CRITICAL MINERALS FROM LIGNITE: THE PROCESS AND PRODUCTS

May 25, 2023
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May 25, 2023
CRITICAL MINERALS FROM LIGNITE:
THE PROCESS AND PRODUCTS

May 25, 2023

Nolan Theaker, Senior Research Manager
Critical Minerals, Institute for Energy Studies
Defining Critical Minerals

Critical Minerals

Rare-Earth Elements (REEs)
- Not rare but found together
- Chemically similar and difficult to separate
- Each with a different use

Critical Minerals (CMs)
- Catch-all term for the critical minerals that are not REEs
- No other common factor
Critical Minerals Play a Vital Role in Our Modern Economy and National Security
More than 80% of U.S. critical minerals are imported.
Elements with Greatest Potential to Contribute to the Williston Basin Market
Developing New Sources and Innovative Ways to Extract CMs and REEs

Existing Lignite Coal Mines

Produced Water

Coal Ash

ND Shales: Pierre, Niobrara, Upper and Lower Bakken

Deep Unminable Coal Seams by In Situ Extraction
Business Findings and Takeaways

• Regional industries
  – End users of final products
  – Defining business model

Mountain Pass REE Mine, California
Goals of This Webinar

What does it take to process REEs and CMs from lignite?

- What methods?
- How many steps and involved parties?
- Where do handoffs exist?
ENTERING THE FLOWCHARTS
Preview: What Is the Overall Picture?

Coal Utilization → Carbon Products and Power → REE Magnets and Other

Lignite at Margins → REE Mixed Concentrate → REE Refining

REE Refining → CM Concentrates → CM Refining → Semiconductors

Semiconductors → REE Processing → Semiconductors

Sorbent/Fertilizer → Li-Ion Battery Components → Low-Emission e⁻

Direct Sale → Wind Power Motors → Disk Drives → Electric Vehicles

Gyrosopes → MRI and Diagnostics

Europium for Phosphors → Gadolinium for X-Rays

Sc/Al Alloys for Aerospace → YSZ Ceramics

Metal for Semiconductors → Cloride for Fiber Optics → Semiconductor Wafers
Diving into Mixed REE Concentrate

Mixed REE Concentrate

Lignite at Margins → Physical Processing → Overburden Rock and Clays

Chemical Processing → CM-Bearing Solution

CM-Depleted Lignite → Impurity Purification

Other Coal Uses → REE Separation

CM Refining → CM Separation

Solution Impurities

MREO Concentrate → Wastewater

Other Coal Uses

CM Refining

Wastewater

Critical Challenges. Practical Solutions.
How Does This Look?

60%–90% Pure Mixed REOs

Image credit: UND Institute for Energy Studies
REE Refining and Processing

- Lignite at Margins
  - REE Mixed Concentrate
    - Refining
      - HREE Concentrate
        - Medical/Defense Applications
      - SEG Concentrate
        - SEG Purification
      - LREE Concentrate
        - La/Ce Disposal or Sale
    - Separation and Processing
      - Scandium/Yttrium
        - Scandium Metal for Alloying
      - Yttrium Oxide for Ceramics
        - YSZ Ceramics
- Magnet REEs
  - Metallization and Alloying
  - Magnet Production
- Scandium/Yttrium
  - Scandium/Al Alloys for Aerospace
- Direct Sale
  - Wind Power Motors
  - Disk Drives
  - Electric Vehicles
  - Gyroscopes
  - MRI and Diagnostics
  - Scandium Metal for Alloying
  - Yttrium Oxide for Ceramics
  - YSZ Ceramics

REE Refining and Processing
Elements with Greatest Potential to Contribute to the Williston Basin Market
REE Refining and Processing

- Lignite at Margins
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  - Magnet REEs
    - Metallization and Alloying
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- Scandium Metal for Alloying
- Europium for Phosphors
- Gadolinium for X-Rays
- Scandium/Aluminum (Sc/Al) Alloys for Aerospace
- Yttrium Oxide for Ceramics
- YSZ Ceramics
- Direct Sale
  - Wind Power Motors
  - Disk Drives
  - Electric Vehicles
  - Gyroscopes
  - MRI and Diagnostics
  - Electric Vehicles
  - Disk Drives
  - Gyroscopes
  - MRI and Diagnostics
What Does the Refining Box Entail?

Lignite at Margins

REE Mixed Concentrate

Refining

Three Paths of Refining
(that have been materially researched)

Chemical

Electrical

Physical

Chemical refining is the dominant path to date.

This is typically solvent extraction.

Image credit: Elettronica Veneta Mixer-Settler
All rare earths are chemically similar.

Any method for separating REEs is extremely difficult.

Breakthroughs are reducing the process from hundreds or even thousands of steps to tens per element.
Products of Refining

Hundreds to Thousands of Steps

Purity: 99.9%+

Purity: 99.9%+

Purity: 26.7%

Neodymium Disk Magnets

Image credit: Metal Tech News

Image credit: Corsica LLC

Image credit: Amazon
CM Refining

This does not show all CMs that can be produced.

The CMs shown are likely some of the most valuable.
A Note on Purity
Semiconductor vs. REE purity

REEs typically need between 3N and 5N.

Semiconductors (Ge and Ga included) need typically 6N–12N, or up to 100,000,000 times more pure than REEs.

Purity Expressed as N

- $3N = 99.9\%$
- $5N = 99.999\%$
- $11N = 99.999999999\%$
- $12N = 99.9999999999\%$

To purify from 11N to 12N purity, remove 1 mg of impurities from a railcar of metal.
CM Products

**Semiconductor Metals**
(Ge and Ga)
- More than 90% import-reliant
- Key weakness identified by DOD suppliers

**Battery Components**
(cobalt and graphite)
- Primary constituents of both electrodes in lithium-ion battery
- Account for 54% of battery cost
Carbon Products

- By no means an exhaustive list
- CM-depleted lignite has unique properties
- Value vs. market size
Critical Minerals

CM-Depleted Lignite

Coal

Extraction Process

REE Products

CM Products

Electricity

CM-Depleted Lignite

Graphite

Graphene

Carbon-Rich Material

Smart Phones
Military Equipment
Farming

Medical Equipment
Kitchenware

Power Plants
Power Lines
Homes/Businesses

Phone Batteries
Car Batteries

Water Filters
Body Armor
Automotive Equipment
Summary of the Process

Many steps—and handoff points—from mined lignite to products.

Different purities and processing methods.

Many companies in many locations.

Shipping solids is easy over long distances.

Anytime a solid is produced, this could be another business.
Mixed REE Concentrate

- Lignite at Margins
  - Physical Processing
  - Chemical Processing
    - Overburden Rock and Clays
    - CM-Bearing PLS
    - CM-Depleted Lignite
  - Impurity Purification
    - Solution Impurities
    - MREO Concentrate
  - REE Separation
    - Other CBP/Uses
  - CM Refining
  - CM Separation
    - Wastewater

- CM-Depleted Lignite
- CM-Refining
- Other CBP/Uses
- CM Separation
- Wastewater
Diagram of REE refining and processing.
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Carbon Ore, Rare Earth, and Critical Minerals Initiative (CORE-CM)

U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL)-Led Program

• Catalyze economic growth.
• Job creation in energy communities.
• Energy communities not to be left behind.
• Domestic production of REEs and CMs.
• Strengthen our national economy and security.
13 CORE-CM Initiative Teams

US BASINS
1. Appalachian Basin, North
2. Appalachian Basin, Central
3. Appalachian Basin, South
4. San Juan River-Raton Basin
5. Illinois Basin
6. Williston Basin
7. Powder River Basin
8. Uinta Basin
9. Green River-Wind River Basin
10. Gulf Coast Basin
11. Alaska Basin
12. Cherokee-Forest City Basin
13. Mid-Appalachian Basin
Williston Basin CORE-CM Project Team

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ACKNOWLEDGMENT

This material is based upon work supported by the U.S. Department of Energy National Energy Technology Laboratory under Award No. DE-FC26-05NT42592.

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