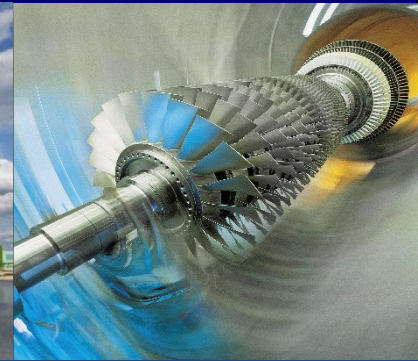
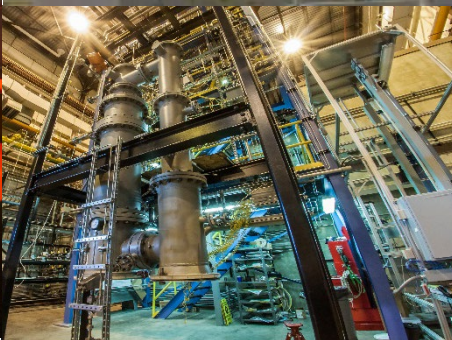
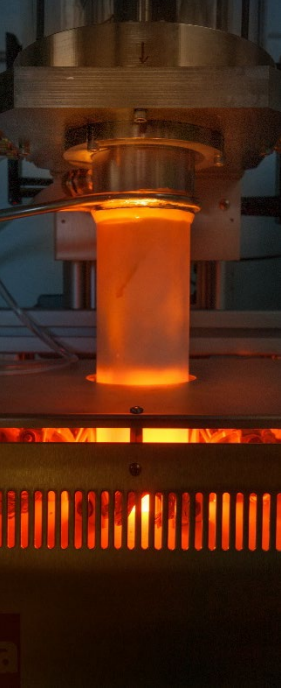




U.S. DEPARTMENT OF
ENERGY

Office of
Fossil Energy



Rare Earth Element Extraction and Concentration at Pilot Scale from North Dakota Coal-Related Feedstocks

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Rare Earth Salts
North Dakota Geologic Survey

August 2020

PROJECT OBJECTIVES AND SUPPLY CHAIN

- **Develop cost-effective, market-supported REE/CM from pre-combustion low rank coal resources**
 - Lignite (ND, MT, TX, LA)
 - Subbituminous (PRB in WY)
 - Feedstock contains high magnet and electronicS-needed REE and CM
 - Germanium, Gallium, REE for magnets
- **Confirm technology at the pilot scale – 500 kg/hr of cleaned coal feed**
 - ~100 grams/hr of REE concentrate production
- **Technology goal: Become new supplier of magnet REE and high-impact CM**



Bench-Scale System for REE Extraction



PROJECT DISCUSSION - OVERVIEW

- **Technology utilizes pre-combustion low rank coals for selective extraction of the REE and CM**
 - Low rank coal – younger, less-carbonized coal
 - Applicable to organic-associated sediments
 - REE/CM extractable at low acid concentrations
 - Able to tune extraction to specifically avoid certain impurities (U & Th)
- **Proven ability to extract up to 80-90% of contained REE**
 - Extractions of costly impurities below 15%
- **Generates a higher-value coal product for value-added use**
 - Activated Carbon – Water Purification (\$1/lb)
 - Humic Acid – Organic Fertilizer (\$1/lb)
 - Low-Fouling Combustion Fuel



Image courtesy of Lignite Energy Council, Jacobi Carbons



PROJECT DISCUSSION - PRODUCTS

- **Project Specific**

- Generate 20+ kg of mixed rare earth oxide (REO) concentrate at >65% purity
 - Enough for all REE-bearing components of an electric vehicle
- Most to be separated into individual REOs by Rare Earth Salts
- Coal to use is blend from active mines and high REE coal seam in ND

- **Technology Targets**

- Produce REO concentrates at >90% purity and identify US-based separations for refining
- Generate separated, purified GeO_2 and Ga_2O_3 streams for electronics use



Produced MREO Concentrate



ENVIRONMENTAL IMPACTS

- **Selective element extraction prevents significant radioactive material upcycling**
 - Uranium and Thorium often behave chemically as the REE
 - UND process specifically prevents most NORM leaching
 - Process sludges and wastewaters have very low NORM content
- **Utilizes small amounts of dilute acids at ambient conditions**
 - No high-temperature acid baking required for REE extraction
 - Extraction method is very water lean, <2:1 water/coal ratio usable for process



PERMITTING PROJECTS

- **Feedstocks sited from active mines are first goals**
 - No mine permits required
 - Take advantage of existing infrastructure, minimal transport
 - Must be distinct from mine
- **Future goal: new mines at high-grade resources**
 - Mine permitting required (up to 10 years)
- **Radioactivity (NORM)**
 - Minimal NORM extraction from coal reduces likelihood of placement with REE
 - Upgraded carbon product will retain this NORM
 - Regulation on coal vs REE vs “standard” may be challenging



Image courtesy of Lignite Energy Council



SCALING UP TECHNOLOGIES

- **Technological Scale-Up Risk**

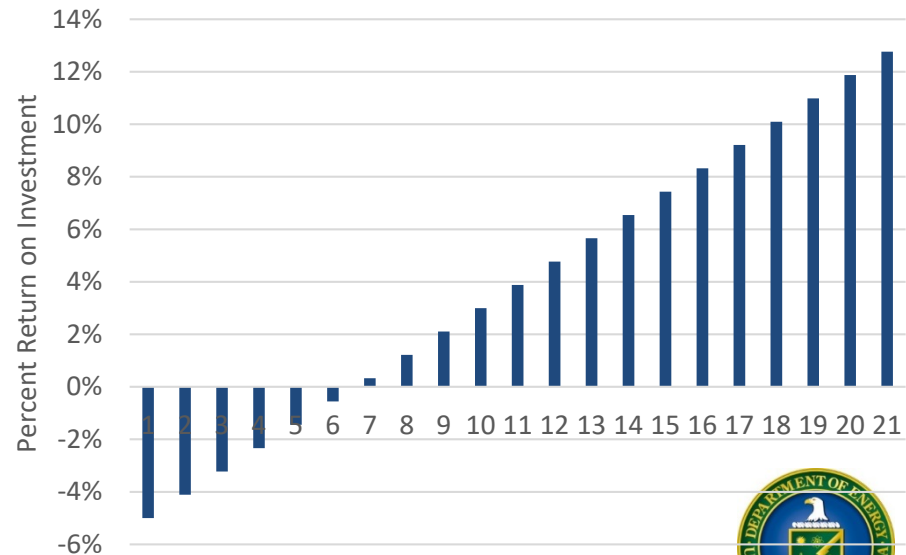
- Equipment and chemicals
- Pilot Testing (May 2021)

- **Economic Scale-Up Risks**

- REE/CM Market Manipulation?
 - Byproduct of upgraded carbons
- Is process economic?
 - \$100/ton processed net revenue
 - 7.5 ton/hr coal feed plant

- **Resource Scale-Up Risks**

- Does an adequate resource with high confidence exist in large quantities?
 - More information needed



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