PROMISING POTENTIAL

NETL, WVU Establish Rare Earth Extraction Facility

By Cassie Shaner

Rare earth elements (REEs) are essential in today's technology-dominant world. They make vibrating cell phones, crisp LED screens and other in-demand technologies possible. Once thought to be rare, REEs are abundant in Earth's crust but also challenging to extract. For decades, the United States and other nations have relied primarily on imports from China, which supplies more than 90 percent of REEs worldwide.

An innovative new facility established in collaboration with NETL has the potential to yield a valuable domestic supply of REEs from a nontraditional source – acid mine drainage (AMD), a waste byproduct of coal mining operations. If successful, the bench-scale Rare Earth Extraction Facility (REEF) at West Virginia University (WVU) will ultimately enhance national security, stimulate economic growth, reinvigorate coal country and promote responsible stewardship of the environment.

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The REEF is a key component of two DOE projects managed by NETL. DOE Assistant Secretary for Fossil Energy Steven Winberg joined officials from NETL and WVU to celebrate the facility's launch in July 2018.

"This is a milestone moment in our Lab's efforts to develop a domestic supply of rare earth elements, which are essential for modern technologies," NETL (Acting) Director Sean I. Plasynski said. "Innovation is central to our work at NETL, and this cutting-edge research supports DOE's core mission to keep America safe and secure. This facility will explore the feasibility of meeting the growing demand for REEs by taking advantage of our abundant natural resources. If successful, we will create business opportunities that stimulate the economy and boost jobs, help the coal industry and ensure national security by reducing our reliance on imports."

UNDERSTANDING RARE EARTHS

The 17 elements typically described as rare earths include the lanthanide series within the periodic table – elements 57-71, the first of two rows often pulled out below the rest of the elements – along with transition elements scandium and yttrium.

These important elements are used in high-technology devices that support a broad range of industries, including transportation, health care and defense. For instance, samarium is used to make studio lights and optical lasers. The U.S. defense industry alone requires about 800 tons of REEs per year.

REEs are divided into two categories – light and heavy, with heavier REEs less plentiful and generally worth more money. However, the value of individual REEs varies based on market conditions. Refined scandium, which is more scarce than other REEs, can command as much as $15,000 per kilogram.

REEs do not occur naturally in elemental form, but the vast coal resources throughout the United States contain quantities sufficient to meet the country's needs for years to come.

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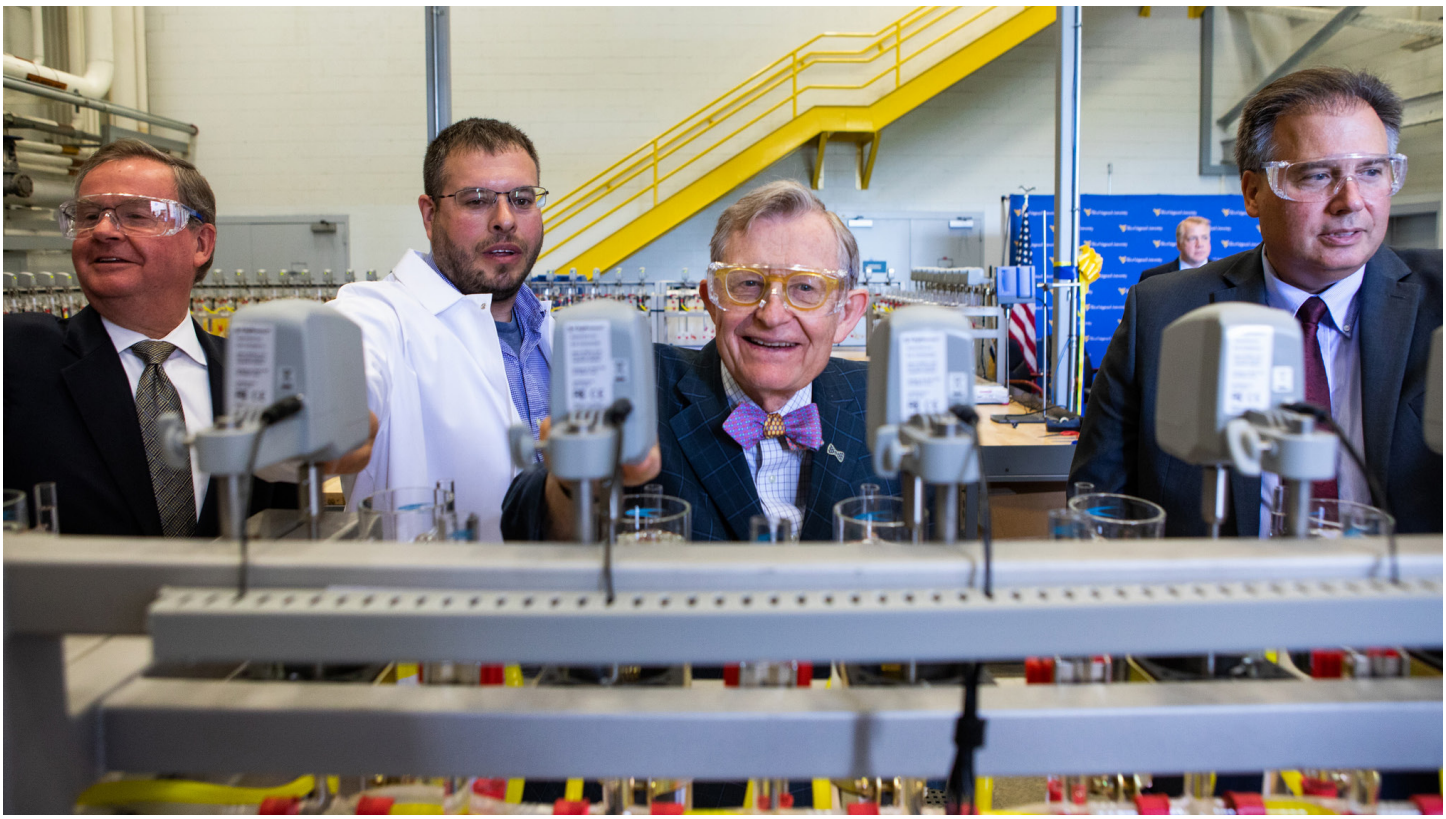

Assistant Secretary for Fossil Energy Steven Winberg, Rare Earth Extraction Facility Operator Chris Vass, WVU President E. Gordon Gee and NETL Director (Acting) Sean I. Plasynski check out mixer-settlers used to extract rare earth elements from acid mine drainage at the facility's commissioning celebration on July 18, 2018.

The Rare Earth Extraction Facility aims to produce about 3 grams of rare earth concentrates per hour with a purity of at least 2 percent – or 20,000 parts per million – from acid mine drainage sludge. The continuously operating Rare Earth Extraction Facility features 100 mixer-settler units used to extract valuable rare earths through a two-stage chemical separation process.

HOW IT WORKS

The REEF's origins date back to the late 1990s, when the U.S. Geological Survey was tasked with looking at AMD treatment sources to determine whether anything of value could be extracted. Government officials were primarily interested in precious metals, but scientists at the USGS conducted analysis for much of the periodic table. The data was later shared with Paul Ziemkiewicz, director of the West Virginia Water Research Institute at WVU, who referred to it when DOE issued a 2015 funding opportunity announcement seeking to identify sources of REEs and ways to extract them. Ziemkiewicz recognized that REEs were found in the raw AMD water but not in the treated effluent, which meant that REEs were being extracted with solid residues, or sludge, generated during AMD treatment.

WVU received $3.4 million from DOE as part of a $4.3 million project, led by Ziemkiewicz and managed by NETL, aimed at recovering REEs from AMD. The REEF is a key component of the project's second phase, which investigates the technical feasibility of extracting REE concentrates with a purity of at least 2 percent – or 20,000 parts per million – from AMD sludge. During phase 1, WVU and its partners confirmed AMD as a viable source of REEs and developed an extraction and separation process. The REEF, a continuously operating facility commissioned in phase 2, employs a two-stage chemical separation process that includes acid leaching and solvent extraction to produce about 3 grams of REE concentrate per hour.

Raw AMD contains acid and dissolved metals. Because some of these metals are regulated for public safety, AMD must be treated by raising the pH to a neutral level, oxidizing the metals and removing regulated metals such as iron, aluminum and manganese. The resulting orange sludge is primarily composed of metal hydroxides.

The REEF process involves bringing in sludge from existing AMD treatment facilities and acidifying it to remove a portion of the gangue – waste consisting of iron, aluminum, manganese and gypsum. This produces an REE-enriched pregnant leach solution that goes to the solvent extraction circuit, where it is emulsified with a mixture of kerosene and

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an extractant that grabs REEs while leaving the gangue in the aqueous phase. This takes place in mixer-settlers and can then be repeated as many times as necessary. REEF has 100 mixer-settlers that successively raise the concentration of REEs by rejecting the remaining gangue while classifying the REEs on an elemental basis. Once the desired concentration of REEs is achieved, the extractant is treated to release a nearly pure REE product.

Rockwell Automation, another partner in the REEF project, is investing about $700,000 in in-kind services, equipment and expertise to make the processing system fully automated – a move that will enable easier scale-up as the technology advances.

A second project awarded to WVU will make use of the same facility and process as it seeks to extract REEs from AMD prior to treatment, while it is still naturally acidic and before it is contaminated with gangue. Ziemkiewicz also serves as principal investigator for that project, which he said offers even greater potential benefits. The $864,000 project could extract enriched REE concentrates of higher purity and be more economical by eliminating steps within the sludge-based extraction process.

'NO DOWNSIDE'

A native of Kansas City, Jessica Mullen has always enjoyed the outdoors – particularly hiking and biking. When she came to the Appalachian region for postdoctoral work at NETL's Morgantown, West Virginia, site, she fell in love with the area's natural beauty. She also understood people's concerns about the impact of energy operations on the environment.

Mullen's scientific curiosity and passion for the Earth drive her work at NETL, where she is proud to serve as the federal project manager for both WVU projects aimed at extracting REEs from AMD. She noted that while AMD is a pollutant that must be treated per federal regulations, it's also abundant in Appalachia.

"Customarily, it has been considered a liability, but it could be a potential economic windfall with benefits to the environment and local job market, all while meeting the security needs of the nation," Mullen said. "We're all hopeful that this research is going to be a win-win-win. There's really no apparent downside to this."

According to WVU's research, estimates based on the volume of AMD generated in Pennsylvania and West Virginia alone suggest that their sludges could generate up to 2,700 tons of REEs per year. A survey of 154 AMD treatment facilities found enough sludge in surface storage to generate additional REEs worth $122 million.

In addition, a conservative techno-economic analysis performed as part of the project found that REE extraction from AMD sludge is economically attractive with a refining facility projected to generate positive cash flow within five years. The REEF work is focused on demonstrating the feasibility of the extraction process as well as the economics.

"One of the biggest issues that we've always faced in acid mine drainage treatment is how do you pay for this over the long haul," Ziemkiewicz said. "This provides an additional revenue stream not only for communities but also for the industry itself. Now they have two products. They've diversified their revenue stream, and it's paying them to keep treating their AMD and keep it out of streams."

Ziemkiewicz said the continuous process created at the REEF is ambitious compared to a traditional laboratory bench-scale project, because everything must work perfectly to ensure success. But the fully automated process should also make the near-turnkey technology more economically attractive for potential investors.

DOMESTIC SUPPLY BY 2020

WVU's REEF-related projects are among 22 projects across the country managed by NETL's REE program. Since the program launched in 2014, it has expanded exponentially to tackle a variety of REE projects tied to three key technology areas: enabling technologies, separations technologies and process systems. All are focused on producing a domestic supply of high-purity, salable rare earth oxides from coal and coal byproducts, which NETL aims to achieve by 2020.

"We have an aggressive portfolio of projects with innovative partners across the country. Our success hinges on co-production of materials, demonstration of environmentally benign processing and competitive economics," said Mary Anne Alvin, Technology Manager for NETL's REE program. "Facilities like WVU's Rare Earth Extraction Facility are critical in achieving our objectives as we work to provide significant value to our national security, energy independence, environmental future and economic growth."