Update on U.S. DOE's Office of Fossil Energy: Critical Minerals and Rare Earth Elements R&D Q&A

1. **Do the rare earth elements (REE) remain in the coal ash after combustion? If so, wouldn't ash storage facilities represent a more highly concentrated and more easily accessible source of REE ores than mining new coal?**

   Yes, the REE remain in the coal ash after combustion providing a more concentrated feedstock than coal. However, for differing coal types, the vitreous glass encapsulation can vary making recovery difficult. In addition, REE bound in some coal (lignite, organic-bound) are more easily extracted (lower acid usage) within the coal, rather the produced ash.

2. **Do we have an estimate of the share of critical minerals that will be needed for mobile and personal applications (vs. grid-scale energy storage)?**

   There are many studies looking at the future demand of critical minerals (CM) for future technologies such as this recently funded study by the World Bank: https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action

   However, we do not have an exact estimate of critical minerals needed for mobile and personal applications compared to grid-scale energy storage.

3. **Where are critical minerals and rare earths processed today?**

   Critical Minerals are mined and processed throughout the world. For more information on Rare Earth Elements, please see the United States Geological Survey link: https://www.usgs.gov/centers/nmic/rare-earths-statistics-and-information

4. **What makes coal the best source for critical minerals and rare earths?**

   There is a vast amount of sedimentary and coal related deposits domestically here in the U.S. The nature of these resources is such that much of the infrastructure required to support production operations is already in place. Coal basins have the required work force, supply chain, and academic resources. In some cases, CM production can be undertaken on degraded abandoned mine properties, including solid and liquid waste streams, and revenue from the production of CM can be used to cover the costs of restoring these lands. These considerations, *reduced exploration costs, and the nature of permitting requirements can shorten lead times required for new production operations, as compared with hard rock deposits.*

Some rocks and sediments associated with coal deposits have been found with concentrations of heavy rare earth elements (HREE) that exceed those of conventional deposits, and total rare earth concentrations that can lead to commercial production. Research is underway to find means to economically extract REE and other CM from these unique resources, leading to U.S. domestic production of these materials.

5. **Beyond coal, what other potential feedstock may prove to be useful candidates to extract key elements?**

   This site offers an overview of the geology of REE deposits of various conventional types. Table 2 in the link outlines those conventional REE deposit types. https://geology.com/usgs/ree-geology/

6. **The Energy Storage Grand Challenge identified cobalt, lithium, platinum-group metals, and naturally occurring graphite as the most important elements/minerals. Are you finding these in your work?**

   Research projects in DOE-NETL's Program portfolio have primarily been focused on REE recovery from coal-based resources. Understanding the importance of all CMs, projects are assessing co-production of CM. To date, CM from coal and coal by-products such as cobalt, have frequently been detected, and processing circuits are being developed for not only extraction of cobalt, but alternate CMs, as well as the production of graphitic materials (graphene) with REE.

   Co-production of REE and lithium from brines (geothermal and produced from oil & gas operations) is a current area of research interest.

7. **To what extent does recycling (during processing) play in helping to provide reuse...is it economical?**

   If a material (e.g., acid for leaching and extracting REE from feedstock resources; solvents used in solvent extraction processes; etc.), can be reused or recycled for continued use of processing additional materials as the coal-based feedstock, the overall economics of the separation process is expected to be improved. If regeneration of the material is needed to remove contaminants or if the material is depleted during processing or regeneration, then the cost of regeneration or replenishment will need to be considered and factored into the overall process techno-economic analyses. Notably, each of these aspects will be process dependent.

8. **Are there any technology developments for metallization?**

   REE metallization efforts have been undertaken in DOE-NETL's REE Program through two Office of Science SBIR Phase 1 projects. Efforts to address the entire CM value and supply chain are *essential to ensure future domestic manufacturing and on-shore supply of commodity and national defense equipment*

9. What processing is required to make the REEs in coal refuse usable?

The processing steps involve 1) the transfer of rare earth elements from solid form to a liquid form, 2) controlled precipitation steps to eliminate or minimize the content of major contaminant ions, 3) selective precipitation using oxalic acid and 4) roasting to remove the oxalate and produce a mix of rare earth oxides.

If successfully performed, a rare earth oxide mix (MREO) having a purity greater than 95% can be realized from coal refuse. Afterwards, several stages of solvent extraction can be utilized to separate the MREO into individual rare earth oxides which can further be processed into a metal form. The rare earth individual concentrates with a purity of 99.99% can be commercially utilized while converting to metals elevates the value of the final product.

10. What is the relative cost between REE supplied from China, vs our best option for extraction from coal or coal by-products (coal ash, acid mine drainage, etc.)?

The cost of extracting REEs from coal-based materials is a work in progress with efforts to reduce the operational costs to less than $100 per kg of rare earth oxide mix (MREO) produced. The lowest cost source is likely acid mine drainage although the REE quantities recovered from this source is likely relatively low. Extracting the REEs directly from the coal and coal refuse has the potential to supply enough REEs to meet the U.S. annual demand. However, cost reductions are needed to be competitive with conventional sources.

11. What do you do with the by-product? 17.5 million vs 4600 mt? What happens to all the other refuse material?

The remainder of the 17.5 million tons of coarse refuse currently placed in permitted storage areas will be returned to the same storage area after treatment. There are several scenarios for extraction of the REEs: (1) heap leaching of the coarse refuse and (2) recovery of the material containing energy value followed by use as a utility fuel in a fluidized bed combustor (FBC) under conditions that yield the combustion residue as an easily leachable material, and heap leaching of the material containing no energy value.

12. Are there any domestic buyers of the MREO material? Who are the ideal buyers for the final products?

Companies that further refine MREO into individually separated, high purity rare earth oxides would be the type of company that may be interested in purchasing mixed rare earth oxide depending on the content of the mix and the content of contaminant elements such as the radionuclides, arsenic and mercury. Another option includes the use of a toll refiner, who does not specifically purchase the material, but separates the MREO for a charge, which may be sold as separated, high-purity REOs.