Appalachia and Eastern U.S. Regional Needs and Opportunities for R&D on Rare Earth Elements and Critical Minerals Technology

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Appalachia and Eastern U.S. Regional Workshop

Critical Minerals Sustainability

December 17, 2020





Presentation Outline

- 1. Critical Minerals for Energy
- 2. Regional Expertise
- 3. R & D Opportunities for Rare Earth Elements Industry in Appalachia



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Federal Agencies Supporting Critical Minerals Programs

- <u>United States Department of Commerce</u> Work with federal Departments to coordinate strategies to reduce Nation's dependence on critical materials
- <u>Department of Defense</u> Ensure secure and reliable supplies of critical minerals; contribute to public policy formation
- <u>United States Geological Survey</u> Develop data base for mineral resources
- <u>United States Department of Energy</u> Conduct ongoing assessments of material criticality
 - Science fundamental research to advance understanding of critical materials down to the atomic level
 - EERE early-stage applied research to diversify supply, develop substitutes, and drive reuse and recycling of materials critical to clean energy technologies
 - FE feasibility of recovering rare earths from coal and coal-based resources



Materials in Clean Energy Technologies and Components - DOE

| | Photovoltaic Films | Wind Turbines | Veh | Lighting | | |
|-----------------|-----------------------|---------------|---------|-----------|-----------|--|
| MATERIAL | Coatings | Magnets | Magnets | Batteries | Phosphors | |
| Lanthanum | | | | • | • | |
| 윑 Cerium | | | | • | • | |
| Praseodymium | | • | • | • | | |
| Neodymium | | • | • | • | | |
| tig Europium | | | | | • | |
| کے Terbium | | | | | • | |
| စို့ Dysprosium | | • | • | | | |
| Yttrium | | | | | • | |
| Indium | • | | | | | |
| Gallium | • | | | | | |
| Tellurium | • | | | | | |
| Cobalt | | | | • | | |
| Lithium | | | | • | | |
| Manganese | | | | • | | |
| Nickel | | | | • | | |

2011 Critical Materials Summary, DOE, 2011



Energy Institute

5

DOE Criticality Matrix for Energy Minerals For Clean Energy Technologies - DOE Figure 1. Short-Term (present-2015) Criticality Matrix Figure 2. Medium-Term (2015–2025) Criticality Matrix



2011 Critical Materials Summary, DOE, 2011



29 Elements Critical to One or More Emerging Energy Technologies – MRS

| Energy Critical Elements: | | | | | | | | 2 He Helium 4.003 | 1 H Hydrogen | | | | | |
|---|---------------------------------------|--|-------------------------------|--------------------------------|---------------------------------|---------------------------------|--|------------------------------------|--|---------------------------------------|--------------------------|-----------------------|------------------------|-----------------------------------|
| | | | | | | | | 10 Ne Neon 20.1797 | 3 Li Lihium | | | | | |
| | | | | | | | | | 11 Na Sodium | | | | | |
| | | | 31 Ga Gallium 69.723 | 32 Ge Germanium 72.61 | | 34 Se Selenium 78.96 | | | | 21 Sc Scandium | | | | 25 Mn Manganes 54,9380 d |
| 46 Pd Palladium 106.42 | 47 Ag Silver 107.8682 | | 49 In Indium 114.818 | | | 52 Te Tellurium 127.60 | | | 37 Rb Rubidium 85.4678 | 39 Y Yttrium 88,90585 | | | | 43 TC Technetium |
| 78 Pt Platinum 195.078 | | | | | | | | | | 57 La Lanthonum | X | | | 75 Re Rhenium |
| 65 Tb Terbium 158.92534 | 66 Dy Dysprosium 162.50 | | | | 70 Yb Ytterbium 173.04 | 71 Lu Lutetium 174.967 | | | | 58 Ce Cerium | 59 Pr Praseodymium | 60 Nd Neodymium | 61 Pm Promethium | 62 Sm Samarium |

Securing Materials for Emerging Technologies -American Physics Society / Materials Research Society, 2012

Co

Rh

Rhodium

lr.

Iridium

64

Gd

Gadolinium

RU Ruthenium

Os

Osmium

Ευ

Europium



Fossil Energy Interests in Critical Minerals

- Procuring Rare Earth Elements
- Critical Minerals for Energy Applications
 - Nickel for boiler tubes
 - Materials for high temperature turbine applications
 - ...
- Advanced Manufacturing Technologies



Supply Chain Phases in Ensuring Rare Earth Element Supply Chain

- Upstream
 - Mining
 - Concentration
- Midstream
 - Separation
 - Processing
- Downstream
 - Manufacturing



Rare Earth Elements - Yttrium and the Lanthanides



USGS Scientific Investigations Report

The rare earth elements compromise 15 elements which range in atomic number from 57 to 71 (Lanthanum [La -#57] – to – Lutetium [Lu - #71]). The elements in this sequence are also commonly referred to as "lanthanides". Yttrium [Y -#39] is also typically included with the rare earths elements group because it shares chemical, physical and application properties with the lanthanides.



Geological Research to Map Critical Minerals in the Appalachian and Eastern Region

USGS Earth Mapping Resources Initiative (MRI) Program





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Collaboration Among Academic / State / Industry Institutions in Appalachian Region – Minerals Recovery

CAST – Center for Advanced Separation Technologies

NMP – National Minerals Partnership (Eastern Universities)

NMLRC – National Mine Land Reclamation Center (Eastern Region)

AIRES – Appalachian Research Initiative for Environmental Science

UCFER – University Consortium for Fossil Energy Research

AONGRC - Appalachian Oil and Natural Gas Research Consortium Va Tech, WVU, Kentucky + 4 western universities & Industry Adv. Comm. – [mineral separations technology research]

CMU, Penn State, Pitt, WVU, Va. Tech, U. Kentucky – [mining research (inc. rare earths), workforce development]

WVU, Penn State, Federal & State Mining Organizations, Industry – [mine land remediation]

Va Tech, WVU, Marshall, Kentucky, Ohio State, Penn State Pitt – [mining, reclamation, medical research]

NETL, Penn State, CMU, MIT, Ohio State, Princeton, Kentucky, Pitt, Va Tech, WVU – [REE, advanced materials]

WV, KY, OH, PA State Geological Surveys, WVU – [mineral reserves]



Industrial Organizations

REE Research

- **CONSOL** Energy ٠
- Battelle •
- Tetra Tech •
- ISI Physical Sciences, Inc. ۲
- Anactisis, Inc. •
- **RTI** International •
- Marshall Miller Associates •
- Inventure •
- SR (Southern Research) ٠

Advanced Manufacturing

Energy Industries of Ohio

WV

CURC-NETL-DOE

Annual Meeting

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Special Metals, Huntington,





National Energy Technology Laboratory

- Field Research Laboratory for Office of Fossil Energy
 - Mission Areas include:
 - Assess U.S. REE Resources
 - Develop and Optimize Novel Production Systems
 - Develop, Construct, and Validate Process Proof-of Concept Facilities
 - Develop State of the Art In-house Laboratory Facilities
 - Conduct In-House Research on REE Technologies
- Work with External Collaborators via CRADA agreements
- Manage Federal Externally Funded Research Programs



Organizations in Appalachian and Eastern U.S. Region with Expertise in Rare Earth Element Research



M. Alvin (NETL) presentation to National Coal Council January 29, 2019

estVirginiaUniversity.

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<u>Research Opportunities – Early Program History</u>

- FY 2014-2015: Assess and Analyze feasibility of economically recovering REEs; Initiate In-house Research Programs
- FY 2016-2017: Initiate Funding Program to include external agencies to develop and test commercially viable advanced separation technologies; support programs in field sampling and characterization and initiate Phase I of bench scale and pilot scale separations research program
- FY 2018 -2019: Continue to Phase II of bench scale and pilot scale separations, develop field sensors, and initiate salable high purity REE separations programs



<u>Research Opportunities – Current In-House Program Status</u>

- Real-time aqueous REE detection
- U.S. coal basin sedimentary assessment
- Separation-recovery and technical economic assessments of REE technologies
 - Leaching of acid mine drainage solids
 - Fly ash studies
 - Sorbent research on production of REE from acid mine drainage, programs with central Appalachian basin underclays, and development of cost analysis tools



<u>Research Opportunities – Current Extramural Projects</u>

- REE Separation Recovery programs on bench-to-pilot scale and pilot scale separation facilities
- Bench Scale Processing using acid mine drainage as the feedstock for REE extraction and leaching processes for low-rank lignite coals
- Modular Pilot-Scale Processing with coal refuse feedstock; Pilot-scale processing with coal ash feedstock
- Lower TRL programs on materials characterization & monitoring and REE separation & recovery



<u>Research Opportunities – Future Programs</u>

Rare Earth & Critical Minerals Production Research

- Develop demonstration-scale facilities with mixed Rare Earth Oxide concentrates
- Conduct economic & process efficiency improvements
- Determination of technology gaps
- Metalization
- REE Critical Minerals co-production
- Low TRL level studies on second-generation REE production technologies



<u>Research Opportunities – Future Programs</u>

- Advanced Manufacturing & Workforce Development
 - Fabrication of materials with REE and Critical Minerals will require advanced research and manufacturing technologies for successful deployment; many value-added jobs will be added through having plentiful supplies of REE and critical materials to develop new technologies
 - Programs are also needed to ensure an adequate workforce to effect the design of new technologies and new applications.



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