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ESG Perspectives

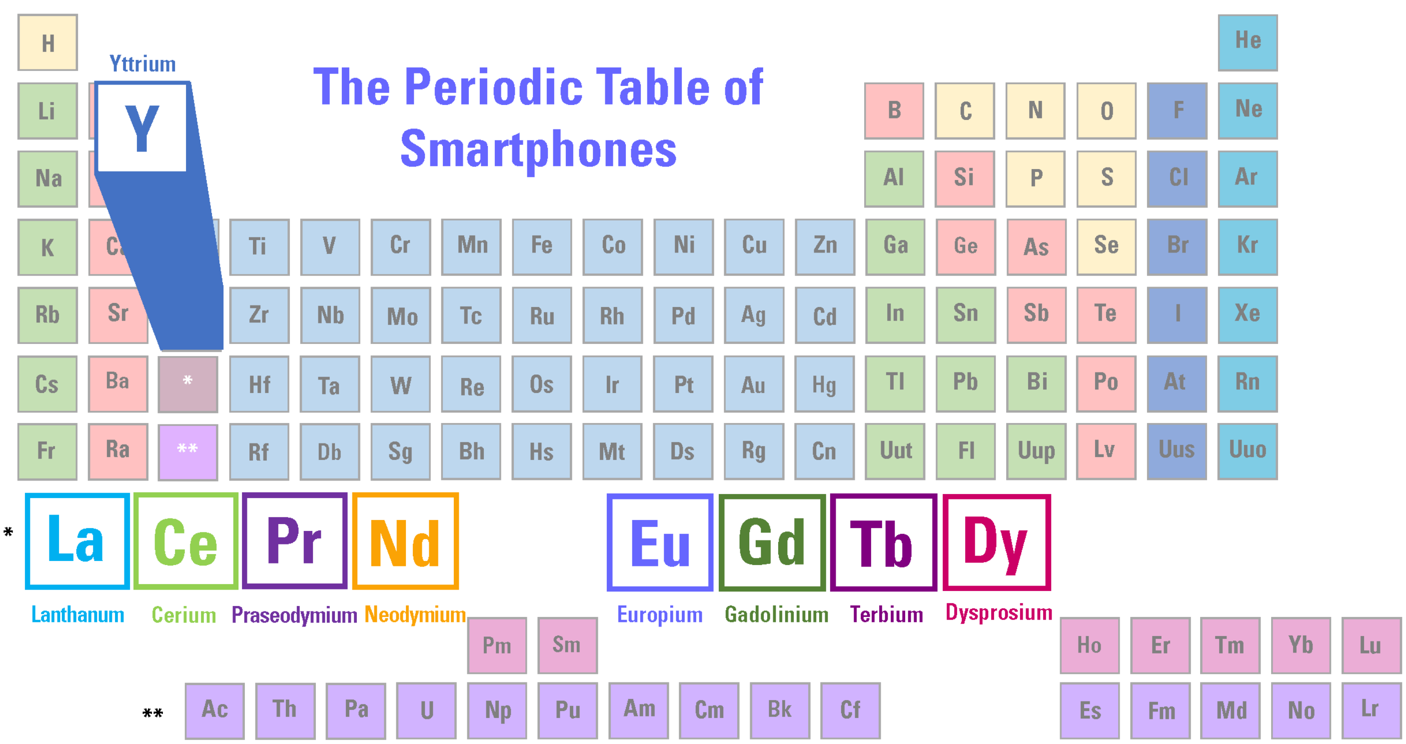
A Rare Opportunity in Coal Waste

It is said that one man's trash is another man's treasure, and treasure is what researchers are finding in toxic coal mine waste. Several American universities, independent laboratories, and the Department of Energy (DOE) have discovered significant amounts of valuable rare earth elements (REEs) in coal mine waste. Rare earth elements can be found in nearly every item with an on/off switch, including smartphones (as shown below) and other computer electronics, but extraction in the United States has been, until recently, difficult due to the high cost and complexity of developing the appropriate facilities. These researchers are finding that REEs may be readily recovered in an environmentally safe way and marketed to help pay for the vast clean-up costs now borne by the coal and public utility industries. Indeed, coal and, more importantly, coal combustion byproducts represent a significant potential source for critical elements, including REEs, with estimated amounts in the range of 50 million metric tons.[1]

A Strategic Importance

Global consumption of REEs has tripled in the last 25 years, from 45,000 metric tons to 155,00 metric tons in 2016, and they are considered important to U.S. national security, energy independence, environmental future, and economic growth.[2] Before 1965 there was relatively little demand for REEs, but with the introduction of color TV technology in the mid-60s came increased demand. A wide variety of products used today rely on REEs, including satellite communications, guidance systems, capacitors, sensors, lasers, fiber optics, medical imaging, ultraviolet-resistant glass, photo-optical glass, and many more. In 2017 the U.S. consumed an estimated 11,000 metric tons of rare earth elements.[3]

Rare earth elements are a group of 17 chemical elements on the periodic table that tend to occur together in nature, are all metals, and are not as rare as their name implies. These metals have many similar properties and



Rare earth elements used in the production of smartphones.

they are often found together in geologic formations, such as coal seams and deposits. They were named "rare earth elements" because most were identified by scientists during the 18th & 19th centuries as "earths," which were defined originally as materials that could not be changed further by heat and were thus considered to be rare in nature. Contrary to historical findings, REEs are moderately abundant but difficult to extract from surrounding matter because of the way in which they bond freely with one another in minerals and clays. As a result, these natural properties make for a difficult extraction effort involving significant capital investment, time, and adverse environmental chemical processes.

The China Monopoly

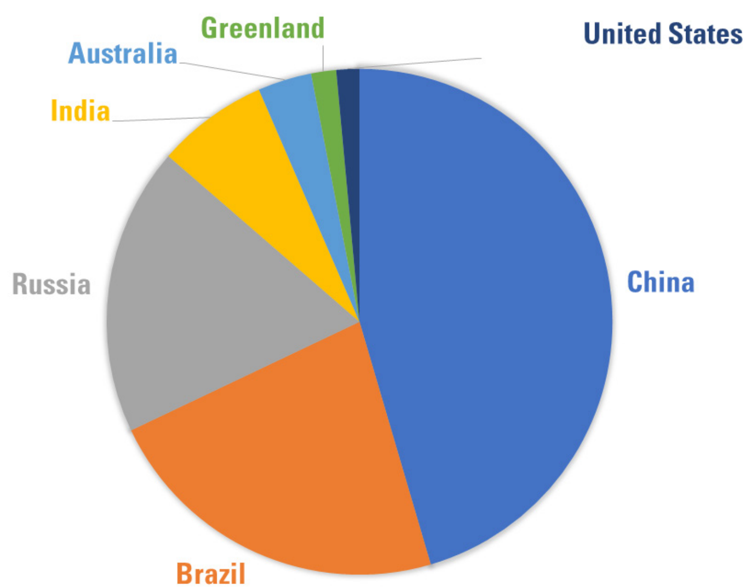
Global REE resources are estimated to be 110 million metric tons of rare earth oxides. Despite these known deposits -- which largely exist, in descending order, in China, Brazil, Russia, India, and Australia -- the global supply of REEs is limited by the high cost and complexity of developing extracting and separating facilities. From the mid-1960s thru the early 1980s the United States was was a dominant global supplier of REEs. During this period the Mountain Pass Rare Earth Mine, located about 50 miles southwest of Las Vegas, Nevada, just inside the California border, was the largest rare earth producer in the world.

China began producing notable amounts of REEs from its coal deposits within Inner Mongolia in the early 1980s and became the world's leading producer of REEs by the early 1990s. Because of China's involvement in the basic manufacturing of high tech products, its REE production grew rapidly, from 16,000 tons in 1990 to over 105,000 tons at the end of 2017. In this process China steadily strengthened its stranglehold on the global supply of REEs, thus forcing prices lower and thereby eliminating competition while forcing the closure of the Mountain Pass Mine, America's only REE supplier.

Today China controls over 37% of the estimated worldwide reserves of REEs and over 80% of reported global production in 2017. China produces five times as much REEs as Australia, the second largest producer, and nearly 100% of the global supply of the critical "heavy REEs," which are essential to the manufacture of magnets for computing devices, cellphones, wind turbines, and automotive catalytic converters, to name a few. As a result, it wields significant power over this critical global supply chain.

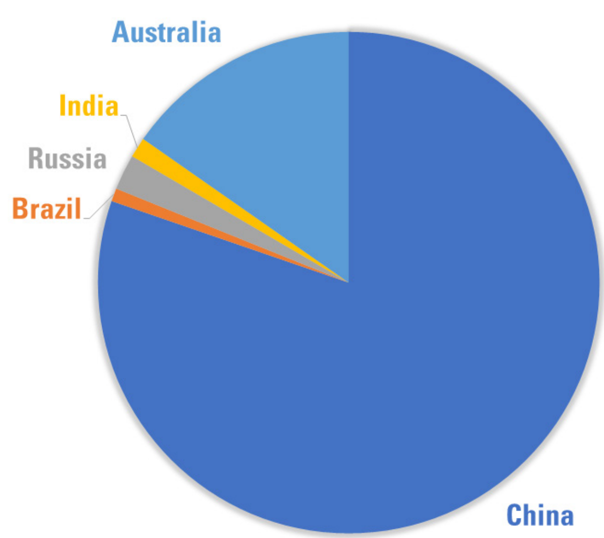
China's global dominance of the REE markets has been long in the making and was consciously developed as a matter of domestic policy to be exercised by its national leaders, such as Deng Xiaoping, the paramount leader of the People's Republic of China from 1978-1989. At that time, he was quoted as saying "the Middle East has oil; we have rare earths…it is of important strategic significance; we must be sure to handle the rare earth issue properly and make the fullest use of our country's advantage in rare earth resources."[4]

WORLDWIDE REE RESERVES



Source: Geology.com

WORLDWIDE REE PRODUCTION



Source: Geology.com

Currently, the U.S. is beholden to China for nearly 80% of REE imports. China outproduces the U.S. on REEs by a factor of 25:1 and has stated intentions of significantly reducing its global exports of REEs by 2020. China intends to conserve limited resources, enabling its domestic manufacturing requirements and meeting its growing domestic consumer demand. Because of these trends, the production and supply of crucial REEs is becoming a strategic national defense issue for the U.S. According to the 2013 Worldwide Threat Assessment of the National Intelligence Office, rare earths are "essential to civilian and military technologies and to the 21st Century global economy, including green technologies (e.g., wind turbines and advanced battery systems) and advanced defense systems." Moreover, in May 2017, Secretary of State Mike Pompeo told a U.S. Senate committee that U.S. dependence on foreign sources of rare earths was a "very real concern."[5]

With REEs, the time between a mining company's decision to initiate the development of a mineral deposit and its production can take 12 years or more. Essentially, there is no shortcut to opening a new mining property. Hence, if a single country, such as China, controls most production and makes a firm decision to reduce or eliminate global REE exports, it is likely that a dangerous and destabilizing situation will arise for manufacturers worldwide until a new source of supply can be identified. The question is, will American industrial policy be able to break this monopoly and regain some control in the present and ongoing "trade war" environment?

North Korea: A Joker in the Deck?

With China in a seemingly insurmountable REE production control position there has been a global effort to uncover new sources of supply. Interestingly, the present REE world order may soon be destabilized by the United States' efforts to engage with North Korea to find both political and, more importantly, commercial common interests.

U.S. Secretary of State Mike Pompeo knows the importance of rare earth elements, and North Korea has reportedly found one of the world's largest deposits of REEs -- potentially worth billions of U.S. dollars -- just 150km northwest of Pyongyang. This discovery is arguably a central concern behind the Trump Administration's new and ongoing embrace of the Democratic People's Republic of Korea (DPRK).

According to recent Asia Times reports, China is believed to control over 95% of the global production of REEs, with an estimated 55 million tons in deposits.[6] Surprisingly, North Korea is now reported to hold at least 20 million tons of recoverable natural REE reserves. If true, this would give North Korea an enviable position among the world's top producers of REEs. Therefore, if the U.S. fails in negotiating a favorable political arrangement with Kim Jong-un and the DPRK, the winner, once again, may be Beijing and, indirectly, Moscow, given the longstanding Russia-China geopolitical strategic partnership.

This whole new puzzle may revolve around who offers the best return on investment to the DPRK leadership and can demonstrate the ability to devise a profitable production chain in short order. This will undoubtedly be a tough deal for the U.S. to win in view of South Korea, China, and Russia's respective efforts to attach the DPRK to their planned Eurasia integration and intentions for developing its agriculture, hydropower, and now most-prized mineral wealth.

Just months ago, a meeting between the Trump Administration and Kim Jong-un would have seemed impossible. But given these recent REE deposit revelations and our strategic economic interests, could it be that the U.S. and the DPRK may eventually find common ground through the "Art of the Deal?" Only time will tell.

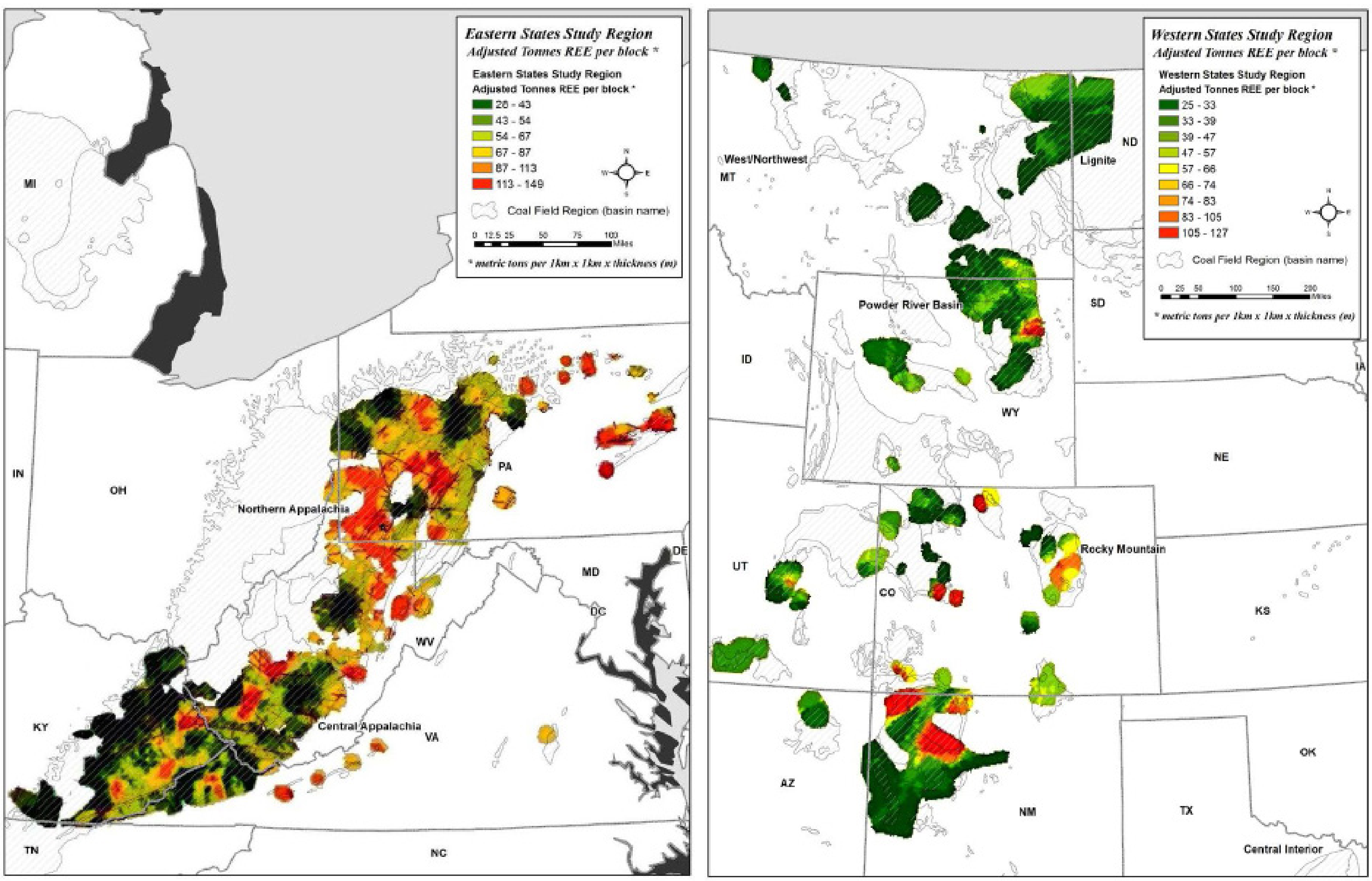
Trump China Tariffs: Boon or Bust for REE Conservation and Development?

On July 10, 2018 the Trump Administration announced a new round of tariffs aimed at China. Through this action the Administration levied a 10% import tax on $200 billion of Chinese goods imported to the U.S. Interestingly, among those goods were raw REEs. Last year China exported roughly $141 million worth of REEs to the U.S. For some, these actions were considered ill-timed, unnecessary, and ultimately detrimental to U.S. manufacturers that are highly dependent upon these materials. REE demand from clean technologies alone in 2020, 2025, and 2030 is expected to reach 33.3, 33.6, and 59.1 thousand tons, respectively.[7]

But for others, including President Trump, this was a first shot over the bow and a counter measure against the "Made in China 2025" national domestic policy, which seeks to establish China, not the U.S., as the dominant global high-tech provider and manufacturer by 2025. In part, this action by the Administration was meant to bring public and political attention to the growing need for a change in American industrial policy about the conservation and development of REEs.

Clearly, in the short run, U.S. companies and consumers could suffer from these tariffs, as there are few alternative sources for the supply of much-needed REEs. However, we believe that the added costs that are likely to accrue from these actions will help to spur and boost much-needed REE conservation efforts by consumers and manufactures alike. For example, Apple already manages a successful but small recycling program for its old iPhones. Through this program Apple has been able to recover about 24 pounds of REEs for every 100,000 phones they recycle. When one adds up the 500 million retired cellphones (the equivalent of 60 tons of REEs) in existence today, it's easy to see that much more needs to be done, since only about 1% of these devices ever get recycled.[4]

It is our hope that these actions will be a boon to increased corporate, public, and political awareness of the critical need and potential represented in American coal waste recovery technologies to combat our difficult foreign REE import dependency. Through these immensely beneficial and impactful technologies, American communities and workers stand to derive great social, environmental, and economic benefits while serving and strengthening national interests. We hope that the ultimate effect of the tariffs will be more instructive than destructive, and serve to foster a unique alignment between our important national security interests, long-standing environmental imperatives, and the fulfillment of the social needs for many disadvantaged and discarded coal country communities.



Source: U.S. Department of Energy Report on Rare Earth Elements from Coal and Coal Byproductss, January 2017. REEs in U.S. Coal, Map for Appalachian Region (left). REEs in U.S. Coal, Map for central and northern Rocky Mountain region (right).

A Solution in Pollution

According to Mary Anne Alvin, technology manager of REEs at the Department of Energy's National Energy Technology Laboratory (NETL), the U.S. consumes about 11% to 12% of global REE production, which currently stands at about 150,00 metric tons.[8] In a July 2018 article in Chemical & Engineering News, Alvin said, "If there was a disturbance in the supply chain and we need these materials, especially for our national security, the question is, what do we do?"

According to research engineers at NETL, coal and coal byproducts represent a vast untouched resource. With more than 275 billion tons of coal reserves in the U.S., approximately 17 million tons of REEs are present within the coal -- that's a one-thousand year supply at the current rate of consumption.[9] Moreover, each year the U.S. typically produces roughly 75 million to 100 million tons of coal fly ash, which contains even higher concentrations (400 ppm) of REEs. These abundant domestic resources offer a game-changing opportunity for the U.S. and other global consumers of REEs.

In an effort to avert the commercially negative impact of significantly diminished REE imports in the near future, in recent years the Department of Energy (DOE) has invested heavily in more than 30 public, academic, and private enterprise projects. The goal is to develop a variety of potentially sustainable and commercially viable extraction methodologies to secure domestic source REEs from coal waste byproducts, such as coal ash, refuse rock, acid mine drainage treatment sludge, and young lignite coal. All the feedstocks start within a minimum 300 parts per million (ppm) REE concentration level (as compared to Chinese clay deposits that can contain 500 ppm to 5,000 ppm of rare earths). The DOE intends to have a range of economically viable prototype systems in place capable of producing 90% to 99% purity rate REEs by 2020.

From the Ashes of Despair Grow the Roses of Success

There are roughly 400 coal-fired power plants that are operational in the U.S. today. Although the percentage of electric power from coal is expected to decline to 34% of total generation in 2033, down from 39% in 2013, coal-fueled electric generation is forecasted to grow by 3.4% from 2013 to 2033, according to the U.S. Energy Information Association. This is due to America's growing population, which will drive increasing demand for electricity.

Department of Energy Coal Waste Recycling / REE Recovery Project Participants

Universities	Laboratories
Penn State	Battelle Memorial Institute
University of Kentucky	Lawrence Livermore National
West Virginia University	Los Alamos National
Virginia Polytechnic Institute	National Energy Technology
University of North Dakota	Research Triangle Institute
Ohio State University	Pacific Northwest National
University of Utah	Idaho National
Wayne State University	
Rutgers University	
Duke University	
University of Wyoming	
University of California-Davis	

Source: National Energy Technology Laboratory; Rare Earth Elements 2018 Project Portfolio

Several coal byproducts are created when coal is used to generate electricity, and it is estimated that America's coal-fired power plants collectively produce something on the order of 140 million tons of coal combustion byproducts annually. One byproduct, coal ash, is the second-largest waste stream in the U.S., second only to household trash, according to the EPA. The burning of four tons to eight tons of coal produces a single ton of coal ash, and the American Coal Ash Association estimates that there are 1.5 billion tons of coal ash currently sitting in 1,100 coal ash dumps in 37 states (400 dry landfills and 675 wet ash ponds). Other coal combustion byproducts include boiler slag, flue gas desulfurization sludge, and fluidized bed combustion ash.

Much has been written about coal combustion byproduct disposal management strategies, and a lot of money is spent annually on hundreds of related landfills and their monitoring. But it has been found that in many cases, disposal is not the best option; rather, the beneficial use of the coal combustion byproducts could save money and reduce related corporate and government liabilities. Several public utilities have come to understand that recycling their coal combustion byproducts is indeed cheaper in the long run versus the environmentally damaging storage and containment practices of the past. Indeed, in recent years public utilities have on average recycled 52% of their "new burn" coal combustion byproduct. This positive industry trend is expected to continue, with waste recycling goals for many to exceed 75% or more of "new burn" production over the next decade.

A Couple of Success Stories

Although REEs are rarely found in their elemental form, they can be extracted from coal and coal ash. Certain types of coal have high concentrations of rare earth elements (REEs) on the order of hundreds of parts per million (ppm). The good thing about using coal ash rather than coal itself is that combustion has the effect of concentrating rare earths in the ash by a factor of six-to-10 times relative to coal.[10]

To harvest these resources researchers have created a variety of innovative portable separation technologies that can be built at or transported to local coal ash storage waste sites to prepare and process idle ash

The Largest U.S. Coal Power Stations: Ownership & ESG Scores

Rank	Station	State	Capacity in MW	Ownership	ESG Score	Peer Rank %	Environmental Score
1	Robert W. Scherer Power Plant	GA	3,520	Southern Cos. (SO) Next Era Energy (NEE)	60 61	40 46	57 49
2	Gibson Generating Station	IN	3,340	Duke Energy (DUK)	52	50	49
3	Monroe Power Plant	MI	3,280	DTE Energy (DTE)	69	75	59
4	Bowen Power Station	GA	3,202	Southern Cos. (SO)	60	40	57
5	John E. Amos Power Plant	WV	2,933	American Electric Power (AEP)	67	70	57
6	J. H. Miller Power Station	AL	2,822	Southern Cos. (SO)	60	67	57
7	W. A. Parish Power Station	TX	2,697	NRG Energy (NRG)	64	60	61
8	Cumberland Power Plant	TN	2,600	Tennessee Valley Authority	N/A	N/A	N/A
9	Gavin Power Plant	OH	2,600	Lightstone Generation*	N/A	N/A	N/A
10	Rockport Power Plant	IN	2,600	American Electric Power (AEP)	67	70	57
11	Paradise Fossil Plant	KY	2,558	Tennessee Valley Authority	N/A	N/A	N/A
12	Roxboro Power Station	NC	2,558	Duke Energy (DUK)	52	50	49
13	W. H. Sammis Power Plant	OH	2,456	First Energy (FE)	59	38	52
14	Navajo Generating Station	AZ	2,409	Navajo Nation	N/A	N/A	N/A
15	Sherburne County Generating Station	MN	2,400	Xcel Energy (XEL)	73	83	65
16	Martin Lake Power Station	TX	2,380	Energy Future Holdings (EFH)**	N/A	N/A	N/A
17	Belews Creek Power Station	NC	2,160	Duke Energy (DUK)	52	50	49
18	Jeffrey Energy Center	KS	2,155	Evergy (EVRG)	N/A	N/A	N/A
19	E. C. Gaston Power Station	AL	2,013	Southern Cos. (SO)	60	40	57
20	Homer City Generating Station	PA	2,012	General Electric Group (GE)	66	91	67
				Group Average	61	53	56

*Source: Wikipedia.org. Notes: ESG and environmental scores are the most recent provided by Sustainalytics Research. Scores are provided on a relative quality ascendency scale of 0-100. Peer percentile rankings are based upon each company's relative industry ranking. * Lightstone Generation LLC is a joint venture private company of Blackstone (BX) and ArcLight Capital Partners. ** Energy Future Holdings is a private company jointly owned by Kohlberg Kravis Roberts (KKR), Texas Pacific Group, and Goldman Sachs Capital Partners (GS).*

waste for the recovery of high-purity REEs. In addition to the REEs, several of these new technologies can generate other byproducts with commercial value to enhance its economic viability, such as marketable cement substitutes that have been stripped of their most environmentally hazardous substances.

Photo: Pollution from acid mine drainage. Source: C&EN

One pilot program, organized by the University of Kentucky, is targeting a daily production of 500 grams of valuable REEs from a single small-scale processing platform. It is expected that a larger, commercial-scale plant will expand operations by late 2020 and will thus provide an economic boon to the companies and communities that have coped with this troublesome environmental challenge.

Researchers are also successfully creating extraction and separation technologies focused on recovering REEs from acid water, aka acid mine drainage, which flows from coal mines containing high levels of pyrite and iron sulfide. These are the chemicals that prior to the 1970s drained from coal mines polluting many streams and rivers. Left untreated acid mine drainage contaminates drinking water, harms aquatic organisms, and corrodes water-related municipal infrastructure. In today's world mining companies are required to treat acid mine drainage before it can be released into public waterways. In addition, many municipalities are now having to treat acid mine drainage from many abandoned mines at great expense.

The process to treat acid mine drainage involves neutralizing water flowing out of the mines with lime or another alkaline agent. This process creates tons of sludge containing a variety of minerals and refuse chemicals. The sludge is then typically dried in open air retaining ponds or large containers that are then stored in underground sites. This is a costly process that represents about half of the pollution control costs. Interestingly, in the 1990s data from the U.S. Geological Survey showed that REEs were present in acid mine drainage but not in the water itself.

Researchers from West Virginia University (WVU) identified this data and discovered that the sludge created in the treatment process actually contained significant quantities of REEs. In fact, on average, the

U.S. States Power Generation Dependency: Top Ten by Percentage of Mix

Rank	Coal		Renewables	
1	West Virginia	95.6%	Oregon	45%
2	Kentucky	92.0%	Washington	44%
3	Wyoming	87.3%	Maine	36%
4	Indiana	84.5%	South Dakota	35%
5	Missouri	82.4%	Montana	31%
6	Utah	76.2%	Iowa	28%
7	North Dakota	75.1%	Idaho	27%
8	Mississippi	66.8%	Vermont	25%
9	Nebraska	63.2%	New Hampshire	19%
10	Wisconsin	61.3%	Nebraska	19%

Source: U.S. News and World Atlas

sludge contained 2,600 times as much of REEs as raw acid mine drainage. Because of this promising discovery the WVU researchers developed an environmentally friendly leaching process, which produced enriched solid materials from the sludge that contain more than 90%, or 990,000 ppm, of REEs. Based on these findings researchers have built a prototype treatment facility that could open a whole new world of opportunity for coal country by creating economic value in old mine waste and returning clean water to the hardest hit communities.

The creation of REE recovery and mine drainage treatment jobs in Appalachia would be important to the well-being of many coal blighted communities. To this point it's worth noting that recent WVU research surveys of accessible acid mine drainage sites (76) around the northern and central Appalachian coal basins found they contained 1,421 metric tons of REEs in a form that would be recoverable with new environmentally friendly leaching processes. Based on recent REE commodity market prices the value of those recoverable REEs was estimated to be a meaningful $337 million.[10]

Given the strategic importance of REEs to our economy and national security, it is fortunate that the DOE, and the many research teams it has funded, are identifying environmentally friendly methods to recover them. These high-purity, marketable levels of REEs will support our creation of high tech and clean energy products (ironically, from a variety of "dirty" coal combustion byproducts). The developers of these new sustainable waste recovery processes are working to prove commercial viability on larger scales; however, it has yet to be determined which of the many methods will be ready by 2020 to satisfy our anticipated import declines as well as meet our ever-burgeoning manufacturing demand for REEs.

Footnotes

1. A Review of the Occurrence and Promising Recovery Methods of Rare Earth Elements from Coal and Coal By-Products. Wencai Zhang, Mohammad Rezaee, Abhijit Bhagavatula, Yonggai Li, John Groppo & Rick Honaker; Pages 295-330 | Received 09 Feb 2015, Accepted 19 Mar 2015, Accepted author version posted online: 08 Jul 2015, Published online: 08 Jul 2015

2. Rare Earth Elements: What are They? Who Has Them? Institute for Energy Research. July 27, 2016. https://www.instituteforenergyresearch.org/renewable/rare-earth-elements/

3. Consumption of Rare Earths in the United States from 2013 to 2017. https://www.statista.com/statistics/616726/consumption-of-rare-earths-in-the-united-states/

4. Where to Find Rare Earth Elements. PBS. April 2, 2013. http://www.pbs.org/wgbh/nova/next/physics/rare-earth-elements-in-cell-phones/

5. Battle Heats Up for Control of Sole U.S. Rare Earth Mine. Financial Times. May 29, 2017. https://www.ft.com/content/2c3dea3e-3fc2-1 1e7-82b6-896b95f30f58

6. Sexy Metal: The Missing Element in the Korean Puzzle. Asia Times. June 20. 2018. http://www.atimes.com/article/sexy-metal-the-missing-element-in-the-korean-puzzle/?cn-reloaded=1

7. Global Potential of Rare Earth Resources and Rare Earth Demand from Clean Technologies. Baolu Zhou, Zhongxue Li * and Congcong Chen. School of Civil and Resources Engineering, University of Science and Technology Beijing, Beijing 100083, China; blz1985@163.com (B.Z.); chencong0428@126.com (C.C.) * Correspondence: zxli@ustb.edu.cn; Tel.: +86-010-6233-3454 Received: 10 August 2017; Accepted: 18 October 2017; Published: 25 October 2017

8. Rare Earth Elements. National Energy Technology Laboratory. 2018 Project Portfolio. https://www.netl.doe.gov/File%20Library/Research/Coal/cross-cutting%20research/2018-REE-Portfolio.pdf

9. National Lab Works to Extract Rare Earth Elements from Coal. R&D Magazine. September 19, 2017. https://www.rdmag.com/article/2017/09/national-lab-works-extract-rare-earth-elements-coal

10. Rare-earth Recovery. C&EN Washington. July 9, 2018. https://cdn-pubs.acs.org/doi/10.1021/cen-09628-cover

3139-NLD-1/24/2020