U.S. Domestic Rare Earths and Critical Minerals

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Black Hills Chapter Society for Mining, Metallurgy and Exploration (SME) Rapid City, South Dakota

> Krumb Lecture Series – January 18, 2023
> 6:30pm MT (8:30pm ET)



Courtesy of NETL REE-CM Website

Rare Earth Element (REE) Suppliers



https://geology.com/articles/rare-earth-elements



Rare Earth Elements and Critical Minerals



NETL REE-CM Website



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Critical Minerals – Based on Material's Risk Supply & Importance to Clean Energy In 2022, USGS Deemed 50 CMs Essential to the Economic & National Security of the US.

Rare Earth Elements – Dual Use Materials

Carbon Management

energy.gov/fe



DEFENSE

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REE Supply Chains



Mike Harding, Chairman, Lynas 2019



REE-CM Program Goals

COMMERCIALIZATION

Technology available for wide-scale market use

DEMONSTRATION

System demonstrated in operational environment

SYSTEM TESTING System performance confirmed at pilot-scale

DEVELOPMENT Technology component

validated/integrated

DISCOVERY

Develop/rebuild U.S. leadership role in the extraction and processing technologies that support an economic, environmentally benign, and geopolitically sustainable production of domestic rare earth elements and critical minerals for use in clean energy and national defense applications



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PROSPECTING

PROCESSING

Critical Minerals Processing – Mission, Goals, Metrics

Mission

- Develop Economic, Competitive, Sustainable Domestic REE-CM Supply
- Utilize Unconventional & Secondary Feedstock Materials
- Utilize Conventional Extraction, Separation & Recovery Processes

Goals

- Accelerate Design, Construction & Operation of a Domestic FOAK REE Demonstration Facility
- Produce Commercial-Grade Mixed REO/RES Concentrates and Select Critical Minerals under Environmentally Benign Process Operating Conditions
- Extend Processing through Refining, Producing High Purity REM

Metrics

- Production of 1-3 tonnes (MT)/day of Mixed REO/RES
- Minimum REO/RES Concentration

 75% by weight
- Production of High Purity Critical Minerals and Materials (CMM)



Minerals Sustainability Program

Unconventional Feedstock Materials

Acid Mine Drainage; Mineral/Metal Mine Drainage Legacy Impoundment Materials

Refuse/Tailings from Coal Preparation Facilities

Coal Seam Over/Under-Burden Clay and Shale Materials

Power Generation Ash

Produced Waters – Carbon Capture and Storage & Oil and Natural Gas Produced Brines

Associated Chemical Wastes or Waste Streams



REE-CM RDD&D Program Road Map (2014-2022)



PRODUCTION

PROCESSING

Prospecting / Resource Assessment

FOA-2364 – Carbon Ore, Rare Earth and Critical Minerals (CORE-CM) Initiative for U.S. Basins

Objectives

- Basinal Assessment Characterization of Contained REE and CM
- Regional Waste Stream Assessment Wastes and By-Products Associated with CORE-CM Mining
- Regional Infrastructure, Industries and Businesses Assessment – Strategy Development to Integrate and Leverage Regional Attributes for Economic Growth Utilizing the Basin's CORE-CM Resources and Other Minerals and Waste Streams
- Technology Innovation Centers Basin-Specific Public-Private Partnerships



FOA – Funding Opportunity Announcement

Processing

FOA-2003 – Process Scale-Up & Optimization/Efficiency Improvements for Rare Earth Elements (REE) and Critical Minerals (CM) Recovery from Coal-Based Resources

Objectives

- Design, Construct and Operate Small Pilot-Scale Facilities
 - Conventional Separation Processes
 - Unconventional Coal-Based Feedstock Resources
 - Co-Production of MREO/MRES and CM Executive Order 13817
- Address Process Optimization and Improve
 Efficiency
 - Higher Purity & Larger Quantities
 - Improve Process Economics
- Facilities
 - WVU AMD, UND Lignite, UnivKY Refuse
 - PSI-Winner Water Services Fly Ash*

* FOA-1202

U.S. DEPARTMENT OF ENERGY Fossil Energy and Carbon Management energy.gov/fe



Paul Ziemkiewicz, West Virginia University

Advanced Processing / Refining

FOA-2404 – Advanced Processing of Rare Earth Elements and Critical Minerals for Industrial and Manufacturing Applications

Objectives

- Develop Innovative Midstream Processing Technology
 - Pilot-Scale Produced MREO/MRES, CM
 - Increased Resource Availability Coal, Coal By-Products or Alternate Non-Coal-Based Resources
 - Produce High Purity Individual/Binary REO/RES, CM
 - Reduction to Metals
- Process Requirements
 - Environmentally Benign and Sustainable
 - Reduce CAPEX/OPEX by ~20% in Comparison to Commercial Processes – Improved Economics
 - Industrial Supply Chain Stakeholder
 Involvement
- Process Validation Required for Consideration at Demonstration-Scale

ENERGY Fossil Energy and Carbon Management energy.gov/fe Univ KY, WVU, UND, Univ Utah, Florida Polytechnic Univ, Microbeam Technologies Inc.



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Production – Engineering-Scale Prototype Facility

Request for Proposal – RFP89243320RFE000032 – Production of Mixed Rare Earth Oxides (REOs) from Coal-Based Resources

Objectives

- Concept Studies Design, Construction and Operation of an Engineering-Scale Prototype Facility
- Follow-On Feasibility (pre-Front End Engineering Design (FEED)) Studies (AACE Class 4)
 - Processing through REM Production at >99% Purity
- Conventional Separation Processes
- Unconventional Feedstock Resources
- Primary Focus Production of 1-3 tonnes/day MREO/MRES at a Minimum of 75% Purity, the Majority of Which Is Produced from Coal or Coal-Based Resources

Feasibility Performers

- Energy Fuels Resources
- Materia USA LLC
- MP Mines Operation LLC
- Texas Mineral Resource Corporation (TMRC)
- Tetra Tech, Inc.
- University of North Dakota (UND)
- West Virginia University (WVU
- Winner Water Services (WWS) Physical Sciences Inc. (PSI)



Production – Rare Earth Demonstration-Scale Facility

Request for Information (RFI) FOA-2686 – Bipartisan Infrastructure Law (BIL 20405) – Rare Earth Element Demonstration Facility (Issued 2/14/22; Closed 3/31/22)

Objectives

- Solicit Information from Industry Members, Investors, Developers, Academia, Research Laboratories, Government Agencies, Potentially Impacted Communities, Customers, Others
- **Demonstrate** the Commercial Feasibility of a Full-Scale, Integrated, REE Extraction and Separation Facility and Refinery
- Address the Social and Environmental Justice
 Implications of the Demonstration Facility

FOA-2618 – BIL–Rare Earth Element Demonstration Facility (Issued

9/19/22; Closed 11/21/22)

Objectives

- Phase 1 Front End Engineering Design (FEED) studies (AACE Class 3)
- Phase 2 Design, Construction and Operation of the Rare Earth Element Demonstration Facility



CMM – Critical Supply Chain Needs

Material-by-Material Approach Driven by Decarbonization Goals

100% clean electricity by 2035: 30 GW offshore wind by 2030 Zero-emission transportation: 50% EV adoption by 2030

clean power generation

- Neodymium, Praseodymium, and Dysprosium for magnets
- Lithium, Cobalt, Nickel, Manganese, and Graphite for energy storage
- Iridium & Platinum for electrolyzers; Platinum for fuel cells
- Gallium for wide bandgap semiconductors, LEDs
- Germanium for microchips (semiconductors)

generators, electric and fuel cell vehicle motors, industrial motors
 Batteries are needed for electric vehicles and grid storage to enable high penetration of zero-emission transportation and intermittent

Magnets enable efficient electric machines including wind

- Iridium and platinum for electrolyzers are needed for green hydrogen production and platinum for fuel cells used in transportation and stationary energy storage
- Wide bandgap power electronics enable high voltage power generation (like wind) to connect to the grid
- Microchips for sensors, data, and control play an important role in SMART manufacturing, which will be needed to increase efficiency and minimize waste (inclusion GHGs); Fiber and infrared optics

America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition



JOAL S

Fossil Energy and Carbon Management energy.gov/fe An Opportunity to Facilitate Resilient Domestic Critical Material Supply Chains – Discussions on the Infrastructure, Investments and Jobs Act, Section 41003d in Golden, CO | United States Energy Association, July 14, 2022.

CMM Supply Chain – Assessment

Clean Energy (12)	Nd, Pr, Dy, Ir, Pt, Li, Ni, Co, Mn, Ga, Ge, Graphite				
Cogl-Based Resources					
Tier 1 Assessment (8)	Nd, Dy, Pr, Li, Co, Ga, Ge, Mn				
Net Import Reliance	50% Ge, Li 76% Co 100% Mn, Dy, Pr, Nd, Ga				
Tier 2 Assessment	Ni, Graphite, Cu, Eu, Tb, Y, Lu, Sm, Nb, In				



Fossil Energy and Carbon Management

CMM – Production & Supply Chain Purity Requirements

СММ	Production	Principal Reserve Location	Estimated World Reserves	Major Form Traded	Purity
Со	Metal By-Product in Extraction of Cu, Ni	Canada, Asia	7.6 million tonnes	Co Salt	2N to 3N
Dy	Refined from Mineral Forms; Isolated from Natural Alloys	China (Asia Pacific)	1.41 million tonnes of Dy Metal Equivalent	Dy Oxide	<u>></u> 2N
Ga	Found in Al and Zn Ores	North America, Europe	900,000⁺ tonnes	Ga Oxide	4N to 7N
Ge	By-Product of Cu, Zn, Lead Sulfate Production	U.S., France	450 tonnes Ge in U.S.; Difficult to Estimate World Reserves	Ge Oxide	5N
Li	Mined from Igneous Rocks and Sedimentary Clays	Asia, U.S.	20 to 30 ppm of Earth's Crust	Li Concentrates & Compounds	4N
Mn	Found with Numerous Minerals in Nature	South Africa, Australia, China, Gabon, U.S.	630 million tonnes	EMD & EMM	2N to 3N
Nd	Mined in Monazite & Bastnaesite deposits	China, Japan	8 million tonnes	Nd Oxide	2N to 3N
Pr	Mined in Monazite & Bastnaesite Deposits	China, Japan	2 million tonnes	Pr Oxide	2N to 4N



REE-CMM Program – Pathway to Commercialization





Fossil Energy and **Carbon Management**

FECM Critical Mineral Processing Program – Contact Information



Courtesy of NETL REE-CM Website

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