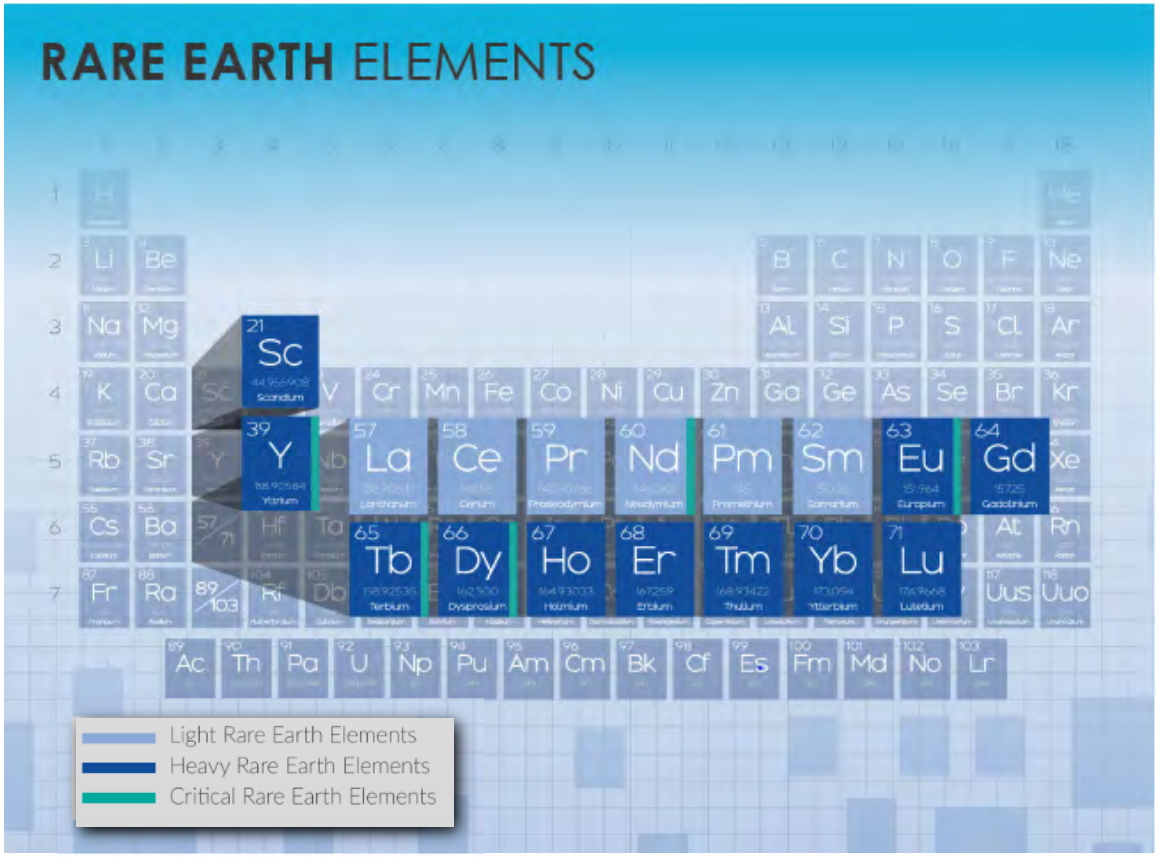
NATIONAL ENERGY TECHNOLOGY LABORATORY



2017 PROJECT PORTFOLIO

U.S. DEPARTMENT OF ENERGY | the ENERGY lab
National Energy Technology Laboratory

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Introduction

BACKGROUND

The U.S. Department of Energy (DOE) Office of Fossil Energy conducts programs to ensure the availability of ultraclean (near-zero emissions), abundant, low-cost domestic energy from coal. These efforts are designed to fuel economic prosperity, strengthen energy independence, and enhance environmental quality. As the Office of Fossil Energy's research laboratory, the National Energy Technology Laboratory (NETL) is engaged in research, development, and demonstration (RD&D) activities to create technology and technology-based policy options for public benefit.

As part of its RD&D technology portfolio, NETL has initiated the Rare Earth Elements (REEs) from Coal and Coal By-Products RD&D Program, which focuses on developing REE separation and recovery technologies, addressing the current global REE separations market and process economics, and demonstrating environmentally benign REE separation processing capabilities. The quantities of REEs in our nation's vast coal resources offer the potential to reduce U.S. dependence on foreign sources for these critical materials, and to create new industries in regions where coal plays an important economic role.

PROGRAM OBJECTIVES

The overall objectives of NETL's REE program are to demonstrate the techno-economic feasibility and performance of existing commercial or newly developed REE separation technologies. These technologies are focused on separating and recovering REEs from coal and coal by-products containing a minimum of 300 ppm total REEs, and concentrating the REEs to levels greater than or equal to 2 percent by weight, tentatively producing 90 to 99.99 percent high-purity, salable, individual rare earth metal oxides by the year 2020. These objectives will be accomplished through laboratory REE separation projects and demonstration of concept feasibility at bench-scale through pilot-scale facilities and integrated processing systems. Ultimately, these efforts will ready REE separations technology for commercial deployment. Key success factors for this program include co-production of materials and critical elements, successful demonstration of environmentally benign processing, and competitive economics.

KEY TECHNOLOGY AREAS

The REE Program consists of three key technology areas: Enabling Technologies, Separations Technologies, and Process System Development. Figure 1 on page 7 shows how the key technology areas relate to the program efforts.

1. Enabling Technologies include resource identification, sampling, and characterization; techno-economic analysis; and field/process sensor development.

Significant progress in locating field sites and assessing the composition of potential coal and coal by-product materials containing REEs has been made. Efforts continue to focus on identifying the best source of materials to support future commercial REE production. Chemical and physical characterization efforts to determine REE elemental concentrations and phase compositions in coal and coal by-product resources are essential for developing viable REE separation processes.

Techno-economic analyses are being conducted to evaluate the international REE market demand and to assess the economics of commercially producing REEs from conventional separation as well as potentially new and advanced transformational separation processes. A preliminary high-level REE jobs analysis is being developed that includes an estimation of the economic impacts of constructing and operating an REE separations and processing facility (or facilities) in the United States.

Portable sensors for identifying promising REE coal-based resources in the field, as well as devices for determining REE concentrations in process separation flow streams, are being developed and evaluated. These technologies are tentatively scheduled to be field-tested at bench-scale separations test facilities and validated to commercial-ready status during use in pilot-scale demonstration projects. While significant progress has been made in identifying field site locations and assessing the composition of potential coal and coal by-product REE-containing materials, continued effort is essential to identify the "best" source of materials to support future commercial REE production. Chemical and physical characterization efforts addressing REE elemental concentrations and phase compositions in the coal and coal by-product resources are essential for developing viable REE separation processes.

2. Separations Technologies include utilization or modification of current commercial physical separation systems (i.e., beneficiation via size, density, froth flotation, magnetic, ultrasound), hydrometallurgy and solvent extraction/digestion processes, and pyrometallurgy techniques (i.e., electro-slag refining, acid roasting) to separate and concentrate REEs from coal-based resources such as coal, coal refuse, clay/sandstone over/under-burden materials, aqueous effluents, acid mine drainage sludge, and power generation ash. Advanced or new transformational REE separation concepts such as physical, chemical, electrical and thermal extraction, acid/base leaching, and ion exchange; reactive grinding, photochemical, ultrasonic-assisted, microwave-aided, photophoretic, plasma, and supercritical CO_2 separation; as well as advanced sorbents and membrane systems, are being considered to further enhance REE separation.

3. Process System Development, demonstration, and commercialization include validating the performance of bench- and pilot-scale technologies, as well as determining the economic feasibility of separating REEs from coal and coal-related resources containing a minimum of 300 ppm REEs and concentrating them to an initial pre-concentrate matrix of greater than or equal to 2 percent by weight, with further integration of additional extraction systems that could help generate high-purity, salable rare earth compounds (such as oxides and/or metals, carbonates, etc.).

Ultimately, domestic generation of high-purity REEs may lead to the production of REE-containing products in the United States, thus enhancing our national security and stimulating economic growth. Domestic REE generation is envisioned to advance U.S. on-shore manufacturing of REE-containing parts, equipment, and end-products such as wind turbines, magnets, automobile engines, cell phones, computers, and satellites. REE generation also supports other industry and technology needs for processes such as catalysis, development of alloys and high-temperature coatings, petroleum refining, development of batteries medical equipment, and defense among others. In addition, an available domestic supply of REEs may lead to commercialization of new and advanced materials and equipment.

Additional information can be found on NETL's Rare Earth Elements web page and energy data eXchange database.

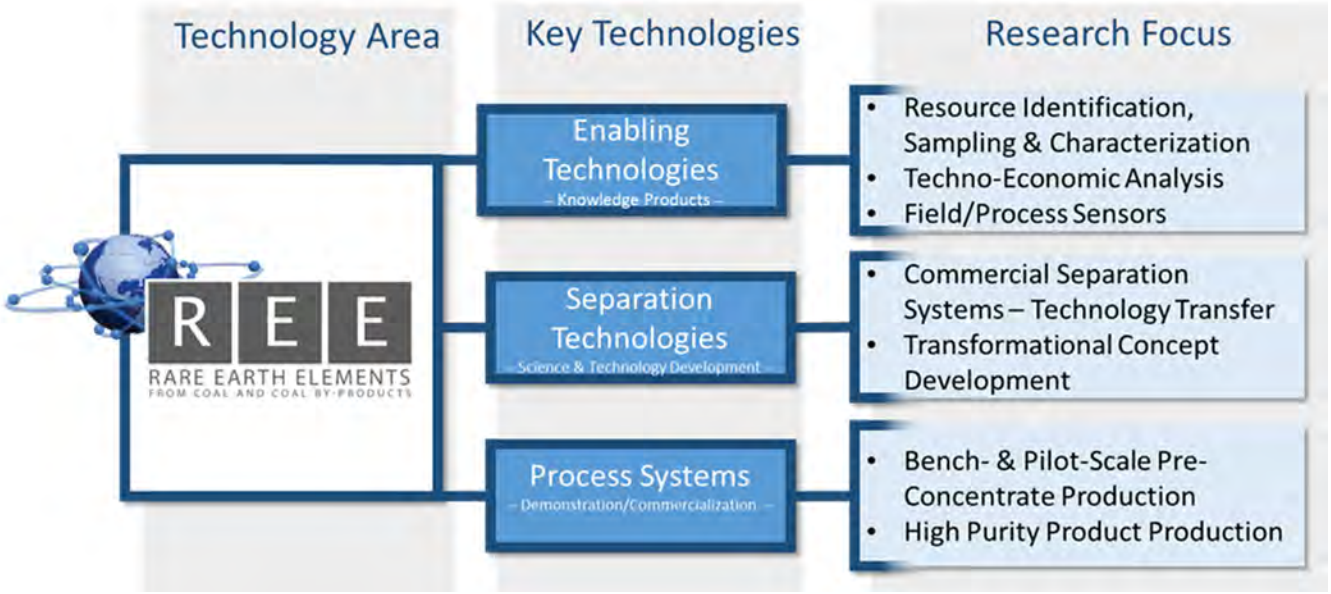


Figure 1. Key Technology process map for RD&D focus efforts.

Rare Earth Elements – Pilot-Scale Test Facilities

High Yield and Economical Production of Rare Earth Elements from Coal Ash

Technology Partner: Physical Sciences, Inc.

Award Number: FE0027167

Project Duration: 3/1/2016 – 8/31/2017

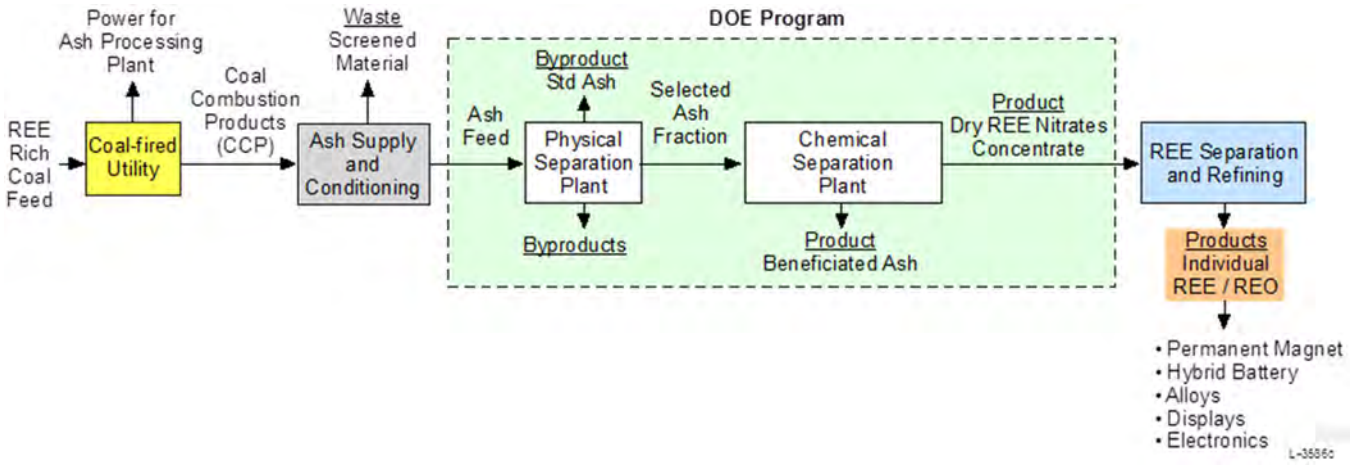
Total Project Value: $1,250,291

Key Technology Area: Separation Technologies

Project Partners: University of Kentucky and Equinox Chemicals LLC

Physical Sciences Inc. will build on previous work to optimize the enrichment/recovery process stages and build and demonstrate the REE extraction process component in a continuous mode. In Phase I, the project team will design a pilot-scale plant for economically producing high-yield rare earth element concentrates and commercially viable co-products from coal ash using environmentally safe physical and chemical enrichment processes. The team will help optimize individual process stages, unit operations, and process parameters. In addition, the team will develop a detailed techno-economic model of the continuous process—including ash feedstock and reagent inputs, REE concentrate, and co-product outputs of commercial value—that considers capital and operating expenses.

If the project advances to Phase 2, the pilot-scale circuit will be designed to process a dry ash throughput of 1–5 tons per day of rare earth mineral concentrates with purities of at least 2 percent REEs by weight, with the goal of producing dry mixtures of nitrates with REE concentrations above a 5 percent and, preferably, greater than 10 percent by weight threshold. The proposed work, if successful, will demonstrate an environmentally benign and economically feasible method of providing a reliable and cost-competitive domestic source of rare earth elements and water recovery.



Schematic of Physical Sciences, Inc. Separation Processes and Products of the Ash Processing Plant

Plasma Arc Gasification Based Rare Earth Element Recovery from Coal Fly Ash

Technology Partner: Southern Research Institute

Award Number: FE0027102

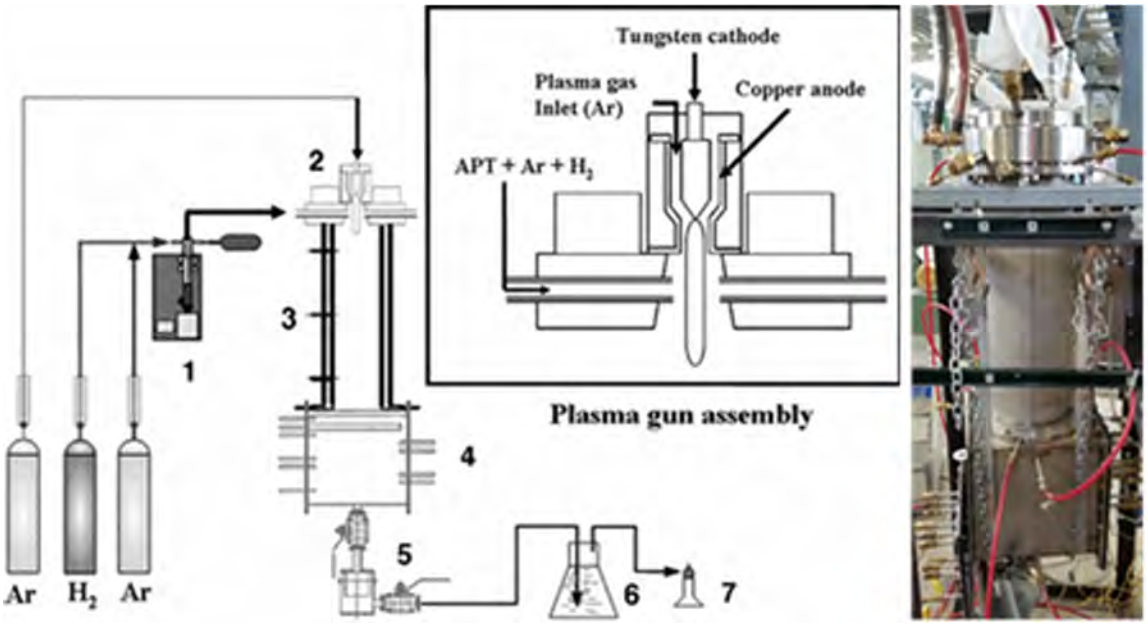
Project Duration: 3/1/2016 – 8/31/2017

Total Project Value: $1,289,000

Key Technology Area: Separation Technologies

Project Partners: ArcSec Technologies, Inc. and Reaction Engineering International

Southern Research Institute and its project team will evaluate the feasibility of an innovative technology designed to concentrate rare earth elements (REEs) from coal fly ash (CFA). Project partner ArcSec has developed an alternating current graphite electrode plasma arc technology for CFA vitrification that will be utilized to concentrate REEs in fly ash. The technology has two options: a plasma smelting process and a plasma smelting process plus volatilization and sequential condensation. In option one the molten metal is collected and then tapped for further processing to concentrate the REEs. In option two, the molten metal pool is vaporized to apply sequential condensation to further concentrate the REEs into groups. The Phase 1 work will include sampling and characterizing CFA from eight coal-fired power plants that utilize eastern bituminous coal (especially eastern Kentucky coal) for REE content and conducting a comprehensive feasibility study for the project. The team will conduct bench-scale experiments utilizing a plasma furnace to evaluate the fate of REEs in the space between the top slag layer and the bottom molten metal layer. Potential enhancements to promote the partitioning of REEs to the molten metal layer will be evaluated, and the plasma volatilization of the molten metal layer will be modeled, including sequential condensation of enriched REE material from the gas.



Southern Research Institute Plasma Reactor System.

Economically Viable and Environmentally Benign High Performance Technology to Recover REE from Coal By-Products

Technology Partner: Tusaar Corporation

Award Number: FE0027155

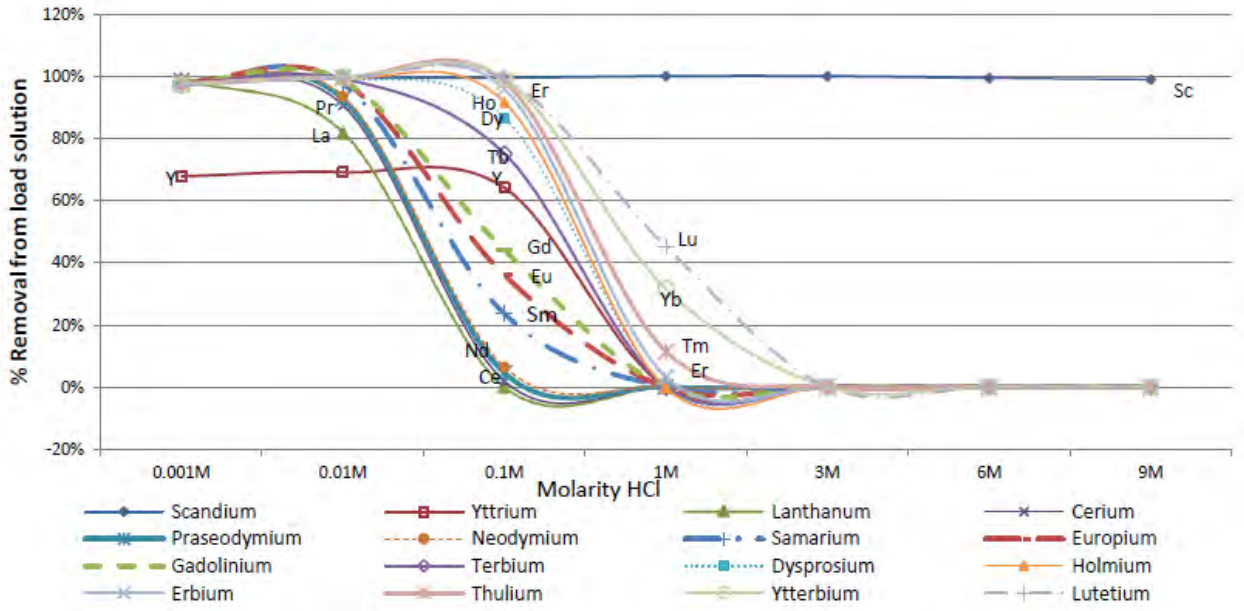
Project Duration: 3/1/2016 – 8/30/2017

Total Project Value: $1,230,546

Key Technology Area: Separation Technologies

Project Partners: University of Wyoming, Veolia Waste Management and Quicksilver Scientific

In this Phase I project, Tusaar will use proprietary technology involving leaching processes and metal sorption media to develop a bench-scale rare earth element (REE) extraction process able to handle approximately one kilogram batches of coal by-product material and deliver a product that meets or exceeds DOE requirements. Tusaar has developed novel and environmentally friendly media to sequester over 45 different metals from aqueous streams. At the project end, the flowsheet delivered will contain the following processes: (1) possible beneficiation of coal product source material, (2) coal product leaching, (3) radioactive material separation, (4) REE sequestration and recovery, and (5) waste water treatment for heavy metal removal. Current technology can digest fly ash to a recovery of 10 to 50 percent of the REEs. These percentages are expected to increase with further process development. Once in solution, Tusaar's media will enable 80+ percent recovery of these elements. Successful execution of this project should help reduce U.S. dependence on foreign nations for rare earth metals. This project will also provide a radioactive material separation process to further refine the fly ash for much-needed additional beneficial uses. The separation of uranium and thorium from the fly ash will enable its use in applications where it currently cannot be utilized.



Pilot-Scale Testing of an Integrated Circuit for the Extraction of Rare Earth Minerals and Elements from Coal and Coal By-Products Using Advanced Separation Technologies

Technology Partner: University of Kentucky Research Foundation

Award Number: FE0027035

Project Duration: 3/1/2016 – 8/31/2017

Total Project Value: $1,320,009

Key Technology Area: Separation Technologies

Project Partners: Virginia Tech, West Virginia University, Eriez Manufacturing, Blackhawk Mining, and BRC Refining

The University of Kentucky Research Foundation is proposing innovative separation technologies, including an advanced froth flotation process and a novel hydrophobic-hydrophilic separation (HHS) process. The team proposes to use the HHS process to recover coal based on its demonstrated ability to produce low-ash, low-moisture products from ultrafine refuse.

The reject stream from the HHS process will be conditioned with a hydrophobizing agent and subsequently treated by flotation and/or the HHS process to recover rare earth metals (REMs). The reject stream, consisting mostly of clay minerals and fine clay rocks, will be treated with ammonium sulfate to extract rare earth ions from the surface of the clay via an ion-exchange mechanism. The extracted ions will be precipitated before or after solvent extraction and the precipitates combined with the REM concentrate to obtain a final concentrate containing 2 percent by weight REEs. The proposed pilot-scale circuit is expected to have a dry solids feed capacity of one-quarter ton per hour and produce from 5 to 7 pounds per hour of rare earth mineral concentrates with purity levels of at least 2 percent by weight REEs.

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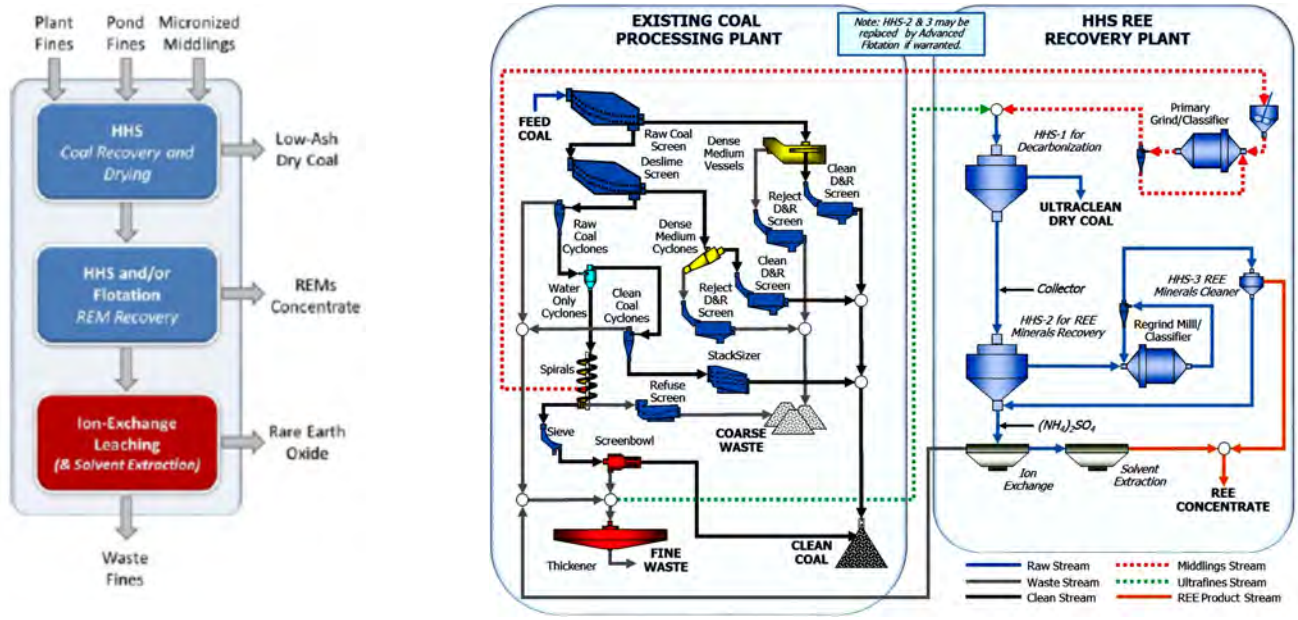


The University of Kentucky Research Foundation Schematic of an Integrated Separation/Recovery Circuit and an Example Implementation Strategy within a Coal Processing Plant

Rare Earth Elements – Bench-Scale Test Facilities

Recovery of Rare Earth Elements (REEs) From Coal Ash with a Closed Loop Leaching Process

Technology Partner: Battelle Memorial Institute

Award Number: FE0027012

Project Duration: 3/1/2016 – 8/31/2017

Total Project Value: $900,014

Key Technology Area: Separation Technologies

Project Partners: Ohio Coal Development Office, the Pennsylvania Bureau of Topographic and Geologic Survey, and the West Virginia Geological and Economic Survey

The objective of this project is to validate the economic viability of recovering rare earth elements (REEs) from coal and coal by-products using Battelle's patented closed-loop Acid Digestion Process (ADP). Specifically, the project team will sample and characterize potential REE feedstocks from three sources: ash from coal power plants, low temperature combustion ash, and residual ash from Battelle's coal liquefaction process. The project will attempt to demonstrate the economic viability of Battelle's patented closed-loop ADP to extract REEs by identifying a promising ash source to produce a pozzolan material and to model/validate the economics for commercial-scale systems based on bench-scale operations. Battelle's ADP has the potential to concentrate the REEs in coal ash to a product of greater than 2 percent REEs by mass, while recovering more than 90 percent of the nitric acid used and improving the pozzolanic activity of the ash by-product. The proposed technology offers a breakthrough for the economic recovery of REEs from coal products on several levels. These include limiting waste streams and optimizing recycling opportunities; producing a concentrated solid form rare earth oxide for easy delivery to a purification facility; and, finally, identifying coal sources containing greater amounts of REEs, thus improving the techno-economics of the operation.

Battelle's ADP Reactor with Acid Recirculation Tank

Novel Membrane & Electrodeposition-Based Separation & Recovery of Rare Earth Elements from Coal Combustion Residues

Technology Partner: Duke University

Award Number: FE0026952

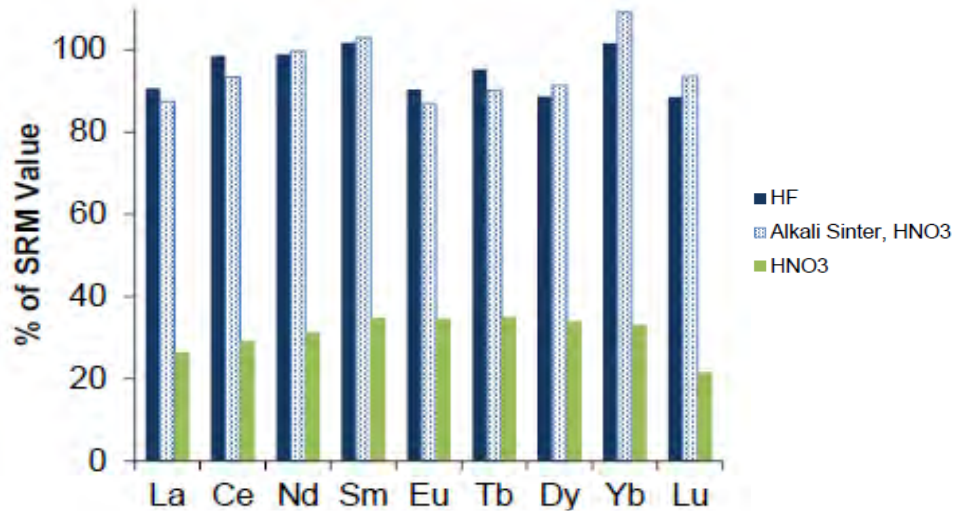
Project Duration: 3/1/2016 – 8/31/2017

Total Project Value: $902,595

Key Technology Area: Separation Technologies

Project Partners: University of Kentucky, Yale University, Research Triangle Institute

NETL is partnering with Duke University to develop a hydrometallurgical-based technology to extract and concentrate rare earth elements (REEs) from coal fly ash and other coal combustion residues (CCRs). The recovered REEs leached from CCRs will be further separated from the leachates by membrane filtration and electrochemical deposition. Specifically, this project will identify and characterize a representative selection of CCR samples as candidates for REE recovery; evaluate the efficiency of hydrometallurgical acid extraction techniques as a function of major CCR characteristics and extraction conditions; and optimize membrane filtration and carbon nanotube-enabled electrochemical deposition techniques for concentrating REEs from CCR extracts. The project team will also perform a technical and economic feasibility study of the proposed separation methods and develop an implementation plan for a bench-scale system. This project will develop technologies to recover REEs from CCR that rival the production tonnage and quality from an existing operational mine. In addition, the project will utilize advanced separation technologies to enable environmentally benign processes relative to conventional approaches that use hazardous chemicals for separating REEs, and will achieve at least 75 percent REE recovery from ash.



Duke University's Percent Recovery of Certain Elements*

**Relative to the Published Reference Concentration Values for the NIST Fly Ash Standard Reference Material (SRM 1633c). REEs were extracted using 3 different acid leaching methods*

Investigation of Rare Earth Element Extraction from North Dakota Coal-Related Feedstocks

Technology Partner: University of North Dakota

Award Number: FE0027006

Project Duration: 3/1/2016 – 8/31/2017

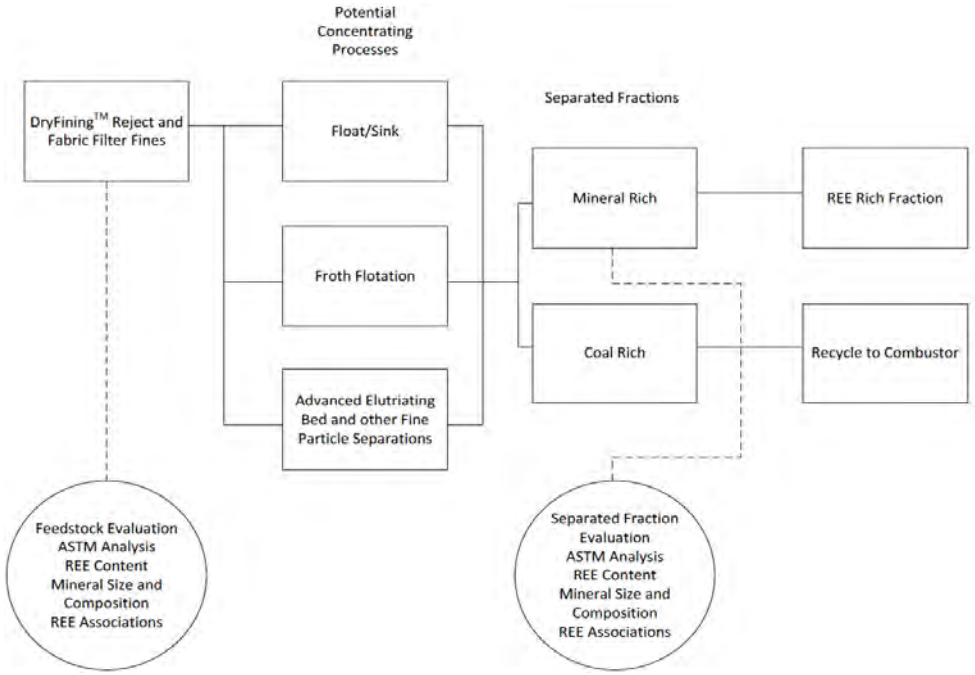
Total Project Value: $936,847

Key Technology Area: Separation Technologies

Project Partners: Energy Barr Engineering, Pacific Northwest National Laboratory, North American Coal Company, Great River Energy, North Dakota Industrial Commission and Lignite Energy Council

NETL is partnering with University of North Dakota to develop a high performance, economically viable, and environmentally benign technology to recover rare earth elements (REEs) from North Dakota lignite and associated sediments from a lignite drying system reject stream. Specifically, this Phase 1 project will develop sampling protocols for and obtain statistically representative samples of lignite, associated roof and floor materials, and coal drying reject stream; determine the abundance and modes of occurrence of rare earth elements and relevant material properties; determine the potential to concentrate REEs through mineral processing methods that include gravity separation, fine coal cleaning technologies, and novel separation technologies based on size and density of REE-bearing components in the samples; identify the optimum methods to separate and concentrate the REEs to two percent by weight; perform a technical and economic analysis of the optimum methods; and design a bench-scale system (5 to 10 kg/hour throughput) to concentrate REEs.

If this project advances to Phase 2: Development and Testing, the project team would develop an environmentally benign and technically and economically feasible method to provide a reliable and cost-competitive domestic source of rare earth elements at 2 percent by weight purity for a multitude of highly important end-uses. Additional markets could provide tremendous economic benefit to North Dakota, and the region and the nation would benefit from near-zero pollution power generation.



A Pollution-Prevention and Economically Viable Technology for Separation of Rare Earth Elements (REEs) from Powder River Basin (PRB) Coal Ashes

Technology Partner: University of Wyoming

Award Number: FE0027069

Project Duration: 3/1/2016 – 8/31/2017

Total Project Value: $820,596

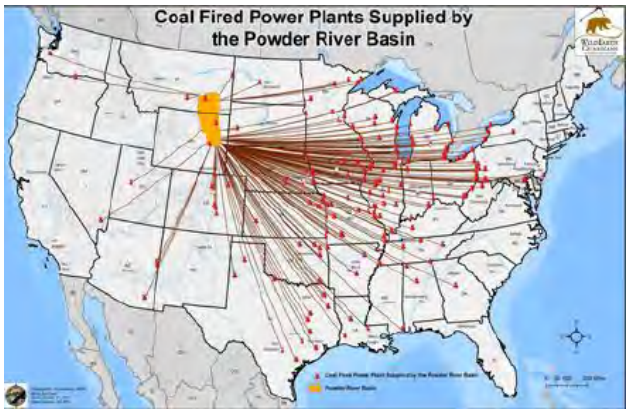
Key Technology Area: Separation Technologies

Project Partners: Rochester Institute of Technology and West Virginia University

NETL is partnering with the University of Wyoming to develop a new cost-effective pollution-avoidance/prevention technology with enhanced performance for recovering high-value rare earth elements (REEs) from coal ash. Specifically, the project team will sample and characterize coal ash and complete a feasibility study of the proposed technology for REE recovery from Powder River Basin coal ashes.

In addition, the team will obtain 2 percent by weight rare earth containing ferric oxy-hydroxide (FeOOH) via three steps: leaching REE from coal ash with CO_2 and $FeCl_3$ under supercritical conditions and assisted with ultrasound; separating REEs loading FeOOH flocs from the leaching mixture by using the FeOOH flocs themselves; and de-watering FeOOH for obtaining at least 2 percent by weight REEs containing FeOOH solid.

This project will advance separation theory and technology development, generate near-zero pollution, achieve at least 90 percent REE recovery from ash, and achieve up to 50 percent energy and 30 percent cost reductions compared to conventional REE recovery technologies.



Recovery of Rare Earth Elements (REEs) From Coal Mine Drainage

Technology Partner: West Virginia University

Award Number: FE0026927

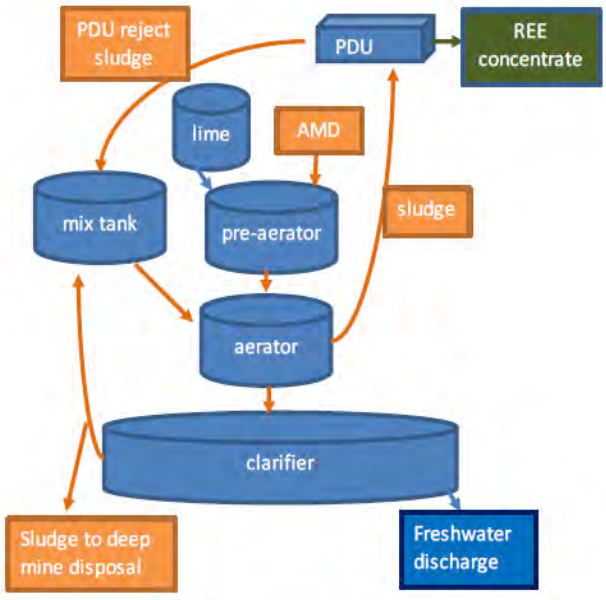
Project Duration: 3/1/2016 – 8/31/2017

Total Project Value: $950,534

Key Technology Area: Separation Technologies

Project Partners: Mepco Inc., Rosebud LLC., and West Virginia Department of Environmental Protection

West Virginia University (WVU) and its partners will develop a cost-effective and environmentally benign process to treat and recover rare earth elements (REEs) from sludges generated during treatment of acid mine drainage (AMD) from coal mines. This project will take advantage of autogenous processes that occur in coal mines and associated tailings that liberate and then concentrate REEs. Studies have shown elevated concentrations of REEs in low-pH effluent to AMD treatment systems that were nearly absent in the discharge water. This indicates that REEs precipitate with more plentiful transition metals in the AMD sludge, most likely as hydroxides. AMD sludge REE extraction will initially consist of acid dissolution followed by two complementary refining options: selective electro-coagulation and solvent extraction/stripping. Both options will be evaluated for efficiency, concentration, waste stream liabilities, and cost. The benefits of this project include utilizing AMD sludge as a domestic source of REEs in concentrations and volumes sufficient to alleviate our nation's reliance on foreign supply. Estimates based on the volume of AMD generated in Pennsylvania and West Virginia suggest that their AMD sludges represent about 45,000 tons per year of REEs—about 25 percent of global REE demand. The WVU REE prediction model will help determine REE production at a given site as a function of concentration and discharge volume. The resulting load calculation will determine the mass of REEs produced annually at a given site.



Schematic of the West Virginia University AMD Treatment System and the Process Recovery Development Unit (PDU)

Rare Earth Elements – Research & Innovation Center

Rare Earth Elements from Coal and Coal By-Products

Technology Partner: National Energy Technology Laboratory – Research & Innovation Center (RIC)

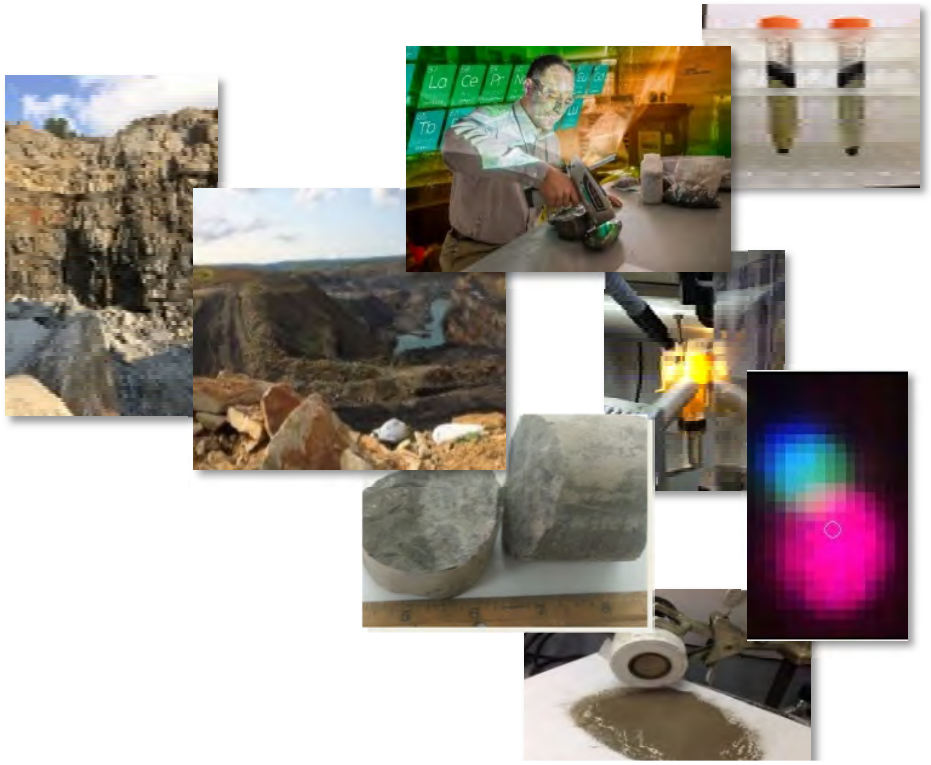
Award Number: FWP-RIC REE FY2016-2020

Project Duration: 10/01/2015 – 9/30/2020

Total Project Value: $34,768,734

Key Technology Area: Enabling Technologies, Separations Technologies, Process Systems

The National Energy Technology Laboratory's (NETL) Research & Innovation Center (RIC) is conducting a collaborative Field Work Proposal (FWP) to develop technologies to recover rare earth elements (REEs) from coal and coal by-products. The purpose of this FWP is to demonstrate the feasibility of advanced technologies to improve the economics, reduce the environmental impact, and produce domestic coal-based REEs. This NETL project focuses on identifying and characterizing domestic field site REE coal-based resources, developing in-field and in-situ process advanced REE sensors, and addressing the potential use of advanced characterization techniques to identify the phase composition of the REE-containing minerals. NETL is also developing novel, advanced, transformational REE separation techniques and processes (i.e., physical and mechanical separation, chemical separation, thermal separation, and advanced sorbent development) to separate REEs from coal-based resources containing a minimum of 300 ppm total REEs. A bench-scale (near pilot-scale) REE separations and processing facility is being designed.



NETL RIC Technology Development Areas

Rare Earth Elements – Identification and Characterization

Tetra Tech, Inc. - Rare Earth Element Identification and Characterization of Coal and Coal By-Products Containing High Rare Earth Element Concentrations

Technology Partner: Tetra Tech, Inc.
Award Number: FE0026448
Project Duration: 10/1/2016 – 4/30/2018
Total Project Value: $373,300
Key Technology Area: Enabling Technologies

NETL is partnering with Tetra Tech, Inc. to identify, locate, field sample, and chemically analyze U.S. domestic coal and coal by-product solid and/or liquid materials that contain high rare earth element (REE) concentrations (i.e., ≥300 ppm total REEs). This project supports NETL's REE Program by identifying U.S. coal-based resources for developing technologies to separate and recover rare earth elements for use in producing commercial products and national defense equipment.

Tetra Tech, Inc. - Rare Earth Element Identification and Characterization of Coal and Coal By-Products Containing High Rare Earth Element Concentrations

Technology Partner: Tetra Tech, Inc.
Award Number: FE0026929
Project Duration: 10/1/2016 – 4/30/2018
Total Project Value: $376,200
Key Technology Area: Enabling Technologies

NETL is partnering with Tetra Tech, Inc. to identify, locate, field sample, and chemically analyze U.S. domestic coal and coal by-product solid and/or liquid materials that contain high rare earth element (REE) concentrations (i.e., ≥300 ppm total REEs). This project supports NETL's REE Program by identifying U.S. coal-based resources for developing technologies to separate and recover rare earth elements for use in producing commercial products and national defense equipment.

University of Kentucky - Rare Earth Element Identification and Characterization of Coal and Coal By-Products Containing High Rare Earth Element Concentrations

Technology Partner: University of Kentucky
Award Number: FE0026443
Project Duration: 10/1/2016 – 4/30/2018
Total Project Value: $400,000
Key Technology Area: Enabling Technologies

NETL is partnering with the University of Kentucky to identify, locate, field sample, and chemically analyze U.S. domestic coal and coal by-product solid and/or liquid materials that contain high rare earth element (REE) concentrations (i.e., ≥300 ppm total REEs). This project supports NETL's REE Program by identifying U.S. coal-based

resources for developing technologies to separate and recover rare earth elements for use in producing commercial products and national defense equipment.

West Virginia University - Rare Earth Element Identification and Characterization of Coal and Coal By-Products Containing High Rare Earth Element Concentrations

Technology Partner: West Virginia University
Award Number: FE0026444
Project Duration: 10/1/2016 – 4/30/2018
Total Project Value: $400,000
Key Technology Area: Enabling Technologies

NETL is partnering with West Virginia University to identify, locate, field sample, and chemically analyze U.S. domestic coal and coal by-product solid and/or liquid materials that contain high rare earth element (REE) concentrations (i.e., ≥300 ppm total REEs). This project supports NETL's REE Program by identifying U.S. coal-based resources for developing technologies to separate and recover rare earth elements for use in producing commercial products and national defense equipment.

XLight Corporation - Rare Earth Element Identification and Characterization of Coal and Coal By-Products Containing High Rare Earth Element Concentrations

Technology Partner: XLight Corporation
Award Number: FE0026527
Project Duration: 10/1/2016 – 4/30/2018
Total Project Value: $214,795
Key Technology Area: Enabling Technologies

NETL is partnering with XLight Corporation to identify, locate, field sample, and chemically analyze U.S. domestic coal and coal by-product solid and/or liquid materials that contain high rare earth element (REE) concentrations (i.e., ≥300 ppm total REEs). This project supports NETL's REE Program by identifying U.S. coal-based resources for developing technologies to separate and recover rare earth elements for use in producing commercial products and national defense equipment.

Abbreviations

ADP ..... Acid Digestion Process

AMD ..... Acid Mine Drainage

CFA ..... Coal Fly Ash

CCR ..... Coal Combustion Residue

DOE ..... Department of Energy

FeOOH ..... Ferric Oxy-Hydroxide

FWP ..... Field Work Proposal

HHS ..... Hydrophobic-Hydrophilic Separation

HNO_3 ..... Nitric Acid

NETL ..... National Energy Technology Laboratory

PRB ..... Powder River Basin

RD&D ..... Research, Development and Demonstration

REE ..... Rare Earth Element

REM ..... Rare Earth Metal

RIC ..... Research and Innovation Center

SRM ..... Standard Reference Material

U.S. ..... United States of America

WVU ..... West Virginia University

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