciplinary research projects, applications research, and commercialization efforts spanning the life cycle of the materials of interest. This strategic approach to projects and funding for applied research, which bridges breakthrough research with short time frame commercial development, will boost a robust critical materials policy.

Balanced investments in fundamental and applied research across all technical readiness levels are required to increase the supply of critical materials and to provide alternatives. Without a strong basic scientific research foundation, innovation cannot be implemented fully. Education should also be designed and planned considering fundamental research to full-developed technologies.

The ACS recognizes a need for comprehensive workforce development and stresses multidisciplinary research and education go hand-in-hand especially in areas such as mineral

[1] Department of the Interior. America's Supply Chains 2021. *Fed. Regist*. **2021**, *86*, 11849-11854.

[2] U.S. Geological Survey, Department of the Interior. 2022 Final List of Critical Minerals.

[3] Arrobas, D.L.P.; Hund, K.L.; McCormick, M.S.; Ningthoujam, J.; Drexhage, J.R. *The Growing Role of Minerals and Metals for a Low Carbon Future;* International Bank for Reconstruction and Development/The World Bank: Washington, D.C., 2017.

exploration, traceability, hydrometallurgy, and product development. Education of a new generation of professionals with the capacity to work in multidisciplinary teams across academic, industry and government entities will be essential to success. Training a broad array of professionals will be necessary to ensure the sustainable development of domestic supplies, including new sources, supply chain resiliency, recycling, conservation, and alternative technologies.

Public and Stakeholder Outreach

The ACS recommends increased federal efforts to create industry, government, and academic collaborations to inform the public and stakeholders of the supply and demand issues for critical materials. The public is generally unaware of the numerous critical materials we rely upon for our technology. The process of discovery, processing, and production is behind the scenes, and there is not enough awareness of potential supply chain disruptions. To increase public knowledge about the need for a national critical materials strategy, outreach efforts are necessary to inform our citizens of the benefits and risks to our economy, societal stability, and national security. Government, industry and academia each have their own avenues of outreach to the public and specific stakeholders, and a coordinated interagency collaboration with industry and academia will be most effective in disseminating this information.

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