Recovery of Rare Earth Elements from Acid Mine Drainage

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Rare earth elements in acid mine drainage become high-grade concentrates at WVU's Rare Earth Extraction Facility

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Chairwoman Murkowski, Ranking Member Manchin and members of the Committee, thank you for the opportunity to offer relevant testimony and to answer your questions in my areas of experience and expertise.

I am the Director of the West Virginia University Water Research Institute, a component of WVU's Energy Institute. The Institute serves to facilitate collaborative and innovative solutions for the energy future of West Virginia and the United States.

West Virginia University is a public, land-grant, research-intensive university founded in 1867. It is designated an "R1" Doctoral University (Very High Research Activity) by the Carnegie Classification of Institutions of Higher Education; funding for sponsored research programs and grants exceeded $185 million in 2017

The Water Research Institute conducts sponsored and grant-funded research programs in the areas of watershed restoration, acid mine drainage treatment, mitigation of mining and gas development impacts on water and land. Most recently we developed a research initiative around recovery of critical minerals (CM) and rare earth elements (REE) from acid mine drainage.

Introduction: Rare Earth Elements or REE are essential for advanced technologies from smart phones and robots to top-secret national defense systems. The REE metals have remarkable chemical properties but are so evenly dispersed throughout the earth's crust that economically attractive concentrations are extremely rare. Also, nearly all conventional sources of REE occur with the radioactive elements thorium and uranium and they are concentrated by the same processes used to release REE from their host minerals. The result is commonly a mildly radioactive tailings stream that must be managed in perpetuity. As a result, the U.S. imports nearly all its rare earth elements from China, which supplies about 89 percent of the world's rare earth needs. India and Russia provide most of the balance of these strategically important materials. However, researchers at West Virginia University found that treating one of the biggest sources of pollution in the United States, acid mine drainage or AMD is a rich source of rare earth elements, or REEs (figure 1).

Figure 1. Typical AMD sludge settlement cells at a Pennsylvania coal mine. The orange material in the foreground is enriched with rare earth elements. After the metals precipitate, the clear water in the far cells is discharged via a regulated discharge point.

The U.S. has one operating REE mine, at Mountain Pass, CA. It ships its REE concentrate to China for refining to metal where companies often use it to manufacture advanced electronic products for export. With no domestic supply chain, the U.S. is vulnerable to interruptions in the international market. So, in 2015, the U.S. Department of Energy's National Energy Technology Laboratory solicited ideas across the U.S. for extracting rare earth elements from coal and related byproducts. Our research team at West Virginia University, was awarded the first of three grants in early 2016 to study the potential of extracting rare earth elements from the solid residues or sludges left over after treatment of AMD.

AMD forms when pyritic waste rock from coal mines is exposed to air (figure 2). This acid then leaches rare earth metals out of the rock. AMD treatment concentrates the rare earths in sludges from which the REEs can be captured and refined into marketable products. Recovery of value from AMD would also help stimulate AMD treatment

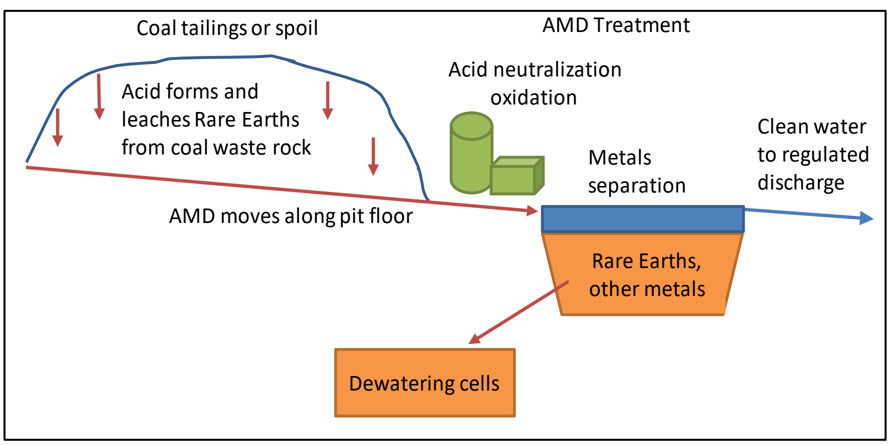

Figure 2. Acid mine drainage leaches rare earth elements out of surrounding rock. AMD treatment then causes all metals including rare earth elements to precipitate.

at abandoned mines and allow operators to offset treatment costs.

We found that REE concentrations in AMD treatment solids exceed many of the world's best commercial deposits. And, whereas most conventional rare earth deposits are encased in hard rock and located in remote wilderness, AMD sludge is already extracted from the host rock and easily accessible resulting in modest processing costs.

In the near future the AMD treatment systems at both operating and former mine sites could be managed as rare earth production facilities, recovering rare earths from ongoing AMD production and from sludge stored in dewatering cells (figure 3). For example, REEs at one site that is treated by the WVDEP's Office of Special Reclamation has an estimated value of $1.9MM exclusive of transport and processing. The goal of our currently funded USDOE/NETL project is to quantify those processing costs.

The WVU researchers evaluated the reserves at 140 acid mine drainage treatment sites throughout West Virginia, Pennsylvania, and Ohio. They are also developing commercially viable refining methods. If successful, the project could lead to economic diversification and new economic development opportunities for Appalachia's coal towns. While the coal market may fluctuate over time, acid mine drainage is constant. Long after mining is done, the mines still generate AMD and REE. Some of the richest AMD comes from sites where mining ceased 30 years ago. Our strategy involves extracting a REE concentrate from AMD at the mine for refining at a central facility. This involves treatment of the AMD for compliance with regulatory requirements while leaving the bulk of the waste stream for disposal at the mine under its currently permitted conditions.

Figure 3. Typical AMD sludge storage cell at a West Virginia coal mine. The contained rare earth value of this small cell is estimated at $325,000.

We conducted a regional survey and found 700 tons of REE in AMD sludge cells on mine sites in the northern and central Appalachian Coal Basins. Those mines produce about 1,000 tons of REE annually with an estimated, contained value of $245 million. The stored number is low because most AMD treatment sludge is disposed in underground mines or buried on active mine sites. For comparative purposes, the Congressional Research Service in 2011 found that the U.S. Defense establishment uses about 800 tons of REE per year while the overall economy uses about 16,000 tons. Most of those REE are in components manufactured offshore.

To make this a commercial reality, WVU is partnering not only with USDOE/NETL but also members of the coal industry, Rockwell Automation, Inc. and WVDEP. The support received has been tremendous. Success will turn an environmental liability into become an economic opportunity while cleaning up the environment.

Program Status: Our approach takes advantage of autogenous processes that occur in coal mines and associated tailings which liberate then concentrate REEs. In addition, we've found that AMD feedstock yields a favorable mix of valuable heavy and critical REE relative to many REE projects (figure 4). It is important to note that the Mountain Pass REE mine in California and China's largest REE mine at Bayan Obo, both produce largely light REEs while China's heavy REE supply is said to be depleting rapidly (figure 5). REE sourced from coal AMD is non-radioactive, unlike conventional, hardrock sources. A typical, recent sample of our concentrate contained 62% REE oxide with only 0.01% uranium + thorium.

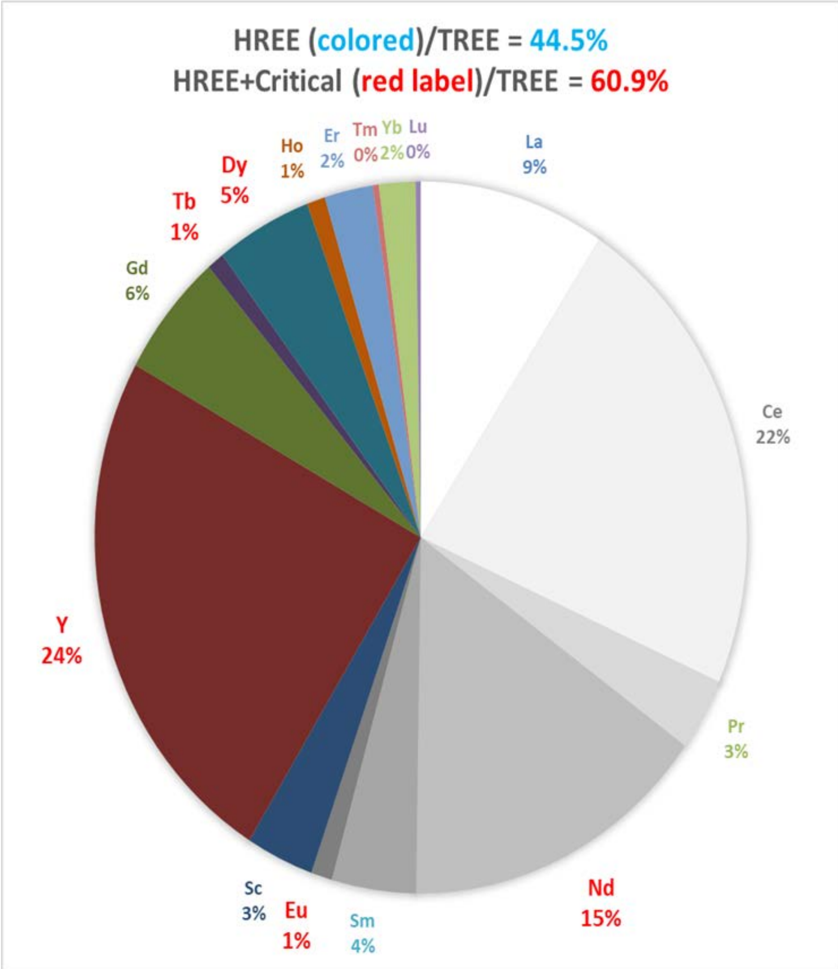

Figure 4. AMD contains a high proportion of the valuable critical and heavy rare earth elements. Together they comprise about 60% of the total rare earths in Appalachian acid mine drainage.

A techno-economic analysis found that REE extraction from AMD feedstock is economically attractive with a refining facility projected to generate positive cash flow within five years. In 2018 we commissioned a pilot plant to demonstrate continuous operations yielding 3 g/hour of REE concentrate. Rockwell Automation is providing technical expertise as well as its sensor and control technology to accelerate market readiness.

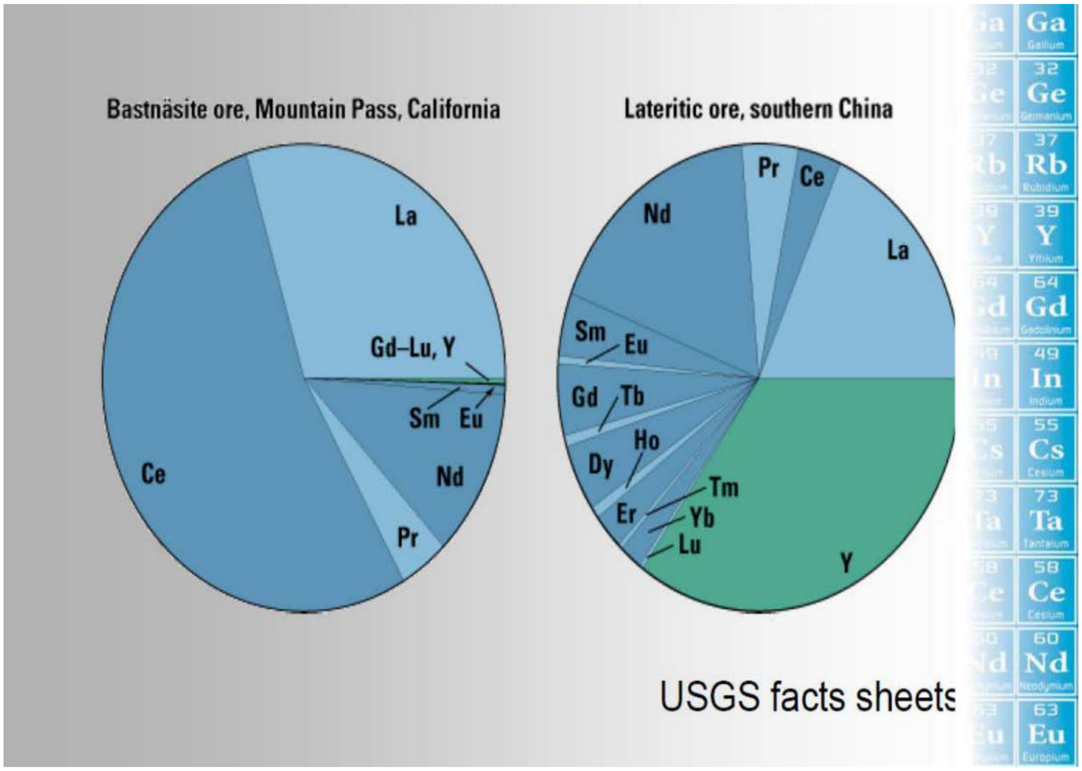

Figure 5. Bastnasite ores are mined at Mountain Pass CA and China's largest REE mine at Bayan Obo (left) they contain less than 12% heavy REE. Nearly all of China's heavy REE come from their laterite deposits (right) which contain about 50% heavy REE.

Thus far, we have produced pre-concentrates from acid mine drainage with 5% REE. Using hydrometallurgical methods at the bench scale, we produced a concentrate with 80% Rare Earth Oxides from AMD treatment sludge (figure 6).

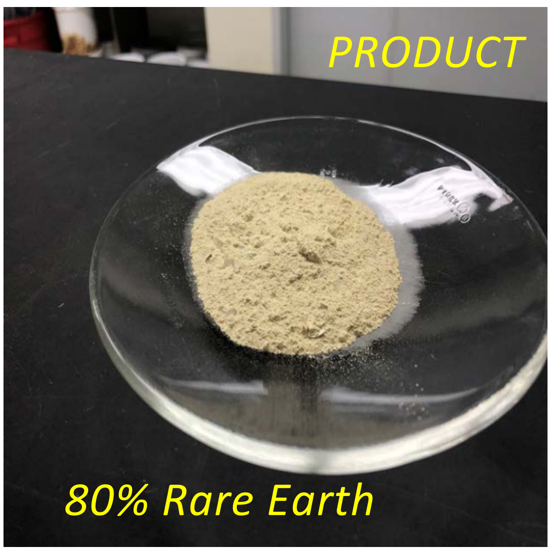

Figure 6. High-grade rare earth concentrate produced by the WVU research team.

Next steps will involve a pilot plant and scaleup of the our REE oxide technology to commercialization. Success will support the base of a domestic supply chain but that is only the start of a broader need to stimulate refining to REE metal and transitioning of domestic REE users to domestic supplies.