U.S. DEPARTMENT OF
ENERGY
Fossil Energy and
Carbon Management

Minerals Sustainability Division

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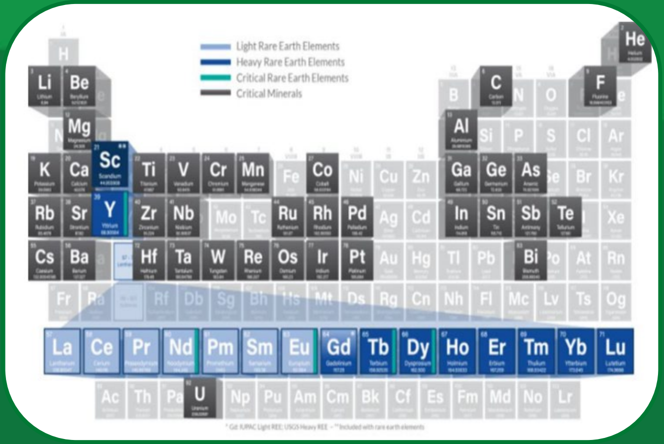
October 23, 2022

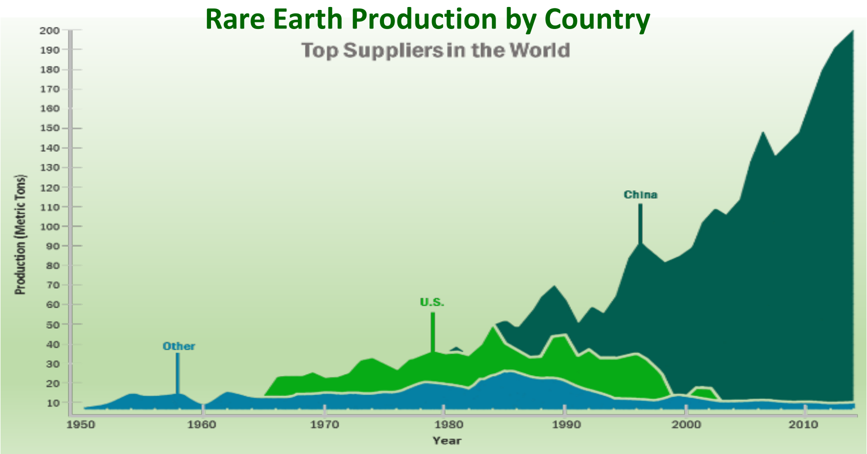


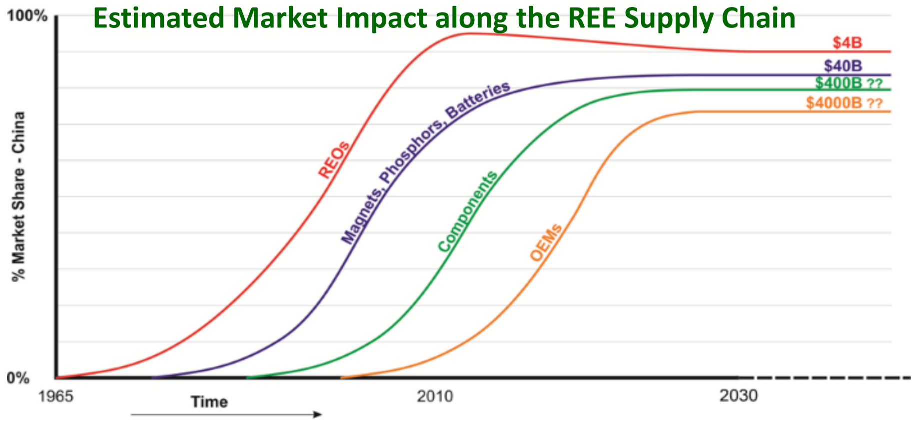


Critical Minerals & Materials Supply Chain Challenges

Key Challenges

- U.S. supply dependence spans from limited imported sources to lack of downstream processing and manufacturing capability to end-of-life and waste management
- Supply chain vulnerability will be amplified by increased demand
- Commodity specific mitigation strategies are needed
- Global and domestic supply chains face many challenges, including sustainability, market issues, and financing



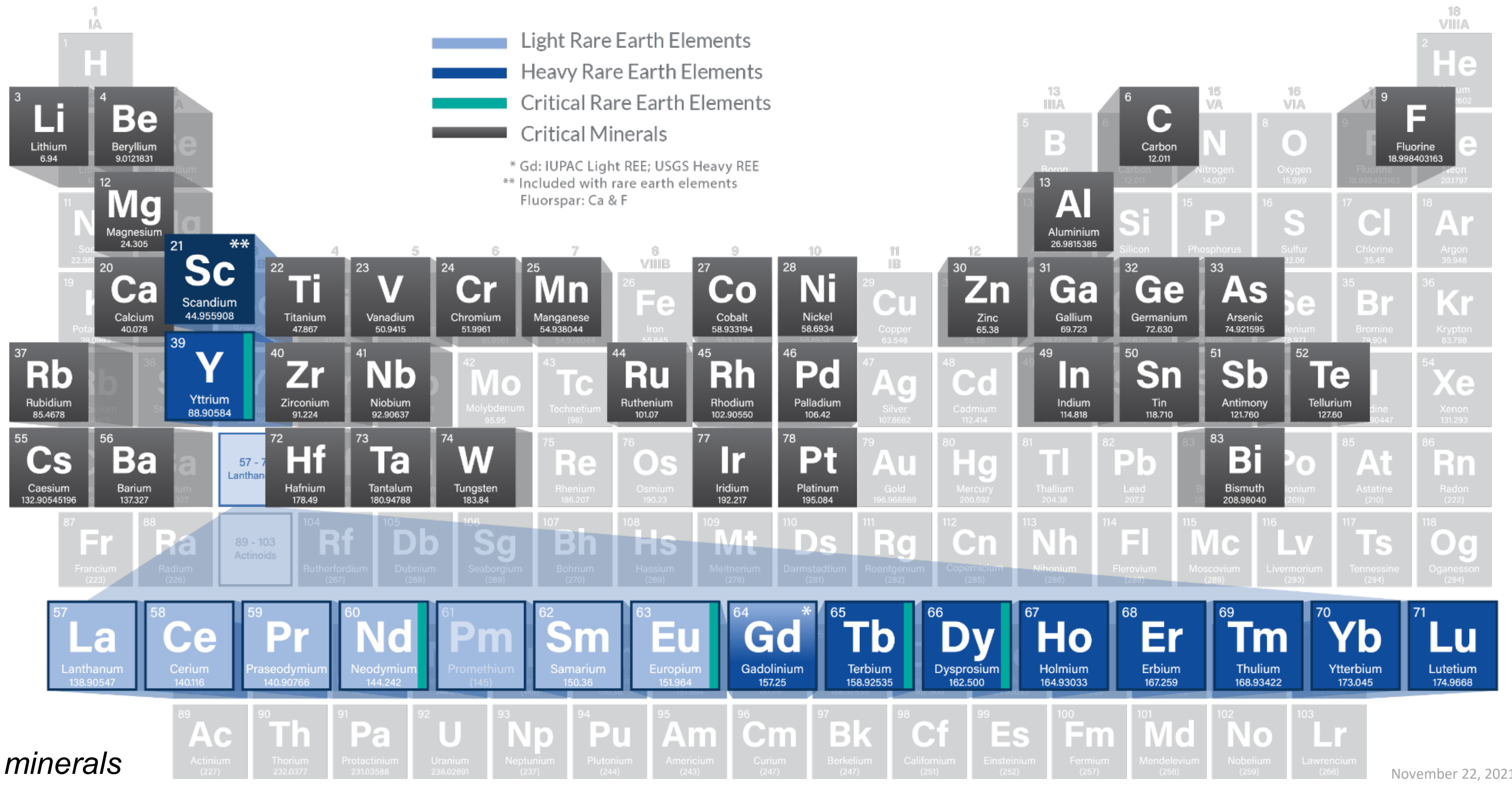


This figure is adapted from a presentation made by Professor K.G. van den Boogaart at the SME Critical Minerals Conference in Denver in August 2014.

Challenge: Absence of Domestic Supply Chains

Foreign Dependance on Critical Materials

- Import-dependent on >80% of U.S. rare earth element (REE) demand
- Import-dependent (>50% from foreign source) on 43 of 50* critical minerals
- Import-reliant (100% from foreign source) for at least 12 critical minerals

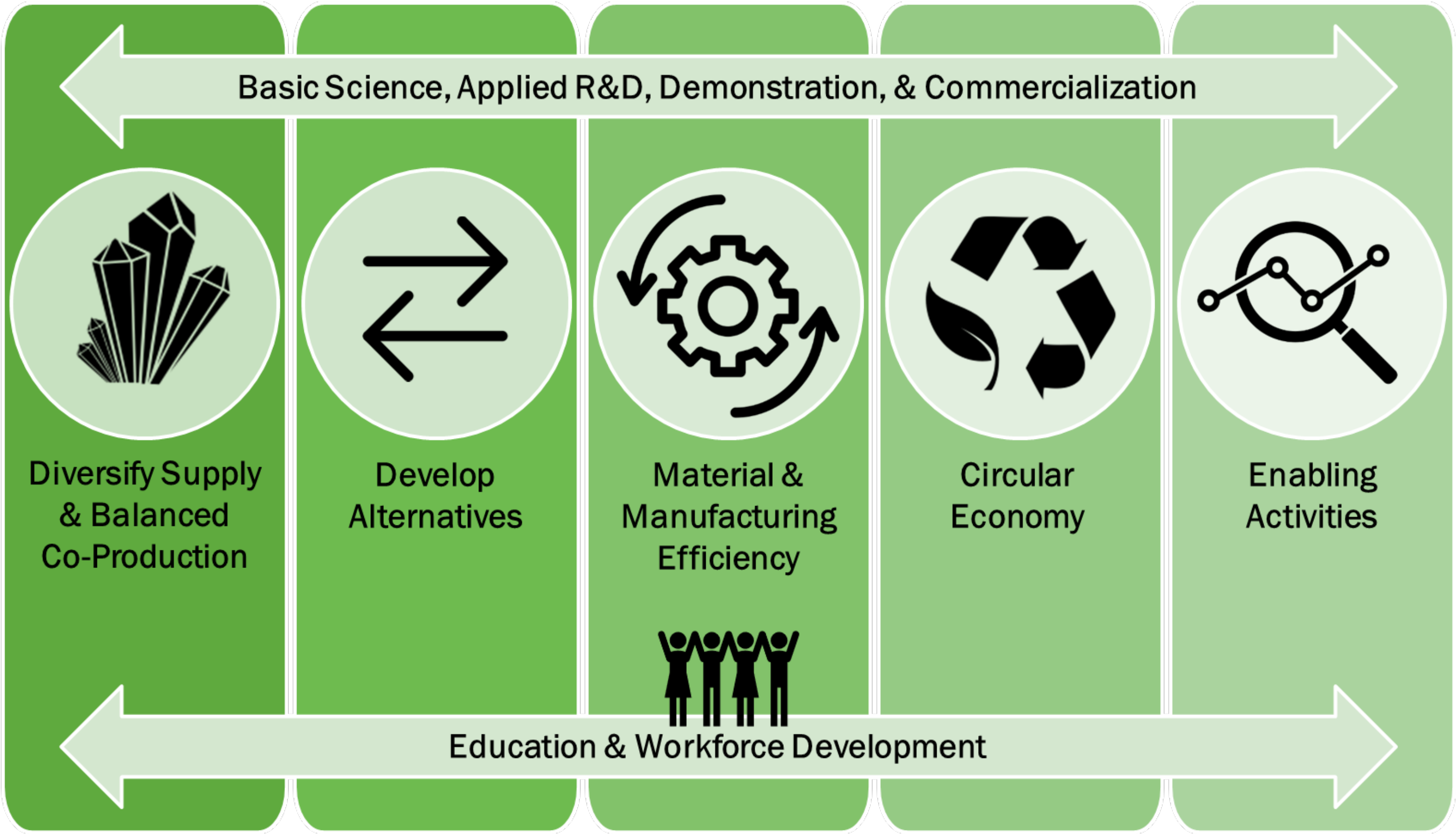


**USGS released new list of critical minerals*
Source: USGS Minerals Commodity Summaries

DOE Critical Minerals and Materials Vision & Strategy

Vision: <u>Resilient, diverse, sustainable, and secure</u> domestic critical mineral and materials supply chains that support the clean energy transition and decarbonization of the energy, manufacturing, and transportation economies while promoting safe, sustainable, economic, and environmentally just solutions to meet current and future needs.

Strategy:



Requires a <u>Material-by-Material Approach</u> as part of an <u>All-of-Government Strategy</u>

Primary Principle: Waste Minimization and Circularity

Reclaiming, recycling waste materials

Maximizing use of feedstock materials

Unconventional & Secondary Sources

Extraction, Separation, and Processing of REEs and Critical Minerals

Manufacturing of Hive Value, High Growth Carbon Products

Minerals Sustainability Division—Vision and Mission

VISION

To catalyze an environmentally and economically sustainable critical minerals and carbon ore resource recovery industry in the United States that will support:

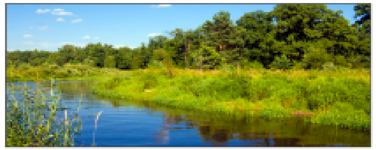
- Clean energy deployment, including creating domestic manufacturing jobs;
- Secure, diverse, resilient, domestic critical minerals supply chains; and
- Environmental and social justice stewardship through co-production- and reclamation-based research and technology development.

MISSION

To support the U.S. transition to a carbon-free economy and a domestic clean energy manufacturing industry by leading the federal government's efforts to:

1. Characterize and assess domestic critical mineral and carbon ore resourses from fossil energy-related byproducts and related resources;
2. Develop advanced resource extraction, processing, and extractive metallurgical technologies; and
3. Evaluate the co-production potential of critical minerals and carbon ore for high-value products.

Minerals Sustainability Division Strategy



Resource Characterization Technologies

- Characterization for opportunities
- Resource assessment and predictive capabilities
- Web-based platform for integrated database system with AI/ML

Critical Mineral Processing

Beneficiation

- Transformation, conventional and unconventional extraction technologies
- Integration of industrial beneficiation/ concentration methods and technologies
- Remediation of existing sites and abandoned mine residuals

Processing

Critical Materials

- Advanced extraction, purification, and reduction technologies through refining and alloying materials
- Enable commercial production through innovations
- First mover and second-generation large-scale pilot projects

Carbon Ore Processing

Carbon Ore

- Housing and infrastructure development
- Advanced carbon material (carbon fiber, graphene, and nanomaterial) production
- Reinvest in critical (graphite and silicon) supply chains

International Engagements, Standards and Supply Chain Development

Ni, CO, Cr for Superalloys

- Identify co-production sources to meet increased demand in these metals
- Application of innovative processing, refining, and alloying technologies to increase purity from the waste materials

Carbon Ore to Products

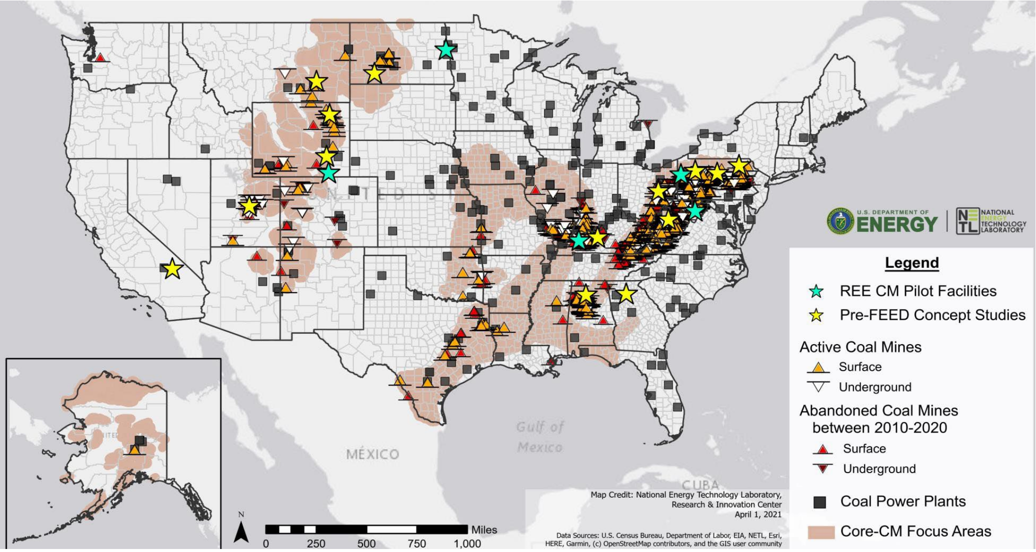
- Assessment and characterization of coal and waste materials
- Environmentally responsible extraction and beneficiation
- Co-production of high purity carbon and critical material products

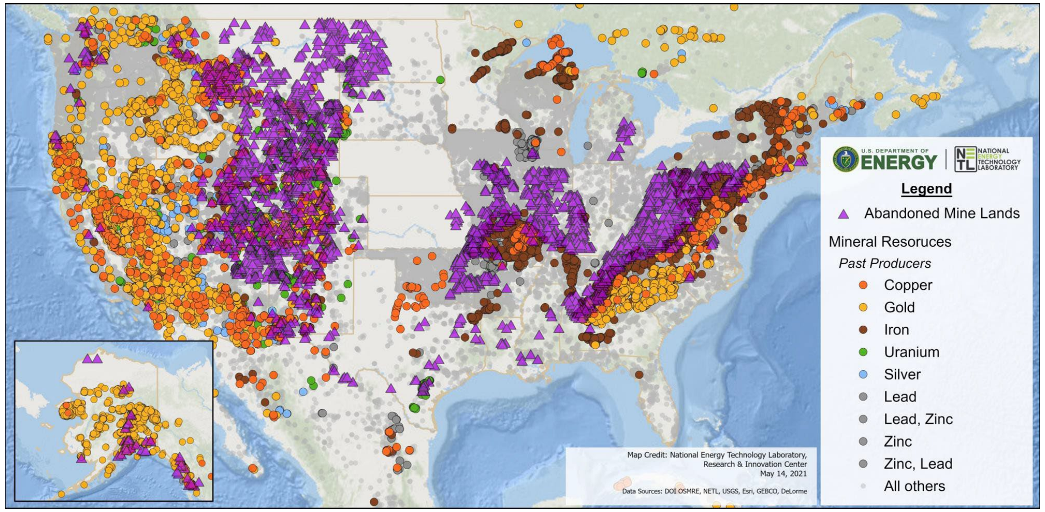
Program Goals

- By 2035, enable unconventional and secondary sourcing for half of domestic rare earth element (REE) needs
  - *Demonstrate **sufficient resources** usable from domestic unconventional (e.g., coal-based, AMD, produced water) feedstocks*
  - *Generate a National Prospectus for REE and other critical minerals*
    - *Regional resource assessments*
    - *Standardize approaches*
    - *Best practices*
  - Demonstrate economically competitive and environmentally **sustainable extraction and processing technologies**
  - Support development of **sustainable international standards** for supply chains

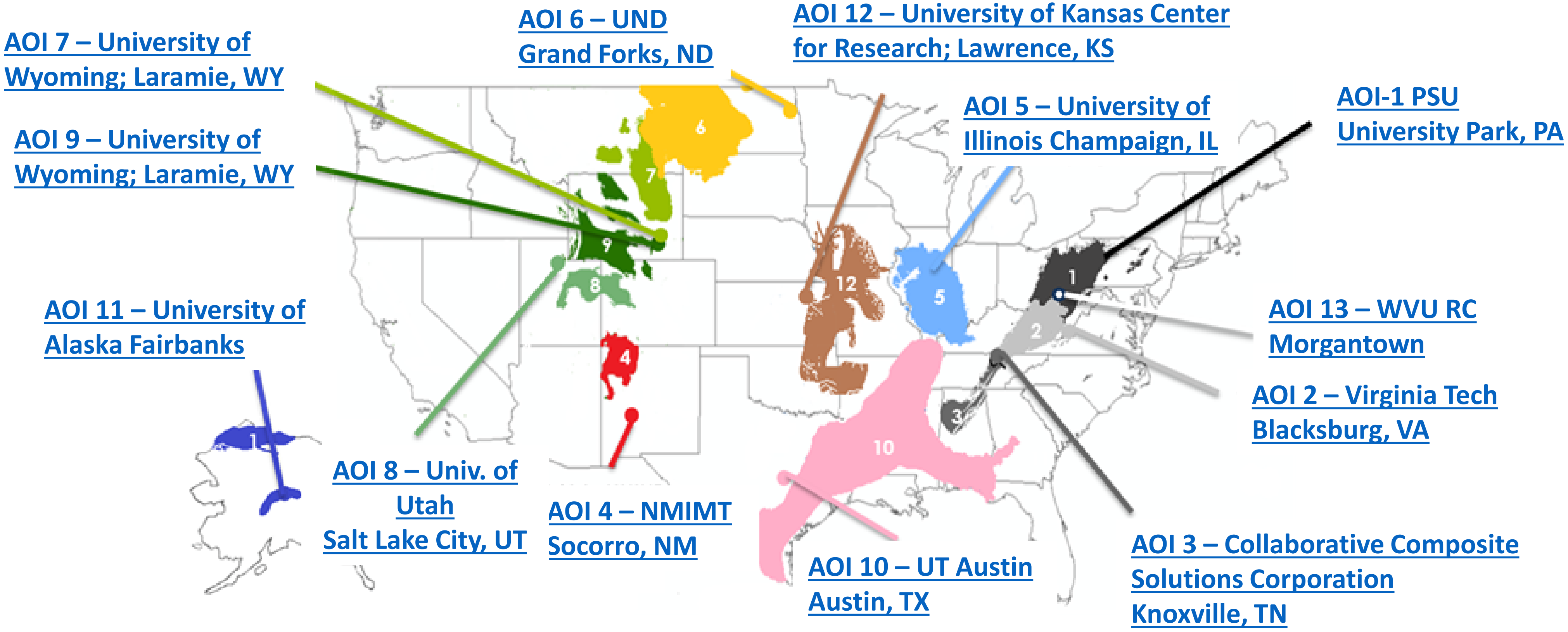
High-level Estimates from Unconventional, Secondary Sources

- **From coal-based resources**
  - **11 - 17 million tonnes** REE from known coal reserves,
    - ~30,000t/yr based on current production
  - 68,000 t from Appalachia coal refuse
    - 12,300 t/yr REE (2018*; 50% recovery), active refuse
  - 331,000 t from PA ash impoundments.
    - Over 10,000 t/yr REE (2018*; 50% recovery), active ash
  - Between 400-1700 tons/yr REE (50% recovery), Appalachia AMD
- **Additional opportunities from produced water, phosphate sludge, metal mine wastes, etc.**





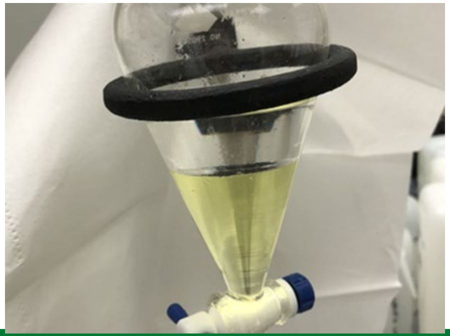
CORE-CM Assessing Regional Opportunities



- Build broad-based regional coalition teams, including Tribal Nations, local communities
- Investigate regional resources (materials, facilities, infrastructure, workforce), opportunities, and challenges
- Catalyze regional economic growth and job creation, while addressing legacy waste and environmental justice
- Enable production of REE, CM and high-value, nonfuel, carbon-based products

DOE Investing in Technology Advancements

- **First-of-a-Kind small-scale projects demonstrated technical feasibility to produce high purity REE from dilute sources (e.g., coal, refuse, ash, AMD)**
- **Feasibility studies for large-scale pilot projects (1-3 metric tons/day CM-REE)**
  - integrate conventional with advanced separation technologies and novel techniques
  - economically recoverable and environmentally sustainable production of CM-REE
- **Advance novel extraction and separations technologies to improve cost and environmental performance**
- **See link for more information:** Critical Minerals Sustainability | netl.doe.gov



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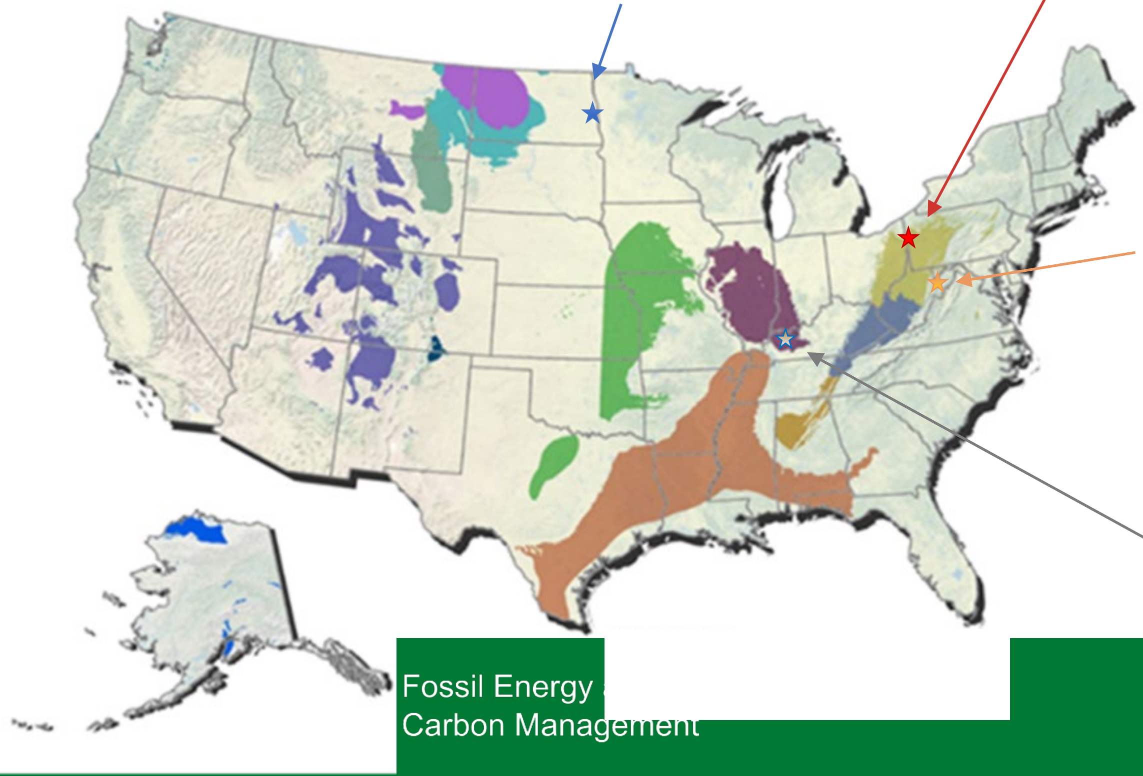
Small scale REE/CM pilot facilities

Pilot-Scale Facilities Producing High Purity MREO, CM (Co, Mn, Ni, Ga, Gd) from Domestic Coal-Based Sources

UND University of North Dakota

- Separating MREO concentrate from **lignite**
- October 2021 pilot facility start-up

2018	2019	2020	2021
5 – 10 g 5 – 15% purity	500 g 30 – 85% purity	Under Construction	



WinnerWater SERVICES / PSI Physical Sciences Inc.

- Pilot plant produced > 1 kg mixed rare earth salts from **post combustion coal ash** in 2020

2018	2019	2020	2021
0.004 kg ≤ 10% purity	.057 kg ≤ 14% purity	0.41 kg ≤ 67% purity	0.67 kg ≤ 91% purity

WestVirginiaUniversity.

- Produced REE pre-concentrates from **AMD and sludge materials** with ~100% REE recovery, 45% is HREEs

2018	2019	2020	2021
44 g 95 – 99% purity		Field pilot Under Construction to start up January 2022	

University of Kentucky

- Produced quantities MREOs in its *modular* pilot-scale facility **from coal refuse materials**

2018	2019	2020	2021
0.6 kg 80% purity	1.5 kg > 90% purity	0.41 kg 98% purity	Pilot processing to begin in fall

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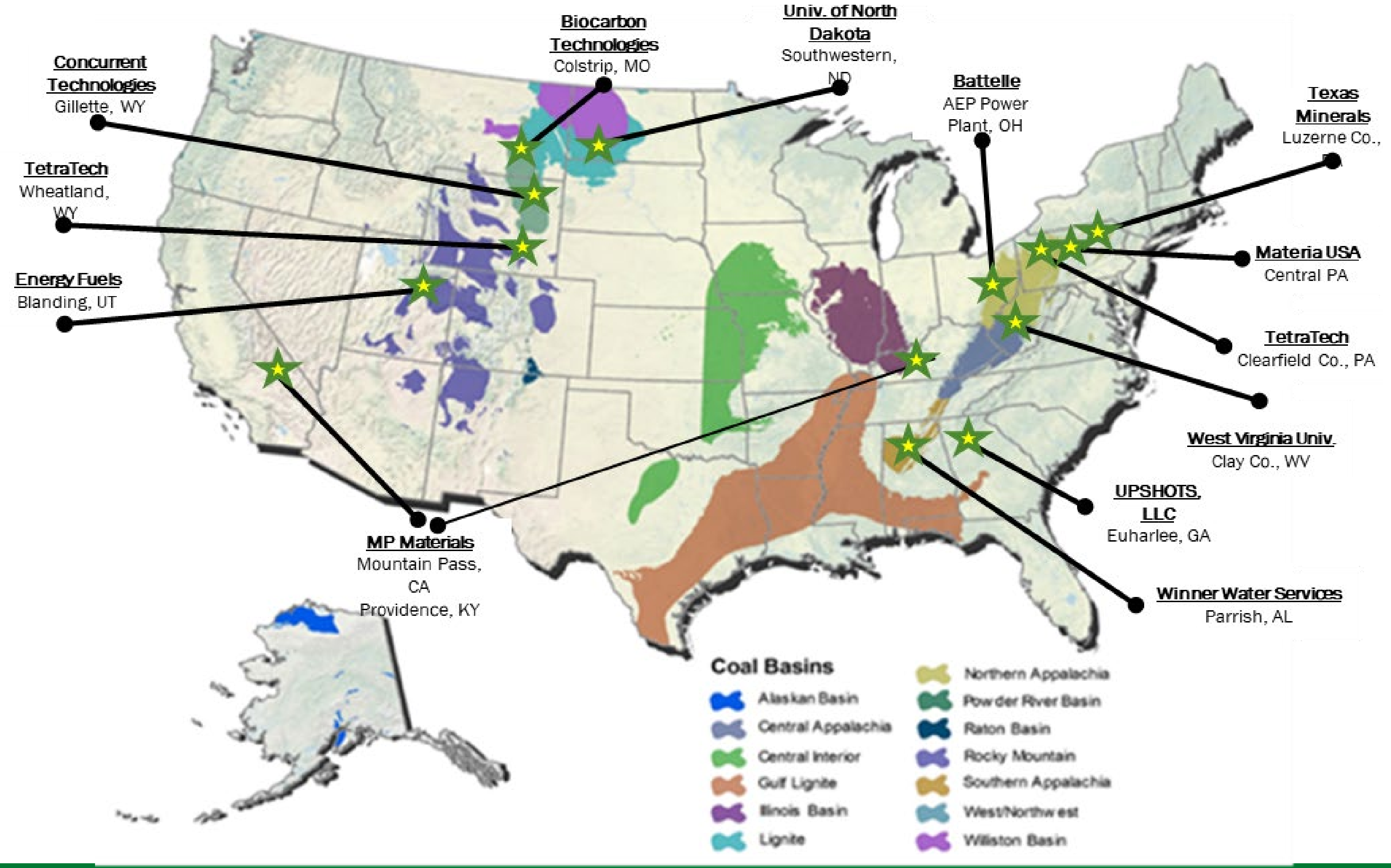
Feasibility (Pre-FEED) Studies

Large scale projects to produce 1-3 metric tons/day of mixed REO/RES and other critical minerals.

13 projects selected for the Concept Phase of the pre-FEED studies



8 projects were selected from concept phase to perform a more detailed pre-FEED study

Contractor	Location
West Virginia University	Morgantown, WV
MP Mine Operations LLC	Mountain Pass, CA
Energy Fuels	Lakewood, CO
University of North Dakota	Grand Forks, ND
Winner Water Services	Sharon, PA
Tetra Tech – PA	Pittsburgh, PA
Texas Minerals Resource Corp	Sierra Blanca, TX
Materia USA LLC	Inwood, NY

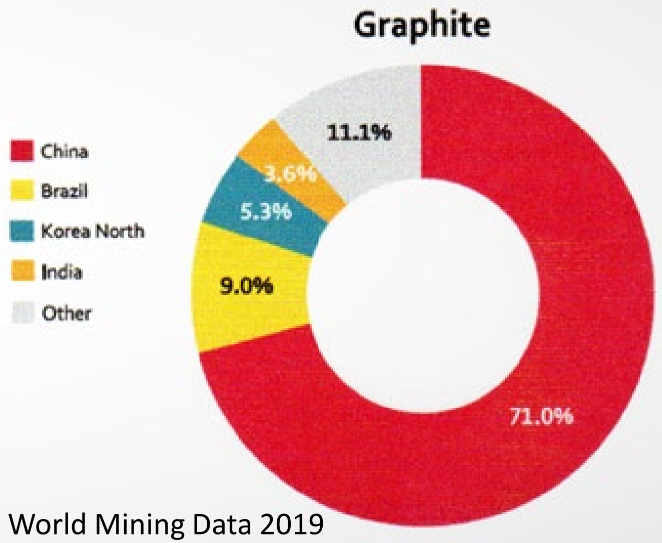
Graphite is critical to the future energy transition

The U.S. imported 58,000 tons of natural graphite in 2019 – Predominantly from China

World Mine Production & Reserves for U.S. & 4 Top Countries – Graphite (tons)			
	Mine Production		Reserves
	2018	2019	
U.S.	-----	----	NA
China	693,000	700,000	73,000,000
Mozambique	104,000	100,000	25,000,000
Brazil	95,000	96,000	72,000,000
Madagascar	46,900	47,000	1,600,000
World Total (rounded)	1,120,000	1,100,000	300,000,000

https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-graphite.pdf

China leads Natural Graphite production since the early 1990's



World Mining Data 2019

3 billion tons of minerals and metals, including graphite, will be needed to deploy clean energy

- Recycling and reuse is not be enough to meet the demand
- Production would need to ramp up more than 450% by 2050

Carbon Ore Processing Opportunities

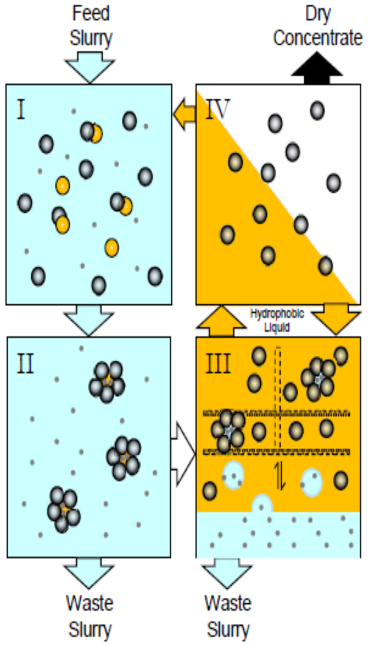
Advanced processing of carbon ore for the development of high value carbon products

Next-Gen Construction & Infrastructure Materials

Carbon Fibers from Coal Tar Pitch

Nanomaterials

Waste Recovery



- Generated predominantly from *coal waste and refuse* – toward remediation
- Enable domestic manufacturing of strategic materials to encourage job creation
- Ensure the health and safety of the environment and people around the use and disposal of carbon-based products

MSD-Related BIL provisions

FECM-responsible, Critical Material-related (~$1B)

- 40205 (c) – REE Demonstration Facility **FOA** released 9/19
- 41003 (b) – Rare Earth Minerals Security **NOI** released 10/12
- 41003 (c) – Critical Material Innovation, Efficiency, and Alternatives
- 41003 (d) – Critical Material Supply Chain Research Facility

RFI returned 9/9

Battery-specific ($3B)

- 40207(b) – Battery Materials Processing Grants **FOA** closed, first round

International Engagement

Responsible stewardship of critical materials is a domestic and international issue requiring high environmental standards across the entire supply chain

DOE engages in ISO efforts to improve sustainability in global critical material supply chains

- ISO TC 298 Rare Earth Elements
  - U.S. proposed developing a sustainability standards for rare earth mining, separation and processing to include environmental, economical and societal impacts
  - Working Group 5 has been established specifically for sustainability, and will be beginning work soon
- ISO TC 333 Lithium
  - New technical committee that is still developing strategic business plan, but is meant to include the full supply chain, excluding LIB as end products
  - Sustainability proposal put forth by the U.S. and is currently posted for a 12-week ballot

OSTP NSTC CMS, International Bilaterals/Trilateral interactions are opportunities to coordinate responsible development of supply chains

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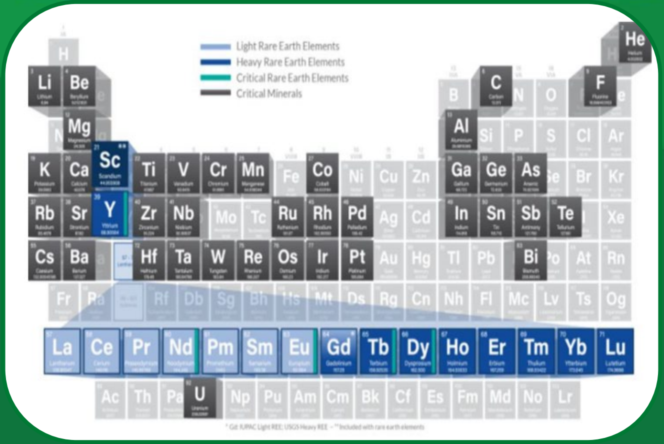
Questions?



Introduction: "Dynamic Dozen" Critical Materials

GOALS

● 100% clean electricity by 2035: 30 GW offshore wind by 2030 ●

● Zero-emission transportation: 50% EV adoption by 2030 ●

- Neodymium, Praseodymium and Dysprosium for magnets → Magnets enable efficient electric machines including wind generators, electric and fuel cell vehicle motors, industrial motors
- Lithium, Cobalt, Nickel, Graphite, and Manganese for energy storage → Batteries are needed for electric vehicles and grid storage to enable high penetration of zero-emission transportation and intermittent clean power generation
- Iridium & Platinum for electrolyzers; Platinum for fuel cells → Iridium and platinum for electrolyzers are needed for green hydrogen production and platinum for fuel cells used in transportation and stationary energy storage.
- Gallium for wide bandgap semiconductors, LEDs → Wide bandgap power electronics enable high voltage power generation (like wind) to connect to the grid
- Germanium for microchips (semiconductors) → 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


STRATEGIC VISION
The Role of Fossil Energy and Carbon Management in Achieving Net-Zero Greenhouse Gas Emissions
ENGAGEMENT
DEMONSTRATION & DEPLOYMENT
RESEARCH & DEVELOPMENT
JUSTICE
NUCLEAR ENERGY
CARBON STORAGE
METHANE MITIGATION
CARBON REMOVAL
CARBON CAPTURE
NET-ZERO EMISSIONS
CRITICAL MINERALS
ENERGY EFFICIENCY
RENEWABLE ENERGY
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