Potential for Recovery of Rare Earths, Lithium, Cobalt and other Critical Minerals from Coal Wastes and Primary Ores in PA and the US

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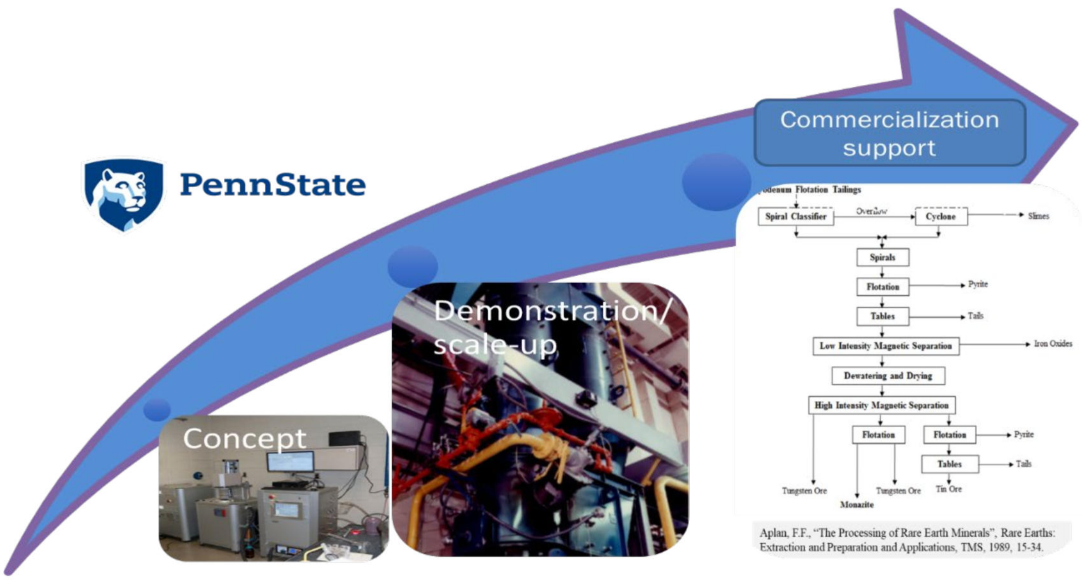


January 10, 2021

Chairman Metcalfe and Chairman Vitali, and members of the Environmental Resources and Energy Committee,

Thank you for giving me this opportunity to offer testimony and answer your questions regarding the benefits and challenges of extracting and utilizing critical minerals found within Pennsylvania and the United States and other issues related to this topic. I am a Professor of Energy and Mineral Engineering and Chemical Engineering and the Director of The Center for Critical Minerals In the College of Earth and Mineral Sciences at the Pennsylvania State University.

The goals of the Center for Critical Minerals are to:

- Develop the science and technology required to establish additional rare earth and critical minerals production capacity and reserve base in the Commonwealth of PA and the US, reducing reliance on imports from other countries.
- Provide support to industrial partners to commercialize science and technology for sources of revenue and economic development in the US.

- Mitigate environmental concerns from energy and mineral industry wastes and the production of value-added critical materials for national security.
- Create engaged scholarship opportunities for students, train a well-trained workforce and broaden employment opportunities for graduates.

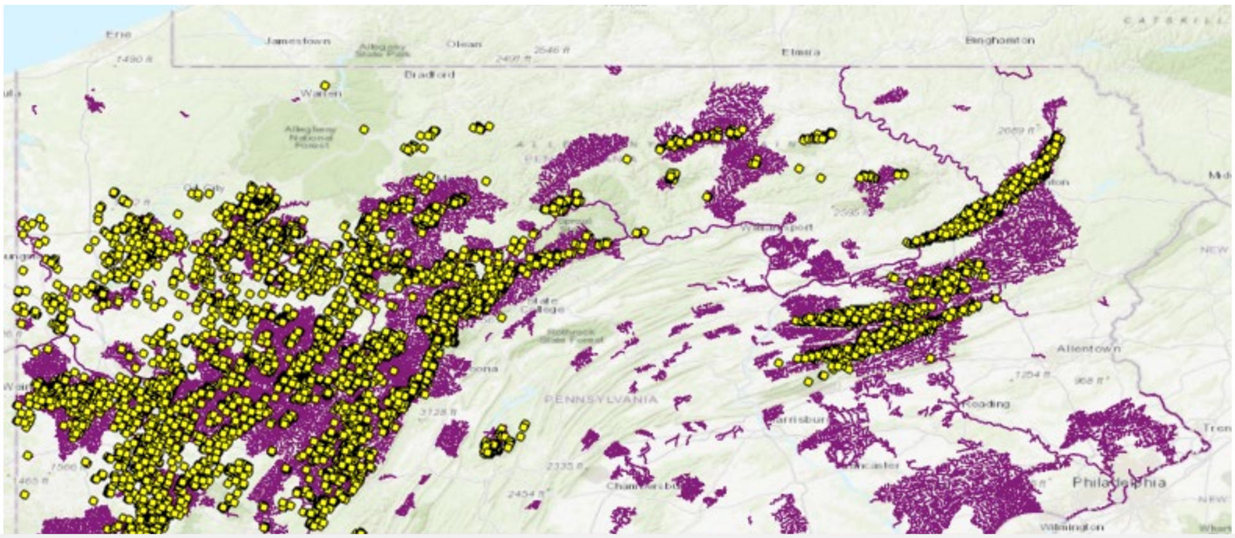
The United States and the world have seen exponential growth in the use of critical minerals for a variety of applications, ranging from sustainable energy and national defense to modern electronic and medical applications. These minerals are used for touch screens and long-lasting batteries in smartphones and computer applications. All the materials we see and use today need to be smaller, lighter, and stronger, and this requires critical minerals. Sustainable wind energy development requires stronger magnets made from neodymium, boron, iron, and other metals. Similarly, arsenic, gallium, germanium, Indium, and titanium are essential for solar energy panels. Electric vehicles are heavily dependent on battery materials such as lithium, cobalt, nickel, iron, phosphorus, and manganese. On the Defense front, each F35 fighter aircraft incorporates about half a ton of rare earth elements. The demand for these elements is expected to grow by a factor of between 3 to 14 times in the next ten years.

Unfortunately, The United States is 100% import-reliant for 17 of 35 critical elements identified by the United States Department of Interior. Another 14 have net import reliance greater than 50% of consumption. According to the International Energy Agency data, most of the world's copper, nickel, cobalt, rare earth elements, and lithium are produced abroad and mostly processed in China.

Penn State has a long history of conducting research and supporting industry for the efficient recovery of rare earths and other critical minerals. Dr. Edward Steidle, former Dean of the College of Earth and Mineral Sciences, in 1952 wrote, "By the year 2000, we will not be wasting our coal ash, in which geochemists have shown there is a notable concentration of rare elements, such as germanium and rare earths." And he also wrote, "American industry will be faced not only with a lack of raw materials at home but also with the difficulty of obtaining supplies abroad…………" Decades of collaborative work with government and industry followed. Today, for example, Penn State's Center for Critical Minerals is working with several industrial partners such as Texas Mineral Resources Corporation, Materia USA, and Energy Fuels Inc., in evaluating various feedstocks from Pennsylvania for designing a multimetal extraction plant.

There are four main challenges in developing domestic rare earth production capabilities. They are 1) finding the highest assay (rare earth contents) feedstock, 2) characterizing these materials for rare earth extraction, 3) developing processing options that are efficient and minimize environmental impact, and 4) financial modeling to ensure that the processes will be competitive in the global rare earth market. A multidisciplinary approach is needed to overcome these challenges involving Geosciences, Mining Engineering, Mineral Processing, Hydrometallurgy, Pyrometallurgy, Materials Science, Plant Design and Simulation, and Financial Modeling. Penn State is uniquely poised to address these challenges, with over 25 faculty members actively involved in research, education, and outreach across these disciplines.

Historically, as a coal mining state, Pennsylvania has abandoned mine lands, coal refuse piles, metallurgical waste dumps, and acidic drainage from abandoned coal mines. Billions of gallons of AMD impair over 5,500 miles of streams within the Commonwealth (Fig. 1).



Purple poly-lines - rivers that have pollution levels higher than state-acceptable levels

Yellow poly-points - locations of abandoned mines

https://www.srbc.net/minedrainageportal/Maphttps://www.srbc.net/minedrainageportal/Map

Figure 1. Location of polluted river waters and abandoned mines in the Commonwealth of PA

In addition to primary ores, the PSU Center for Critical Minerals is concentrating on these secondary sources – overburden and underclays, acid mine drainage and sludge, precious metals from US DOD E-Waste, Fly ash, and power industry wastes, and mine tailings. Some of which may have a lower concentration than traditional ores. The analysis of three acid mine drainage sites and sludge samples is shown in Table 1. The samples are highly enriched in rare earths and offer enormous environmental benefits such as re-mining and reclamation of abandoned mined lands and remediation of acid mine drainage while providing critical elements from domestic sources. Of note is that the heavy to light rare earth element ratio in these AMDs is higher than in many other ores, creating an especially strong niche for these deposits for sought-after heavy rare earth elements.

Because of lower concentration, larger amounts must be processed. Therefore, a multimetal recovery approach is more desirable. Fortunately, Pennsylvania's primary and secondary enriched ores have high assays of not only the rare earths but also of lithium, aluminum, and a number of other critical minerals.

Table 1. Rare Earth Element concentrations in three sites in Clearfield county in PA.

Sample	Material	pH	Eh (mV)	TREE (ppm)	CREE [1] (ppm)	HREE [2] (ppm)	LREE [3] (ppm)	H/L Ratio
Site A:	AMD	3.66	188.1	0.54	0.31	0.31	0.23	1.35
Site B:		4.00	168.5	0.43	0.21	0.18	0.25	0.72
Site C:		3.72	184.5	0.47	0.23	0.21	0.26	0.81
Site A:	Sludge			1043	600	595	447	1.33
Site B:				2787	1332	1175	1612	0.73
Site C:				2487	1233	1131	1356	0.83

1. CREE: Nd, Eu, Tb, Dy, Y
2. HREE: Y, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu
3. LREE: Sc, La, Ce, Pr, Nd, Sm

The current AMD treatment methods use hydroxide base chemicals for neutralization, resulting in the precipitation of minerals from the solution. Using these methods, up to 70% of rare earth elements precipitate at the target treatment pH of AMD, and the rest is discharged with the treated water. Our group has recently developed a two-stage process, shown in Figure 2, using the environmentally friendly carbon dioxide mineralization process. Through this novel (patent-application pending) process, 90% of aluminum and over 85% of the rare earth elements can be recovered at pH values below 7, suppressing the precipitation of most of the iron that would otherwise dilute the target metal concentration.

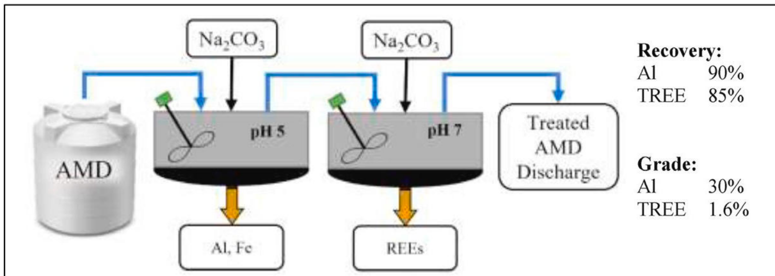
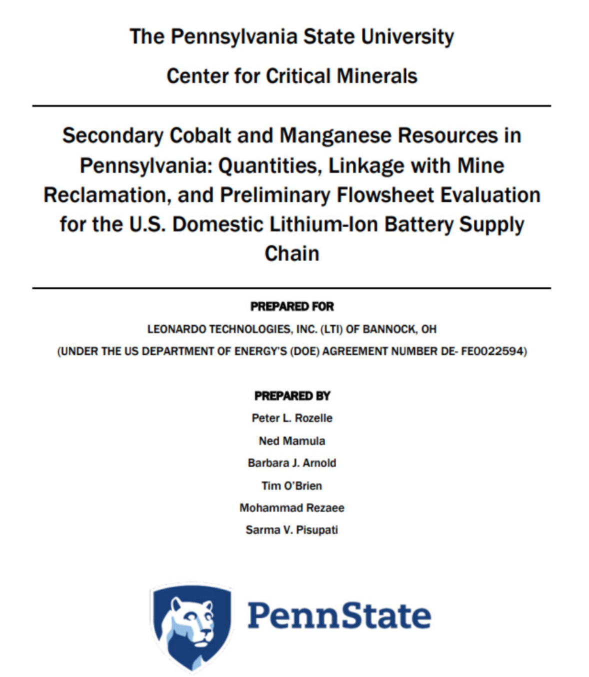


Figure 2. Two staged precipitation process developed at PSU to recover Al and rare earths at or below discharge pH. *(Hassas, B.V., Rezaee, M., Pisupati, S.V., Chemosphere, Vol. 280, 2021)*

Although the coal-associated wastes and AMD provide the most compelling feedstock for critical minerals in Appalachia, given the added benefit of environmental remediation, primary ore concentrates do exist in coal and coal-associated sedimentary units. In a recently completed geological study, lithium contents that exceed 1,000 ppm and alumina contents ranging from 32 to 34 wt.% were found in a clay deposit underlying the Mercer coal[1]. Subsequently, along with partners Materia USA and a local coal mining company, Penn State has further characterized the Mercer "underclay" as a viable feedstock for lithium (battery material), rare earth elements, and alumina.

[1] Rozelle, P. L., Feineman, M. D. White, T.S., Crescenzo, N.., Kump, L. R., Larson, A.R., and Pisupati, S. V., (2021) Mining, Metallurgy & Exploration **38**: 2037-2054.


The Pennsylvania State University

Center for Critical Minerals

Secondary Cobalt and Manganese Resources in Pennsylvania: Quantities, Linkage with Mine Reclamation, and Preliminary Flowsheet Evaluation for the U.S. Domestic Lithium-Ion Battery Supply Chain

PREPARED FOR

LEONARDO TECHNOLOGIES, INC. (LTI) OF BANNOCK, OH

(UNDER THE US DEPARTMENT OF ENERGY'S (DOE) AGREEMENT NUMBER DE- FE0022594)

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Figure 3. Penn State report on Cobalt and Manganese resources in PA

PA's critical mineral resources extend beyond the rare earth elements, lithium and alumina. Our Center for Critical Minerals has published a report on the assessment of cobalt and manganese resources in PA, as shown in Figure 3. The main findings are:

1. The preliminary estimate is that coal refuse in Pennsylvania contains approximately 52,000 metric tons of cobalt. Over a half-million metric tons of manganese are contained in these accumulations.
2. The preliminary estimate is that 60 metric tons of cobalt and over 5,500 metric tons of manganese are being discharged with acid mine drainage into the Commonwealth's waterways every year.
3. The sale of cobalt and manganese commodities recovered from these materials could help offset the costs of mine reclamation and stream restoration in Pennsylvania.
4. Results of initial process development have been presented for the integration of cobalt and manganese from secondary materials into the lithium-ion battery supply chain.

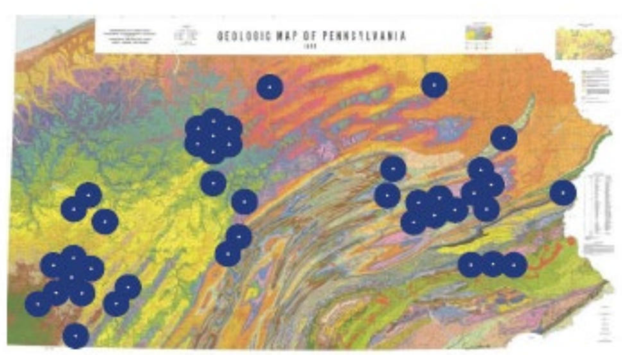

Figure 4. Industries involved in the critical minerals supply chain in Pennsylvania.

Another component that is critical for battery material is graphite, a material that is currently 100% imported. St. Marys, Pennsylvania, is a carbon manufacturing hub in the U.S. With the availability of domestic carbon sources from coal, there is an opportunity to develop synthetic graphite producing capabilities in PA based on PA resources. . The blue circles shown in Figure 4 indicate already existing industrial supply chain infrastructure.

Based on current research results, a process flow chart has been developed for multimetal recovery from PA to recover 90% of lithium, 95% of the iron, >90% of aluminum, and 75% concentrate of mixed rare-earth-element oxides and over 90% of cobalt and manganese from underclays and waste materials. The potential for this to become a burgeoning industry in PA is substantial.

Of course, Penn State cannot do this alone. Along with other academic and government partners, our Power and Minerals Industrial Stakeholders Group (PMISG) comprises over 40 Industry representatives that include the coal, power, transportation, chemicals, and rare metals industries. PMISG meets regularly with us, and several members are taking the lead or supporting our research and development efforts.

To summarize, the Commonwealth of PA and the US have enormous potential to produce critical elements domestically while creating jobs, reclaiming abandoned mined lands, remediating acid mine drainage, and addressing a critical national security issue. It's a win-win-win situation that we simply cannot pass up.

Finally, I want to thank you again for this opportunity!