Characterization of Rare Earth Elements in WV Coal Measures

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West Virginia Geological and Economic Survey
Rare Earth Elements: Essential Components of Modern Technology

Electronic Applications
- LCD Monitors
- MRI machines
- TV Screens
- Fiber Optics
- Lasers

Green Energy Applications
- Solar Panels
- Wind Turbines
- LED lighting
- NiMH batteries

Other Applications
- UV Resistant Glass
- Polishing Compounds
- Fertilizer
- Medical tracers
- Colourants & Sensors
- Optical Glass
- Fluorescent Lighting

Catalysts
- Processing of Chemicals
- Catalytic Convertors
- Gasoline Refining
- Processing

Magnetic Applications
- Power Generation
- Hybrid Car motors and automotive parts
- MP3 Player earbuds
- Hard Disk Drives
- Magnetic Applications for appliances

www.monteromining.com
Rare Metals in a smart phone

SCREEN

- In, Indium
- Y, Yttrium
- Tb, Terbium
- Eu, Europium
- Dy, Dysprosium

ELECTRONICS

- Sn, Tin
- La, Lanthanum
- Pr, Praseodymium
- Gd, Gadolinium

BATTERY

- Li, Lithium
- Dy, Dysprosium
- In, Indium
- Nd, Neodymium
- Tb, Terbium
- Ga, Gallium
- Gd, Gadolinium
- Sn, Tin
- Ta, Tantalum

Homeland Security &
Advanced Military Applications

- Predator Drone
  Neodymium, Samarium
  Electric Motors and Guidance

- Smart Bomb
  Neodymium, Samarium
  Electric Motors and Guidance

- Tomahawk Cruise Missile
  Neodymium, Samarium
  Electric Motors and Guidance

- Night Vision Goggles
  Terbium, Erbium, Gadolinium
  Optical Lenses

- F-22 Fighter Jet
  Europium, Yttrium Terbium, Erbium
  Optical Systems, Visuals and Fiber Optics

- Bullet Proof Vest
  Yttrium
  Hardened Ceramics

- Bradley Tank
  Yttrium
  Hardened Ceramics

- Radar Detection
  Europium, Lutetium
  Signal Amplification

- Nuclear Submarine
  Europium, Lutetium
  Sonar Detection
The Elements

Commodity Prices vary, but can be significant

<table>
<thead>
<tr>
<th>Source</th>
<th>Time</th>
<th>LIGHT RARE EARTH METALS</th>
<th>Last Price</th>
<th>% Week</th>
<th>% Year</th>
<th>31-Dec-2015</th>
<th>Units</th>
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<td>-25.0%</td>
<td>8.00</td>
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</tbody>
</table>
Resources distributed between two main types of deposits: Primary Ores and Lateritic Soils/Paleosols

U.S. Department of Energy analyzed hundreds of coal and coal by-product samples and found highest rare-earth assays in the northern Appalachian region.

https://www.netl.doe.gov/research/coal/rare-earth-elements
RARE EARTH ELEMENTS FROM COAL AND COAL BY-PRODUCTS

Comprising 17 elements from the periodic table, the group known as rare earth elements (REEs) provide significant value to our national security, energy independence, environmental future, and economic growth. REEs are important elements used in high-technology products such as catalysts, cell phones, hard drives, hybrid engines, lasers, magnets, medical devices, televisions, and other applications. The development of an economically competitive domestic supply of REEs will help to maintain our nation’s economic growth and national security.

https://www.netl.doe.gov/research/coal/rare-earth-elements
WVGES Coal Program Interactive Mapping Application: Decades of Coal Research and Field Study

http://www.wvgs.wvnet.edu/www/coal/cbmp/coalims.html
Challenge 1: Identify Prime Feedstocks

**Figure 1**

**REEs During Fractional Crystallization**

- Lower REE concentration
- Magma is REE-enriched.
- Higher REE concentration

Most rare-earth elements remain in the melt due to incompatibility with precipitating minerals.

**Cooling**

Rare-earth element sorting by “exclusion”; they literally won’t fit in the crystal lattice of the forming minerals.

1200°C → 600°C

**Laterite Environment**

(Jiangxi Province, South China)

Hydrothermal Mineralization:
- Iron, Niobium, Fluorite, REE
  (Bayan Obo, Inner Mongolia)

**MULTIPLE MODES OF ENRICHMENT**

Bryan et al., 2015
Multiple Enrichment Modes: several possibilities for concentration within coal measures

Bryan et al., 2015
Enrichment in Roof Rock and Underclay: Lower Kittanning, Clarion Co. PA

Figure 18: Stratigraphic Distribution of REE Content, Lower Kittanning Bed, Clarion County, Pennsylvania, Data from Schatzel and Stewart [42].

Bryan et al., 2015
Enrichment in High-Ash Coals:
Fire Clay Coal Bed, Letcher Co., KY

Figure 15: Stratigraphic Distribution of REE Content, Fire Clay Coal Bed, Letcher County, Kentucky, Data from Hower et al. 56

Bryan et al., 2015
http://geomaps.wr.usgs.gov/parks/pltec/sc306ma.html
West Virginia Governor's Energy Summit
October 6, 2016

Stratigraphic Nomenclature

Upper Pennsylvania
- Gzhelian
- Stephanian

Middle Pennsylvania
- Moscovian
- Asturian
- Bolsovian

Lower Pennsylvania
- Bashkirian
- Langsettian
- Westphalian

Coal Beds

Dunkard Group
- NINEVEH A
- NINEVEH
- FISH CREEK
- DUNKARD
- JOLLYTOWN
- HUNDRED
- WASHINGTON A
- WASHINGTON
- LITTLE WASHINGTON
- WAYNEBURG A
- WAYNEBURG
- UNIONTOWN
- SEWICKLEY
- FISHPOINT
- REDSTONE
- PITTSBURGH
- MORANTOWN
- LITTLE PITTSBURGH
- LITTLE CLARKSBURG
- ELK LICK
- WEST MILFORD
- HARLEM
- UPPER BAKERSTOWN
- BAKERSTOWN
- BRUSH CREEK
- MAHONING
- UPPER FREEPORT
- LOWER FREEPORT
- UPPER KITTANNING
- MIDDLE KITTANNING
- LOWER KITTANNING
- CLARION
- NO. 7 BLOCK
- NO. 6 BLOCK
- UPPER NO. 5 BLOCK
- NO. 5 BLOCK
- LITTLE NO. 5 BLOCK
- STOCKTON A
- UPIRROR MERCER
- STERLING RIDER
- STOCKTON
- COALBURG
- LITTLE COALBURG
- WINIFRED
- LOWER WINIFRED
- CHILTON A
- CHILTON RIDER
- CHILTON
- LITTLE CHILTON
- FIRE CLAY
- CEDAR GROVE
- WILLIAMSON
- PEERLESS
- NO. 2 GAS
- POWERLTON
- LOWER POWERLTON
- EAGLE A
- EAGLE
- LITTLE EAGLE
- MATURE
- MIDDLE WAR EAGLE
- BENS CREEK
- LOWER WAR EAGLE
- GLENALUM TUNNEL
- GILBERT
- DOUGLAS
- LOWER DOUGLAS
- JOGER
- CASTLE
- SEWELL B
- SEWELL A
- SEWELL
- WELCH
- LITTLE RALEIGH
- BECKLEY
- FIRE CREEK
- LITTLE FIRE CREEK
- POCAHONTAS No. 9
- POCOHONTAS No. 8
- POCAHONTAS No. 7
- POCOHONTAS No. 6
- POCOHONTAS No. 5
- POCOHONTAS No. 4
- POCOHONTAS No. 3
- POCOHONTAS No. 2
- POCOHONTAS No. 1

Total REE & REE+Y
Average total Rare Earth Elements + Yttrium (ppm - on ash basis)

Updated July 21, 2016 (n=698)
WVGES is conducting detailed sampling and research in conjunction with TetraTech in support of NETL award.
Challenge 2: Extract REEs from Host Material
https://www.uky.edu/KGS/coal/images/Coal_mining_methods_med.jpg
Large volumes of material must be processed to obtain REEs from host rock

http://www.motioncontrolonline.org/content-detail.cfm/Motion-Control-Technical-Features/Market-Update-Rare-Earth-Magnet-Prices-and-Motion-Control/content_id/322
Post-combustion (fly) ash: Appalachian coals have highest REEs; more difficult to extract due to glassy encapsulation

http://pubs.acs.org/doi/pdf/10.1021/acs.est.6b00085
Goal: Water-Soluble Rare-Earth Concentrate

Challenge 3: Separate the Individual Rare Earth Elements

https://en.wikipedia.org/wiki/Rare_earth_element
Traditional Separation Methods: Multiple Steps, Multiple Solvents
It’s not easy being green...
...but technologies are advancing

Molecular Recognition Technology: A GREEN CHEMISTRY PROCESS FOR SEPARATION OF INDIVIDUAL RARE EARTH METALS

Figure 1

REEs During Fractional Crystallization

Most rare-earth elements remain in the melt due to incompatibility with precipitating minerals.

LIGANDS

- Ligands are customized molecules that attract specific elements
- SuperLig® particles use specialized ligands
- Ligands are covalently attached to SuperLig® particles
- SuperLig® particles fill the column to selectively extract REE
SUMMARY

• Coal measures in WV demonstrate significant resource potential with regard to rare earth elements

• REEs can occur in multiple rock types, and identification of optimal feedstock material is key

• Large volumes of material must be processed at the preparation-plant level; each feedstock stream will require customized processing

• Opportunities exist for recycling of waste products
SUMMARY

• West Virginia possesses the experience, knowledge, and trained workforce to develop and enhance these emerging technologies

• Cooperation and collaboration is essential to overcoming operational challenges
Thank You!

www.wvgs.wvnet.edu