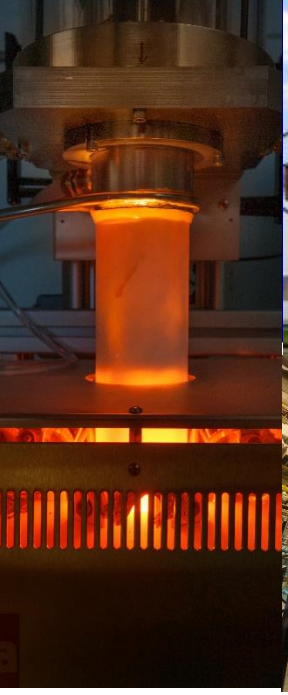
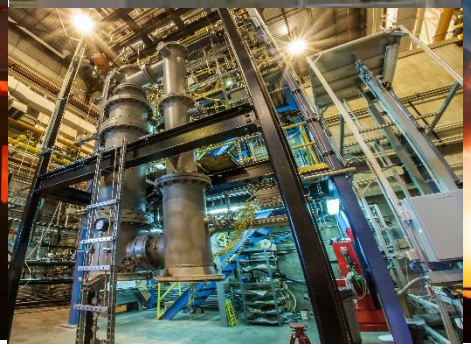
U.S. DEPARTMENT OF ENERGY | Office of Fossil Energy






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

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Title: Principal Investigator

Organization: Physical Sciences Inc.

Partners:
- Winner Water Services
- UK Center for Applied Energy Research

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PROJECT OBJECTIVES AND SUPPLY CHAIN

- Project Objective: Develop and demonstrate a pilot scale plant to economically produce salable rare earth element-rich concentrates from coal ash feedstock

- Impact and Support for Domestic REE/CM Supply Chain: Project develops a technology that will provide a *domestic* supply of REE-rich concentrate for downstream separation and refinement into individual REE, and for recovery of other critical elements.

- Heavy/Light REE or other CMs: Technology efficiently recovers critical HREE (Y, Dy, Tb), LREE (La, Pr, Nd, Gd), Sc and Al.

PROJECT DISCUSSION: KEY PERFORMANCE PARAMETERS

VG-2020-90

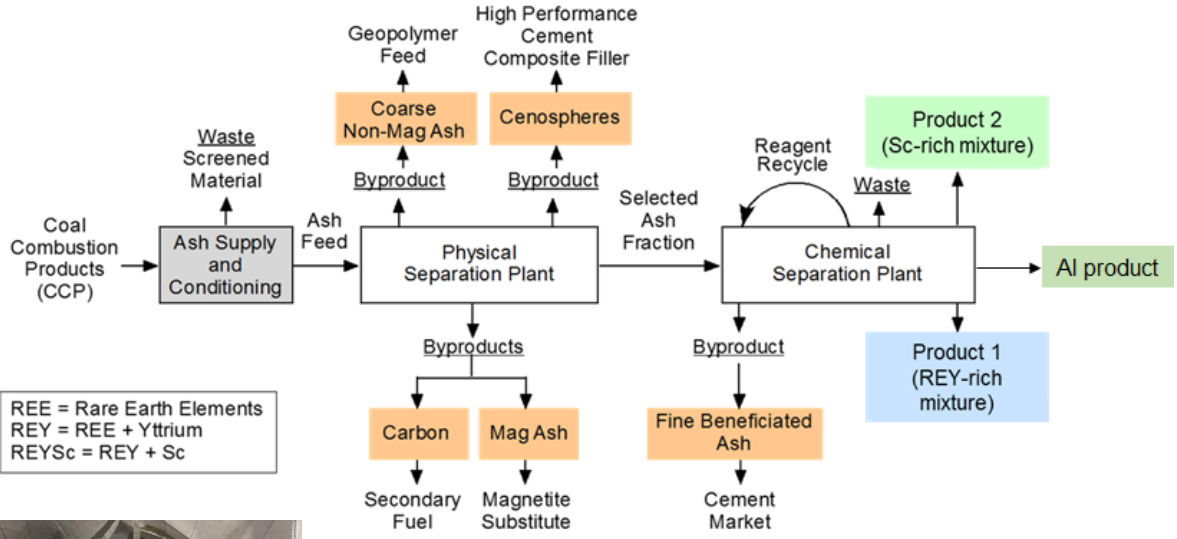
Performance Parameter		Threshold Value	Objective Value
Feedstock REY+Sc Content		>300 ppm	>500 ppm
Return on Investment		< 12 years	< 10 years
REY-enriched Product	Quantity (REY salt)	100 g	300 g
	REY-enriched Oxide Purity (total REY content - elemental basis)	*>85%*	*>90%*
Sc-enriched Product	Quantity (salt/oxide)	1 g	2 g
	Sc-enriched Oxide/Chloride Purity (REY content - elemental basis)	*>85%*	*>90%*
Aluminum Product	Quantity (oxide type material)	100 g	300 g
	Purity (Al content elemental basis)	*>50%*	*>68%*

Key Engineering Technologies Developed/Implemented:

- Physical processing of ash feed to obtain REYSc-rich, processable ash fraction
- Chemical separation of REE and Al from ash fraction
- Post-processing to separate REY-rich and Sc-rich concentrates

PROJECT DISCUSSION: PROCESS OVERVIEW

- Physical separation stage, followed by a chemical separation stage, followed by a post-processing stage
- Primary Products: REY-rich and Sc-rich concentrates, Al product
- Byproducts: cement substitute, cenospheres, secondary fuel



PROJECT DISCUSSION: CAER PHYSICAL PROCESSING PILOT PLANT

VG-2020-90

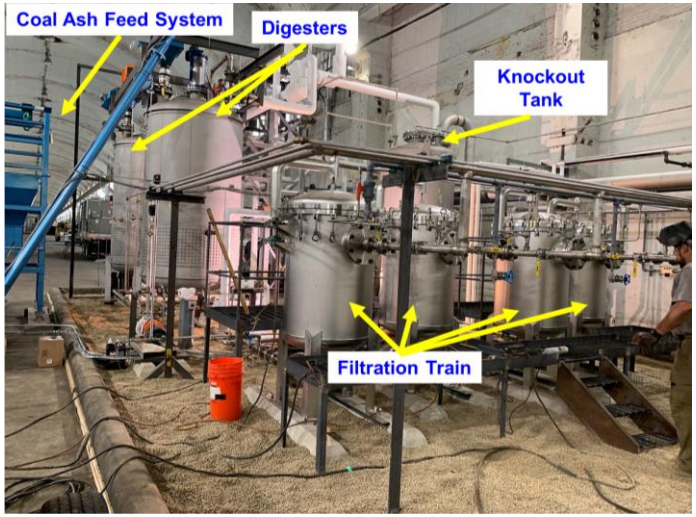
CAER physical pilot plant operational and >15 tons of coal ash processed to date; >50% yield for ash mass fraction for chemical processing

CAER: UK Center for Applied Energy Research

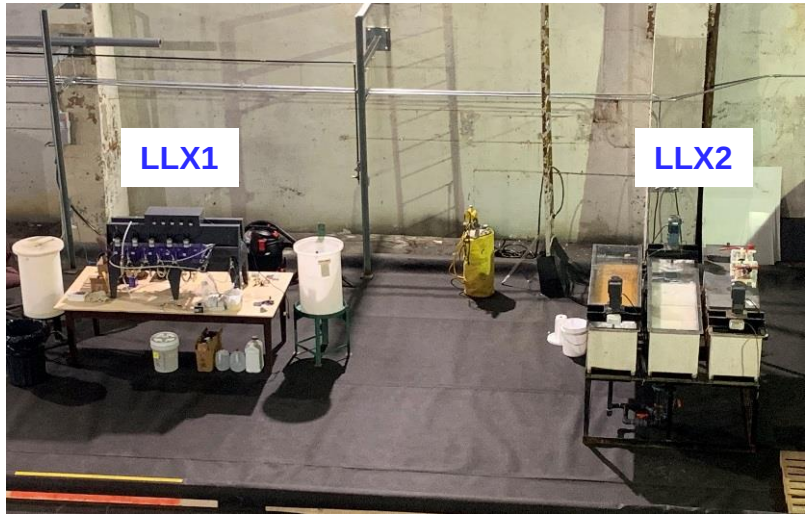
PROJECT DISCUSSION: WWS CHEMICAL PROCESSING PILOT PLANT

VG-2020-90

Plant Overview



Hot Side Operation



Cold Side Operation

WWS chemical pilot plant operational and >5 tons of coal ash processed to date; >20% yield for REYSc concentrate, >50% purity (elemental basis). Deliverable REYSc concentrate production ongoing

Chemical pilot to be modified to integrate post-processing, REO conversion, and Al production

Plant can process various pulverized feedstocks: coal ash, coal, refuse

LLX: Liquid-Liquid Extraction

ENVIRONMENTAL IMPACTS

- Major reagents are recycled at high efficiency, significantly reducing quantities of materials to be disposed and saving on project costs
- Industry-standard disposal methods used by commercial vendors
- Ash fractions from physical processing and digested ash from chemical processing are byproducts of commercial value
- Plant passed requirements for NEPA-CX environmental clearance

PERMITTING PROJECTS

VG-2020-90

- The pilot facility is a self-contained zero discharge facility. As such, no discharge permits are required.

- In order to locate the facility in a building, compliance with the Universal Building Code (UBC) and inspection was required.

- The building, having once served as a torpedo factory, was uniquely constructed and able to meet the UBC definitions for the designated work to be completed as part of the pilot program.

SCALING UP TECHNOLOGIES

- **Our process and equipment are designed to be modular and transportable.**
- **Pilot operations with capacities of 0.4/0.5 tons per day (tpd) utilize standard commercial equipment that lends itself to scaling up via sizing and/or multiple parallel modular units.**
- **A team experienced in FEED studies, A/E design, and commercial scale plant design and implementation has been assembled.**
- **Commercial scale REY, Sc, and Al production from coal ash possible in 2023-2024 timeframe**
- **Example of capacity, products and annual production at commercial scale**
    - Size: 1200 tpd ash physical processing/600 tpd chemical processing
    - REY product: 38.2 tons/year
    - Scandium product: 5.8 tons/year
    - Fine ash product (cement substitute): 186,000 tons/year
    - Physical processing byproducts: 166,000 tons/year